Development of a Research Concept Concerning Equestrian Sport Surface Quality

Equine, Leisure and Sports

For

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Of the Commerce and Industry Chamber of Cologne publicly appointed and sworn expert for riding arenas
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Executive Summary

Previous researches have shown that there is a link between surface quality and equine performance and therewith potential injury risk. Therefore the question about optimal surface rises. But still comparable values and standardized measurement methods are missing. Therefore the aim of this research is to develop a research concept with the criteria easy and cheap. Furthermore attention is payed to the repeatability. So the measurement concept is tested in intra - and inter repeatability. Therefore four assessors are needed to measure four different test surfaces. Always one assessor measures the all methods three times at one surface, so assessor one measures surface one three times. These collected values are necessary to test the intra repeatability. The measured values of all assessors for each surface are needed for the inter repeatability. Also the questionnaires for stable owner and for riders are tested with the main focus on understandability. Based on the results it is to conclude that the developed measurement concept seem to be repeatable if some alterations about the requirements are done. Only the two measurement methods which are mainly based on subjective evaluation should be removed to get more accurate results. Both questionnaires seem to be understandable with really small exceptions. So the developed research concept including the measurement concept and the questionnaires can be used for long term researches.

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Statement of Original Authorship

Hereby I declare that this bachelor thesis is only my own original work and has not been submitted before to any institution for assessment purposes. All used sources I have listed in the reference chapter.

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Chapter 1

• *Introduction* •

In their natural environment, horses are walk on every ground and surfaces (Dreyer-Rendelsmann, (n.,d.)). When many horse hooves use and penetrate the same surface its material alters in quality and may get destroyed through grain break down processes (Dreyer-Rendelsmann, 2012; Gilbert, (n.d); Swedish Equestrian Federation, 2014). This poses the question the about optimal surface material and how this can best support equine performance but limit injury risk at the same time (Dreyer-Rendelsmann, (n.,d.)). Potential injury risk factors include not only nutrition, sex, age, training intensity, genetics, conformation, hoof management, shoe type and pre-existing injuries (Peterson et al., 2008; 2012; (n.d.)), but also surface quality (Chateau et al., 2008; Riggs, 2010; Gilbert, (n.d.); Hobbs et al., 2010; Kruse et al., 2012; Kruse, 2012; Maeda et al., 2012; Malmgren et al., 1994; Miller, 1994; Murray et al., 2010; Northrop et al., 2013); van Weer, 2010; Peterson (n.d.); Salo et a., 2009; Setterbo et al., 2011; 2012 a; 2012 b; (n.d.); Strickland, 2013; Vos and Riemersma, 2006). This link between surface quality and potential injury risk factor is also considered by the code of conduct of the Fédération Equestre International (FEI), the umbrella organisation for equestrian sport disciplines. The code of conduct guidance on: all ground surfaces on which horses walk, train or compete. These surfaces must be designed and maintained to reduce factors that could lead to injuries with particular attention paid to the preparation, composition and upkeep (FEI, 2010).

Due to the link between of surface quality and equine health (Hobbes et al., 2010) the research of equestrian sport surface quality advanced a great deal in the last few years. Measurement devices such as the artificial athlete, accelerometers, bespoke equipment and instrumented horse shoe improved knowledge about how surfaces affect equine performance (Hobbes et al., 2010). Lars Roepstorff, Professor of Equine Functional Anatomy at the Swedish University of Agricultural Sciences is well known in this field.

Stable owners and managers are also affected by the quality of equestrian sport surfaces. They need to handle complaints about poor quality. The main problem is that standardised measurement methods with practical and comparable results are not available. So the main focus of this research project is to develop a practical easy to use measurement concept for equestrian sport surface quality based on the latest scientific research. In line with this, the following questions are used as guideline through this whole project:

1. What measurement parameters are available to establish equestrian sport surface's quality?

2. What simple and low cost concept can be established to measure equestrian sport surface quality and durability?

- 2.1 What measurement methods are simple and cheap but establish surface quality and/or durability?
- 2.2 What questions should stable owners be asked to establish surface's quality?
- 2.3 What questions should riders be asked to establish surface's quality?

3. What can be said about the quality of the developed measurement concept?

- 3.1 Do assessors measure parameters consistently when measuring the same parameter more than once?
- 3.2 Do different assessors produce the same result when measuring the same parameter?
- 3.3 Where the questionnaires understandable to all?

Chapter 2

• Background •

Quality Parameters of Equestrian Sport Surfaces

Horticulturist and agriculturists frequently talk about excellent or poor surface quality (Hellberg-Rode, 2002). They mean, how well their plants are growing on this ground (Hellberg-Rode, 2002). For other parties the ground has an excellent classified quality if the ground is as solid as possible, so you can play ball on it. Consequently the quality assessment of surface, ground or footing it is always depending on usage (Hellberg-Rode, 2002).

Obviously equestrian sport disciplines have entirely different surface requirements than for example beach volleyball sport. However the scientific knowledge about human's physiology is tried to translate in to equestrian sport (Dreyer-Rendelsmann, (n.,d.)). Additionally the key element when focusing on equestrian spirt surface must be without any exceptions equestrian sport surface have to support horse's performance and at the same time reduce loads for the horse (Dreyer-Rendelsmann, (n.,d.)).

So the desired characteristics for equine surfaces are formulated as equestrian sport surface which delivers **security for penetration** and **slippage resistance.** A plane or **even**, **dust free** surface with **constant characteristic** and **low maintenance effort**. Furthermore the surface should be **elastic**. **Durability** plays also an important role for a product when looking at the finical effort new installation of equestrian sport surface brings in. It is definitely not preferable to reinstall a new surface annually. For outdoor arenas it counts also to be **independent concerning weather** conditions. Outdoor arenas are required to be smart in terms of handle individual amounts of water. It should be usable for riding also in wet conditions (Heinrich

Figure 1: Requirements to riding surface (Dreyer-Rendlsmann, (n.,d.); Heinrich & Hemker,

and Hemker, 2012). This means on one hand to store enough water to prevent the surface from getting too dry and dusty (Dreyer-Rendelsmann, (n.,d.)). On the other hand to lead away too much amounts of rainfall and to be frost proof (Dreyer-Rendelsmann, (n.,d.)). Last but not least and often forgotten however still extremely important aspect, an equestrian sport surface which is **harmless for ecology and the human's and horse's health**. (Dreyer-Rendelsmann, (n.,d.); Heinrich und Hemker, 2012). To sustain horse's health also the **right penetration depth** is crucial.

Formulation or to get desirable surface characteristic is quite simple. Ask riders, breeders, stable owners, and stable manager, ask the equine society about the perfect equestrian sport surface and the result will always be a bunch of above named desirable characteristics. However what does these characteristics in simple words mean:

The equestrian sport surface is	**if…**
secure for penetration and/ or resistance for slippage	The surface offers a certain amount of hold which simply avoids that the horse loses balance when it penetrates or even avoids that the horse slips and my fall (Dreyer-Rendelsmann, (n.d.)).
even	No height differences within one riding arena. Only 2% decline can be tolerated by the horse without any problems (Dreyer-Rendelsmann, (n.d)). Not only the penetration layer can be uneven also lower layers can depression take place which leads to unevenness (Dreyer-Rendelsmann, (n.d.)).
dust free	Dust are very small solid particles which are floating in the air for a longer time (Dreyer-Rendelsmann, (n.d.)). Dust is undesirable horse and human do sports on the surface which simply means that the lungs implement more air. In dusty area is this dangerous and may cause illness (Dreyer-Rendelsmann, (n.d.)).
constant characteristic	Differences in material, penetration layer thickness or humidity on the total arena area are an extra challenge for the horse during training which it needs to compensate next to the requested tasks (Dreyer-

	Rendelsmann, (n.d.)). Furthermore unequalised characteristic is associated with an increased injury risk (Riggs, 2010).
low maintenance effort	Stable owner or stable manager want to spent as less time as possible in surface maintenance. Due to the fact that no business is able to manage and to finance surface maintenance several times a day for example after every 20th horse ridden on the surface (Dreyer-Rendelsmann, 2013). At this point the main focus is on costs for labour and machinery (Dreyer-Rendelsmann, 2013).
right penetration depth	Penetration layer should allow penetration but only to a certain amount, so penetration depth between 2cm and 10cm is optimal (Dreyer-Rendelsmann, 2013).
elastic	An elastic surface supports horse's natural movement as well is gentle for horse's tendons and bones (Dreyer-Rendelsmann, 2013).
durability	This character stands in direct connection to fixed costs, because a new surface is a high investment which cannot be redone annually (Dreyer-Rendelsmann, 2013).
independent concerning weather	Especially outdoor surfaces are required to hold moisture and to lead away too much rainfall. Furthermore to be in winter times frost proof (Dreyer-Rendelsmann, 2013).
harmless for ecology and the human's and horse's health	An equestrian sport surface should support the horse as optimal as possible (Dreyer-Rendelsmann, 2013). On one hand the surface has to be gentle for bones,

tendons and muscles (Dreyer-Rendelsmann, 2013). On the other hand it surface and the installed materials need to be conform to the rules of animal welfare law and environmental protection law concerning ground, water and air (Dreyer-Rendelsmann, 2013).

A deeper look to these characteristics show they are partly controvert. A surface for secure penetration and with an ant-slippage character means a riding surface which offers hold (Dreyer-Rendelsmann, 2013). Hold to reduce the load onto muscles and tendons (Dreyer-Rendelsmann, 2013). Problematic is that a surface with this characteristic has a stop effect, so the whole motion of the horse is stopped and therefore less fluent (Dreyer-Rendelsmann, 2013). If the stop effect increases which would mean better hold, the load on bones, tendons and muscles increases as well (Dreyer-Rendelsmann, 2013). So this is already a non-agreement about the principle to reduce the horse's load. This is only one example.

As the figure above shows it is relatively simple to name the desired characteristics and equestrian sport surface needs to have to let perform safe and to support the horse's performance (Dreyer-Rendelsmann, 2013). Although it is known that the 'ideal surface' doesn't exists (Dyson, 2002; van Weer 2010; Dreyer-Rendelsmann, (n.d.)) it is of high importance to find out as much as possible about equestrian sport surface quality and to spread this knowledge to decrease the abrasive factor for the equine athlete.

2.1 Main Materials

Construction

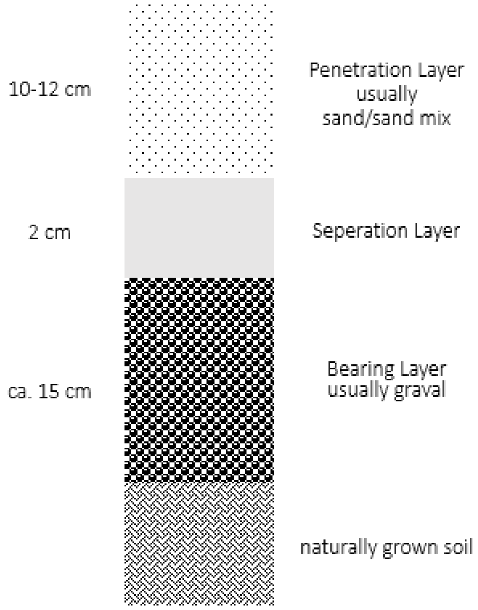

Figure 2: an example of a three layer surface (Heinrich and Hemker, 2012)

The majority of today's equestrian sport arenas are the so-called layer arena which consists of two or three layers. On top of the naturally grown surface is a bearing layer which is headed by separating layer and penetration layer (Dreyer-Rendelsmann, (n.d.)). While a two layer surface consists only of bearing and penetration layer (Heinrich and Hemker, 2012). With the layer arena the water is discharged downwards (Dreyer-Rendelsmann, (n.d.)). The bearing layer is required to be resistance against mechanical loads by maintenance device or horses traffic on the surface (Dreyer-Rendelsmann, (n.d.)). The separating layer is to prevent material mixture between the layers caused by too deep penetration of the hoof (Dreyer-Rendelsmann, (n.d.)). The penetration layer, the sport functional layer is responsible for penetration security, slip resistance, resiliency and appearance (Dreyer-Rendelsmann, (n.d.)).

Bearing Layer

As explained above the bearing layer is the equestrian sport surface's base (Dreyer-Rendelsmann, (n.d.)). Since researches mainly focuses on the penetration layer more scientific evidence is desired to find out about the bearing layer's influence on the surface's sport functional properties (Hobbs et al., 2014). Consequently the materials recommendations for the bearing layer are based on experiences (Hobbs et al., 2014) and regional availability. Limestone, crushed concrete or porous tarmac (asphalt) are traditionally used as rigid base in America (Hobbs et al., 2014). In Europe gravel, crushed rocks or mineral fractions are common materials (FORUM Zeitschriften und Spezialmedien GMBH, 2013). Clay is used to retain moisture in areas with lower rainfall (Hobbs et al., 2014). The layer thickness of the bearing layer should be adjusted to natural grown ground and average rainfall but should be at least three times as large as the largest grain (FORUM Zeitschriften und Spezialmedien GMBH, 2013). Sometimes also woodchips and rubber are installed in the lower layers since it is assumed to deliver extra shock absorption and improves surface's elastic recovery (Hobbs et al., 2014).

Separating Layer

A separating layer is as the name says to separate and prevent material mixture of bearing and penetration layer (Dreyer-Rendelsmann, (n.d.)). Therefore the separating layer is required to have a good grip face for toothing with the penetration layer, to be frost proof as well as water permeable (FLL, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013). Furthermore the separation layer has to be chemical stable, secure against embrittlement (sharp break points), impact and abrasion resistant, shock-absorbing (if rest of construction is not), low stretch and sufficiently resistant to deformation, also towards expansion in the heat and humidity and to have a stable position (FLL, 2014). Consequently it is challenging to find material which meets this complex demand. So typical materials used as separating layer are: mineral material such as fine crushed rocks, split or broken brick material or synthetic materials (FORUM Zeitschriften und Spezialmedien GMBH, 2013). Geotextiles are one example for synthetic materials (FORUM Zeitschriften und Spezialmedien GMBH, 2013). Geotextile fleece are not recommendable as separating layer since the water permeable decreases (FORUM Zeitschriften und Spezialmedien GMBH, 2013) and the wrinkle development increases which is a stumbling risk for the horses (FLL, 2014). Also grass pavers or paving grids are not advisable (FLL, 2014). Consequently the FLL strongly advices to use alternatives (FLL, 2014) such as synthetic mats and grid structures (FORUM Zeitschriften und Spezialmedien GMBH, 2013).

Penetration Layer

On the top layer, the penetration layer, the horses perform (FORUM Zeitschriften und Spezialmedien GMBH, 2013). The penetration layer is required to be even, stable and elastic to offer the horse's hooves firmness to support horse's performance (Swedish Equestrian Federation, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013). So the penetration layer's constitution and quality are together with the adjusted lower layers crucial for horse's performance (FORUM Zeitschriften und Spezialmedien GMBH, 2013). Sand is with 97% the most commonly used material for equestrian sport surfaces (Dreyer-Rendelsmann, (n.d.); FORUM Zeitschriften und Spezialmedien GMBH, 2013; Swedish Equestrian Federation, 2014).

Sand

In society sand is assumed with the well-known beach sand, but sand is not equal to sand (Dreyer-Rendelsmann, (n.d.)). Generally sand is defined as a substance mixture that consists of innumerable grains of sand whose individual property is crucial for the sand mix's total behaviour (Dreyer-Rendelsmann, (n.d.)). Furthermore the term sand is only an initially grain size determination, so in the industry every material with the grain size $\geq$ 0.063mm and $\leq$ 2.00mm is sand (Dreyer-Rendelsmann, (n.d.)). So first of all it is important to distinguish between the natural sand and the industry product: Natural sand developed by the natural process of erosion, physical and chemical weathering processes such as gravity, wind, water and temperature (Dreyer-Rendelsmann, (n.d.); Knecht, 2014; Meier, (n.d); Swedish Equestrian Federation, 2014), result in break down solid materials into small fractions (Dreyer-Rendelsmann, (n.d.); Swedish Equestrian Federation, 2014). So sand is a not-finished product (Knecht, 2014).

Knowing on one hand that sand the major ingredient in equestrian sport surfaces (Dreyer-Rendelsmann, (n.d.); Hobbs et al., 2014; Swedish Equestrian Federation, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013), and on the other hand that natural sand resource is a finite, not renewable resource (Swedish Equestrian Federation, 2014; Evertsson, 2013) develops a demand-supply problem. Therefore in Sweden the government policy require higher tax on natural sand to reduce the sand demand (Swedish Equestrian Federation, 2014). The alternative to natural sand is artificial sand which is manufactured with crushed rock (Swedish Equestrian Federation, 2014). To improve the artificial sand production a Swedish research project was initiated with the long term goal to provide customized sand products (Evertsson, 2013) which may also be beneficial for equestrian sport surfaces sand. The grain shape is main difference between natural (rounded and slightly angular shape) and manufactured sand (sharper and more angulated grains) (Swedish Equestrian Federation, 2014). A disadvantage of crushed rock is that it is not as durable as natural sand (Swedish Equestrian Federation, 2014). Next to shape, sand in general can be assessed by seven criteria: grain size, the original material, place of discovery, grain shape, grain face, grain roundness, and grain hardness (Dreyer-Rendelsmann, (n.d.); Swedish Equestrian Federation, 2014; FLL, 2014).

Grain Size

	Gravel	2 to 63 mm
	Sand	0.063 to 2 mm
Fines/ Filler	Silt	0.002 to 0.063 mm
	Clay	≤ 0.002 mm
Since 2002 there has been international standard classification of natural sand based on grain size (ISO 14688-1)		

Table 1: Grain size scale based on international standard (Swedish Equestrian Federation, 2014).

The surface's grain sizes are determined by the diameter in millimetres (Swedish Equestrian Federation, 2014). Sand is smaller than gravel (2mm - 63mm) and bigger than silt (0.0002mm – 0.063mm) and clay (< 0.0002mm) (Dreyer-Rendelsmann, (n.d.); Arrhen and van Doorn, 2014; Gilbert (n.d.); Meier, (n.d.); Swedish Equestrian Federation, 2014). Allied materials are named since grain's break down alter an once pure sand surface (Gilbert (n.d.)). Due to the fact that the size of a sand grain is equal to the head of a matchstick and clay is invisible for the human's eye (Swedish Equestrian Federation, 2014) the following imaginable comparison was published: "If a grain of sand had the same diameter as the wheel of a bike, a grain of silt would have the same diameter as a bottle cap and a grain of clay would be smaller than the head of a pin" (Swedish Equestrian Federation, 2014). The grain size distribution of a certain sand mix is crucial for the pore sizes between the sand grains (Swedish Equestrian Federation, 2014). Small pores are generated by either small grains or the composition of bigger and smaller grains, since the smaller grains (fines, filler) fill the gaps between the bigger ones (Swedish Equestrian Federation, 2014). The smaller the pores sizes the more the compaction degree (Swedish Equestrian Federation, 2014) which is the ability of a material to stick together to form a solid layer within the surfaces

(Peterson et al., (n.d.)). With increased difference between the sizes, only big and small grains; de-mixing may occur (Dreyer-Rendelsmann, (n.d.)). De-mixing is known from agricultural fields when rocks travel to the top again and again. Translating this to sand surfaces the bigger grains will lay on top and the smaller underneath (Dreyer-Rendelsmann, (n.d.)). To prevent de-mixing it is wise to use a narrowly classed (Dreyer-Rendelsmann, (n.d.); Heinrich and Hemker, 2012) sand, sand-mix with every grains sizes. Narrowly classed sand also decreases the abrasion process (Heinrich and Hemker, 2012) and create a stable and firm surface (Dreyer-Rendelsmann, (n.d.)). In conclusion the sand's grain size distribution affects the equestrian sport surface's property (Swedish Equestrian Federation, 2014). So the portion of fines within a sand mix has to be limited because: A: To separate fines is very difficult and B: mechanical loads by horses and maintenance devices cause a permanent break down process for the sand grains which result in increased fines amount (Swedish Equestrian Federation, 2014).

Original Material/Sand Type

The market for sand and allied materials offers a wide variety of sand types with different origins or treatments (FORUM Zeitschriften und Spezialmedien GMBH, 2013). Origin materials for sand may be shells, lava or quartz (Dreyer-Rendelsmann, (n.d.)). The most familiar and frequently advised sand for equestrian sport surfaces is **quartz** sand (Hobbs et al., 2014). Quartz also termed silica sand and contains a high amount (Meier, (n.d.)) up to 99%, of the quartz mineral (Hobbs et al., 2014). The high internal strength of the mineral (Meier, (n.d.)) deliver a hard durable character which is absolutely beneficial for equestrian sport surfaces (Heinrich and Hemker, 2012). Additionally quartz sand is permeable to water and does not bind it (FORUM Zeitschriften und Spezialmedien GMBH, 2013), which is important to avoid puddles especially in outdoor arenas.

Washed sand is appropriate as equestrian sport surface sand (Gilbert, (n.d.)). The treatment to wash sand means that the smallest particles are washed out (Swedish Equestrian Federation, 2014; Hobbs et al., 2014) consequently it has a determined grain size distribution (Gilbert, (n.d.)). However washed sand has a higher price, it also underlies the break down processes and it requires more maintenance effort due to the travel tendency (Gilbert, (n.d.)), so it is not necessarily advisable.

Place of discovery

Typical places of discovery are sea or river. Sand is also mined in quarries (Meier, (n.d.)). However beach sand is unsuitable as equestrian sport surface because it is too fine, round and smooth so cannot provide firm support (Strickland (n.d.)). Instead it tend to roll and shift under the horse (Dreyer-Rendelsmann, (n.d.); Gilbert (n.d.)) which leads to an insecurity for horse's performance.

Grain Hardness

Since the early 19th century it is determined to assess rock's and stone's hardness with the hardness table by Mohs which is based on the scratch characteristic (Dreyer-Rendelsmann, (n.d.)). The longer the grain travelled (erosion process) the harder it is (Dreyer-Rendelsmann, (n.d.)). Also the grains hardness depends on origin material's mineral content which is fundamental for the sand's property (Swedish Equestrian Federation, 2014). The grain hardness and shape are key factors for the equestrian sport surface's durability (Swedish Equestrian Federation, 2014; Gilbert, (n.d.)). Surface's durability is extremely important since equestrian sport surfaces are consumables so the surface's dying process starts with the first horse walking on the same (Dreyer-Rendelsmann, (n.d.)). Since every material used as equestrian sport surface underlies the break down processes triggered by peak loads of multiple tons by the horse's performance and the sand grains abrasion (Dreyer-Rendelsmann, (n.d.)). This break down processes lead to increased magnitude of microscopic particle which tend to compact and increases dust formation (Gilbert (n.d); Strickland (n.d.)). To minimise the break down process hard durable sand types such as quartz sand should be chosen (Heinrich and Hemker, 2012). Parallel the FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.) advices that at least 8% particles should be smaller than 0.063mm at installation time (FLL, 2006).

Grain Shape and Roundness

Terms for grain shape are round, flat, longish and cubic (Dreyer-Rendelsmann, (n.d.)). Terms for grain roundness are more specific such as sharp angular, angular, angular-rounded, well rounded (Dreyer-Rendelsmann, (n.d.)). The grain shape influences the property of a particular sand mix (Strickland (n.d.)). As already mentioned round grains may roll and shift under horse's hooves so are not ideal as surface material (Dreyer-Rendelsmann, (n.d.); Gilbert (n.d.)). Sharper angulated grains such as artificial sand grains lead to an increased hoof abrasion so be as well not ideal (Swedish Equestrian Federation, 2014). Finally the FFL strongly advised to use coarse and light angular sand, which provides required stability and firmness (Gilbert (n.d.); Strickland (n.d.); FFL, 2006).

Grain Face

Rather the term has to be grain surface, because it describes the surface of the grain, but it may lead to confusion in this context. The grain face could be rough or smooth (Dreyer-Rendelsmann, (n.d.)).

Conclusion (Sand)

Nevertheless pure sand is low in elasticity, less than 2% of the impacted energy is returned (Ahrren and van Doorn, 2014). Additionally research has shown that training on sand based surfaces have the largest risk for lameness (Egenvall et al., 2013). So questions about alternative materials are entitled. Expanding the horizon to different sports surfaces with similar requirements could be athleticism sports surface covers which are required to be elastic, penetration secure and slip resistant. Comparing the human and equine athlete shows immense weight differences. Imagine a horse performing on an athleticism surface, the surface cover would not resist the horse's peak loads and droppings on top of the surface cover would result a slide (Dreyer-Rendlesmann, (n.d.)). While the majority of equestrian sport surfaces (Great Britain Dressage: 77% (Hobbs et al., 2014) Germany: 97%) are sandy surfaces (Dreyer-Rendelsmann, 2013) there are alternatives.

Alternatives to Sand

Organic

An already established alternative to sand surface is the organic surface, mainly wood (Dreyer-Rendelsmann, 2013). Since the parameters durability, firmness and water permeability are critical on organic surfaces (FLL, 2014) an increased maintenance efforts is required to ensure safety for horse and rider (Dreyer-Rendelsmann, (n.d.)). Furthermore both constitutions too dry and too wet can be dangerous: a too wet organic surface gets slippery, especially if the wood is older due to alteration by weathering; a too dry organic surface leads to increased dust formation and it is proven that the wood dust is carcinogenic (Dreyer-Rendelsmann, (n.d.); FLL, 2014). Since bark and hard woods are not recommended the FLL advices to use alternatives with the restriction that treated wood needs to be harmless to environment as well as human's and animal's health (FLL, 2014). There are special certificates which acknowledge the innocuousness (Dreyer-Rendelsmann, (n.d.)).

Grass

Grass based surfaces can only be used when the climate is suitable (Hobbs et al., 2014; Egenvall et al., 2013). Grass based surfaces are assumed to better support the horse's natural movement (Hobbs et al., 2014). Nevertheless the sport functional properties of a grass surfaces are strongly affected by the root structure's quality, moisture content and sufficient nutrition enrichment (Hobbs et al., 2014; FLL, 2014). Both poor quality and too wet grass surface result in decreased shear strength which limits horse's safety then only the use of shoe studs can return the (Hobbs et al., 2014). Grass surfaces underlie alterations of divers influence factors: atmospheric and biological influences, loads by usage and maintenance (FLL, 2014). Indispensable regeneration periods of grass surfaces do not allow permanent and intensive usage (FLL, 2014). These regeneration days and the high maintenance effort led to replace grass surfaces with artificial or synthetic surfaces (Hobbs et al., 2014).

Synthetic

Artificial surface materials have an own place on the today's equestrian sport surface market to meet the individual demand of every discipline (Hobbs et al., 2014). Nonetheless the selection and manufacturing of materials are still based on empirical evidence and marketing strategies (Hobbs et al., 2014). That synthetic surfaces demand is confirmed by the variety of offerings (overview table in the annex). Synthetic surfaces are either pure synthetic surfaces which may consist of carpet pieces or sand mixed with one or several additives such as a wax-coated silica sand, polypropylene fibers, and recycled rubber surface (Arrhen and van Doorn, 2014). Positive about synthetic surface is that they do not underlie weathering processes (Dreyer-Rendelsmann, (n.d.)). Uta Gräf, a well-known German dressage rider and trainer stated about synthetic surface: „Although I only have an outdoor arena, I got the ability to train the whole year due to an excellent surface. (Kolpsch, 2014 AsGround).

2.2 Additives

Introduction

Additives are substances to improve equestrian sport surface's sport -, protection functional and technical properties such as water permeability, water holding capacity, firmness, penetration security, impact resistance and durability (Heinrich and Hemker, 2012; FORUM Zeitschriften und Spezialmedien GMBH, 2013; FLL, 2014). Worldwide there is an unlimited variety of materials used as additives for equestrian sport surfaces (FLL, 2014; Arrhen and van Doorn, 2014). In general additives are divided into **organic material** which are mainly wood products (woodchips, sawdust) **synthetic material** (synthetic fibre or flakes, rubber, wax, chopped fleece) and **mineral material** such as lava (shouldn't exceed 25% of the penetration layer's to prevent extreme hoof abrasion by sharp edges) (Swedish Equestrian Federation, 2014; FLL, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013). Additives are needed since sand the most common main material, (Dreyer-Rendelsmann, (n.d.); FORUM Zeitschriften und Spezialmedien GMBH, 2013; Swedish Equestrian Federation, 2014) is very low in resiliency (Ahrren and van Doorn, 2014), has the tendency to roll (Dreyer-Rendelsmann, (n.d.)) or displaces under the impact of the horse (Miller, 1994), tend to compact over usage time due to grain abrasion (FORUM Zeitschriften und Spezialmedien GMBH, 2013). So there are many issues to use additives such as minimise compaction degree (FORUM Zeitschriften und Spezialmedien GMBH, 2013), reducing hardness of the surface (Miller, 1994) or creating a safer surface (Gilbert, (n.d.)). The additive's wear resistance is limited due to the intense mechanical loads (horse, maintenance), for natural additives also weathering processes accelerate the wear (Heinrich and Hemker, 2012). In general additive's abrasion is more intense than sand abrasion (Heinrich and Hemker, 2012).

Innocuousness

Within the equestrian sport surface market 'new' materials and compositions are constantly offered. Although it is possible to create similar surface properties with unlike materials (Swedish Equestrian Federation, 2014) many offerings are lacking in clear reasoning (Dreyer-Rendelsmann, (n.d.)). Also proven knowledge about material's harmlessness is often missing (Dreyer-Rendelsmann, (n.d.)) which is necessary to ensure protection of environment and animal's and human's health (FLL, 2014). To confirm that materials comply with the requirements a so-called innocuousness declaration must be handed out to consumers (FLL, 2014; Dreyer-Rendelsmann, (n.d.)) to warrant the exclusion of:

→ release of hazardous gases, dust (especially fine dust/respirable dust) and fungal spores to the air;
→ water- or soil contamination or poisoning;
→ fire- or smoke development;

→ hazardous due to contact with or feed off (FLL, 2014).

The same applies for the material alteration due to wear, UV-rays, acid rain, droppings (FLL, 2014).

Most Commonly Used Types

The following paragraphs explain only the commonly used types with advantages and disadvantages.

Wood

→ General: Advantages & Disadvantages

Very traditional (Dreyer-Rendelsmann, (n.d.)) used additive types are wood additives such as woodchips, sawdust or wood shavings (Swedish Equestrian Federation, 2014; Gilbert, (n.d.); Kruse et al., 2012). The aim of mixing wood products to sand has four positives effects:

- ✓ it delays the sand's breakdown process by reducing abrasion (Gilbert, (n.d.)),
- ✓ it opens up the surface for better drainage and water holding capacity consequently creates more cohesion for the surface and reduces dust formation is (Gilbert, (n.d.)),
- ✓ it gives the surface more elasticity (Dreyer-Rendelsmann, (n.d.); Swedish Equestrian Federation, 2014; Kruse et al., 2012),
- ✓ large wood proportions increase the surface's damping ability (Barrey et al., 1991) as long as sand type and wood type fit to each other (Swedish Equestrian Federation, 2014).
- ✓ wood is a renewable natural resource which is consequently easy to dispose if it is worn (Swedish Equestrian Federation, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013) with permission it can be brought out on the farmland (Swedish Equestrian Federation, 2014).

Regrettably the elastic effect lasts only for a short time due to abrasion caused by sand and hooves (Dreyer-Rendelsmann, (n.d.)). One more weakness is that the wood is altered by natural bio-degradable which result in a lack of grip (Swedish Equestrian Federation, 2014). So it is necessary to remove droppings and refill additives in shorter intervals (Swedish Equestrian Federation, 2014).

→ Wood types

Different wood types have various properties which affect surface's behaviour and life time (Swedish Equestrian Federation, 2014). A key element is the resistance of degradation (Swedish Equestrian Federation, 2014). Larch and oak wood additives lasts longer than pine wood additives which lasts longer than fir wood additives (Swedish Equestrian Federation, 2014). This is due to the individual's trees' strategies to resist fungus attacks, which function as resistance against mechanical wear from horses' hooves in equestrian sport surfaces (Swedish Equestrian Federation, 2014). A rule of thumb gives the orientation that a sand-wood surface mix need to be replaced every three to five years (Swedish Equestrian Federation, 2014) but still it dependents on frequency and type of usage, weather- and maintenance influences. In Sweden f.e. it is common to use sawdust form pine wood additives and do an annually "top-up" (refill) (Swedish Equestrian Federation, 2014). If refill instead of replacement takes place, the worn and degraded wood particles will be still part of the surface, so it is necessary to remove droppings and regularly harrow deep to avoid slipping (Swedish Equestrian Federation, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013). When choosing wood types it should also be considered that black walnut wood is highly toxic for horses (Gilbert, (n.d.)).

→ Sand type

When mixing wood with sand it is advisable to use fine natural sand with a grain size of 0-1mm (Swedish Equestrian Federation, 2014). When a sand of grain size 0-2mm is used it is essential that the proportion of 1-2 mm grains do not exceed 10%, the filler quantity should be maximal 5 % and the amount of wood should be less than 20 % (Swedish Equestrian Federation, 2014).

→ Health

When using wood it is indispensable to avoid dust formation since it seem to be carcinogen, proven for beech and oak wood dust (Dreyer-Rendelsmann, (n.d.)). So untreated softwood of pine wood or spruce wood are advisable as additives for equestrian sport surfaces (Dreyer-Rendelsmann, (n.d.)).

Rubber

To prevent that the surface becomes too bouncy, the ratio rubber mixed to sand should be similar to pepper on mashed potatoes (Gilbert, (n.d.)). So was reported by riders who train on very rubberized surfaces that their horses perform poorly and experienced injuries on other surfaces (Gilbert, (n.d.)). Rubber additives are generally made from recycled tires (Gilbert, (n.d.)) and usually associated with a selection of organic combinations and metals (Hobbs et al., 2014). Research has shown that rubber additives include a composition of zinc, polyaromatic hydrocarbons (PAHs), volatile organic compounds (VOCs) and benzothiazole (BT) which perform well in leachate emissions (Hobbs et al., 2014). The emissions are influenced by various factors such as particle size, pH, material age, water salinity and composition of the rubber particles (Hobbs et al., 2014; Swedish Equestrian Federation, 2014). The emissions was assumed to be toxic for waste water (Hobbs et al., 2014). But research was able to confute the expected toxic effect (Hobbs et al., 2014). When producing rubber tyres it result in a porous material which air may permeate (Hobbs et al., 2014). Following equine sport surfaces containing this material may show large temperature rises, especially obvious was this when rubber additives particles were clustered on one surface spot (Hobbs et al., 2014). The temperature change can lead to an accerlated VOCs gas emission and a decomposition process (Hobbs et al., 2014). Equal moisture level and regular harrowing are crucial to avoid large temperature rises (Hobbs et al., 2014).

Synthetics

→ General

Synthetic additives are used in many equestrian sport surfaces for more than 20 years (FORUM Zeitschriften und Spezialmedien GMBH, 2013; Swedish Equestrian Federation, 2014). Originally synthetic additives were introduced to replace wood additives but comparing their benefits show that both have a right to exist (FORUM Zeitschriften und Spezialmedien GMBH, 2013). Also synthetic additives contain a wide spectrum of materials and shapes such as polyester-, polypropylene fibre, yarn, chaffed fleece, chaffed carpet or carpet-, polyurethane- or foam pieces (FORUM Zeitschriften und Spezialmedien GMBH, 2013; Swedish Equestrian Federation, 2014). But still it fleece is not equal to fleece and the same applies for fibre (FORUM Zeitschriften und Spezialmedien GMBH, 2013).

→ Advantages and Disadvantages

While the effects of adding synthetic material to sand is well researched, such as synthetic additives improve shear strength and stability due to the better binding between the sand particles triggered by the fibres, the effect on the horse is still not clear (Swedish Equestrian Federation, 2014).
To avoid problems or even nightmares the following three important questions need to be clarify:

- check if the synthetic additives are clean from residues of materials for example recycled carpet free from rubber or glue backing material (Swedish Equestrian Federation, 2014)
- is the material resistant to UV-light, if not material's degradation process and dust formation is accelerated so surface's life time is shorten (Swedish Equestrian Federation, 2014)
- the size of additives is crucial for quantity and maintenance:
  long fibres → smaller quantities and increase maintenance effort
  short fibres → bigger quantities and less maintenance effort
  (Swedish Equestrian Federation, 2014).

→ Amount

In general it is to say that the higher the proportion of fibre the greater the grip (Swedish Equestrian Federation, 2014). In practice the following proportion work well: 2-2.5kg/m² for a riding school, a competition with high speeds requires 2.5-3.5kg/m² (Swedish Equestrian Federation, 2014).

→ Sand type and size

Since synthetic additives is a generic term for many different materials, recommendations need to be regarded critical. In scientific literature the following statements can be found:

- For an outdoor arena a coarse sand with almost no fine material is suitable to mix with synthetic fibres to ensure horizontal drainage
- to use fine sand (0/1 or 0/2) since fine sand stick better with synthetic fibre than coarse sand
- A different counsel for an indoor arena is to use almost no fine material (at least 5%)

(Swedish Equestrian Federation, 2014).

Silt and Clay

Silt (0.0002 – 0.063 mm) and clay (< 0.0002mm) are smaller than sand (0.063 – 2mm) (Arrhen and van Doorn, 2014; Dreyer-Rendelsmann, (n.d.); Swedish Equestrian Federation, 2014; Gilbert (n.d.); Meier, (n.d.)). Both can also be used as additives, since they retain moisture (Mahaffey et al., (n.d.);

Dreyer-Rendelsmann, (n.d.)) so increase the surface's stability, cohesion and firmness (Gilbert, (n.d.); Hobbs et al., 2014). The right amount of fines is crucial for penetration security, horse's slide amount and surface's degree of compaction, and clods formation that may fly up (Malmgren et al., 1994; Mahaffey et al., (n.d.)). For sure different silt and clay types lead to unlike surface behaviour (Hobbs et al., 2014). To benefit from the fines 10 to 30% are commonly used (Hobbs et al., 2014; Gilbert, (n.d.)). While for dressage an 80/20, for jumping a 70/30 ratio of sand to fines is usual (Gilbert, (n.d.)). Since weather has a strong effect on required material amount there is no ideal receipt and ratios need to be adapted to local conditions (Mahaffey et al., (n.d.); Dreyer-Rendelsmann, (n.d.)).

Salt

Salt is available in different forms such as sodium chloride and calcium chloride (Swedish Equestrian Federation, 2014). The reasons to use slat as additives are binding dust, binding moisture to lowering surface's water need and freezing risk (Swedish Equestrian Federation, 2014). Practice has shown that salt may be dangerous for the drainage system (Swedish Equestrian Federation, 2014). Also it is assumed that slat may cause skin irritation if the horse has small scratches (Swedish Equestrian Federation, 2014). Salt as additives require regular harrowing to prevent salt laying on the top (Swedish Equestrian Federation, 2014).

Wax

→ General

Wax is used in equestrian sport surfaces to coat and bind sandy surfaces (Mahaffey et al., (n.d.)). Wax-coated surfaces can only be found in a few countries (Swedish Equestrian Federation, 2014), in Germany f. e. is no innocuousness declaration yet (Dreyer-Rendelsmann, (n.d.)).

→ Advantages

Wax or oiled surfaces are used when specific performance characteristics desired (Swedish Equestrian Federation, 2014) such as to reduce dust formation also deliver cohesion and friction to support horse's hoof (Dreyer-Rendelsmann, (n.d.); Mahaffey et al., (n.d.); Swedish Equestrian Federation, 2014). Wax can be used to replace high amounts of fines with the significant difference that fines may compact into a curst beneath the top of the penetration layer or clog the drainage, so wax surfaces require less maintenance effort (Swedish Equestrian Federation, 2014):

- require less water (Swedish Equestrian Federation, 2014)
- are hydrophobic which means the surface repels water (Mahaffey et al., (n.d.); Swedish Equestrian Federation, 2014)
- has a reliable vertical drainage (Swedish Equestrian Federation, 2014) if this is not enough to handle rainfalls a single pass with a harrow will result in fast drainage (Mahaffey et al., (n.d.))

→ Disadavantes

Surfaces added with wax can be highly sensitive to temperature changes (Swedish Equestrian Federation, 2014; Mahaffey et al., (n.d.)): the surface gets harder in colder conditions and when the temperature rises softer (Swedish Equestrian Federation, 2014) and evaporation (Mahaffey et al., (n.d.)) and melting may occur (Swedish Equestrian Federation, 2014). To handle this sensitivity watering has to be adjusted (Mahaffey et al., (n.d.)). The higher the proportion of paraffin, the higher the tendency of melting (Swedish Equestrian Federation, 2014). Melting and wax wear lead to the need of 're-waxing' which may be costly (Swedish equestrian Federation, 2014). Very expensive and very difficult is also the disposal of wax-coated surfaces (Swedish Equestrian Federation, 2014).

It's The Mix

The additive's effect on the total equestrian sport surface performance depends on the mixing ratio (Heinrich and Hemker, 2012). The majority of advices, materials and compositions are based on empirical evidence (Hobbs et al., 2014) since additives only rarely researched (Heinrich and Hemker, 2012). Ratio determination is not simply calculating such as adding more fleece leads to a softer surface as it is not proportional (FORUM Zeitschriften und Spezialmedien GMBH, 2013). Various surfaces consists of several additives such as sand with minor amounts of fines with organic matter (Malmgren et al., 1994) or sand with fibre and wax coated (Tranquille et al., 2013). When additives should be mix to an already installed surface a rotary tiller for mixing is indispensable (Swedish Equestrian Federation, 2014). But it should never fall out of focus that mixing should be operated carefully (Gilbert, (n.d.)), hence additives change the whole surface structure (Heinrich and Hemker, 2012) and can also result in nightmares. Imagine too high additive amounts, invalid or waste material such as metal, cable rests or broken glass (Dreyer-Rendelsmann, (n.d.)). Nightmares could be sludge -, fine dusts formation, effluvium, too less firmness due to fast weathering and de-mixing (FLL, 2014).

Particle Sizes

Due to the abrasion effect it is important to know what particles and piece sizes are common:

Additive Material	**Particle Sizes**
fleece	ca. 15-65mm; [15cm (Kruse et al., 2012)]
chopped fleece	ca. 5-30mm
chopped fleece with 15% polyester fibre	ca. 5-30mm; fibre length: 40mm
polyurethane foam (PU-foam)	ca. 5-35mm
granulate	ca.1-3mm
bamboo fibre	ca.25mm
textile fibre CLOPF®	ca. 5-20mm; fibre: ca. 30mm
	(Heinrich and Hemker, 2012)
wood additives wood chips • *with and without bark* wood shavings • *without bark* gate chips • *without bark* sievings • *without bark*	 not defined 0-15mm 0-10mm medium: 0-30mm rough: 10-30mm
	(Dreyer-Rendelsmann, (n.d.))

Rubber	2-3mm
	(Malmgren et al., 1994)

Table 2: Particle size overview of common additives (Heinrich and Hemker, 2012; Dreyer-Rendelsmann, (n.d.); Malmgren et al., 1994).

2.3 Humidity/Moisture

Water is Important

Moisture content is the most important parameter in equestrian sport surface's quality evaluation, as it significantly controls the total surface's property and performance (Setterbo et al., 2012a; Heinrich and Hemker, 2012; Schweizerischer Verband für Pferdesport, 2014; Peterson et al., (n.d.); Swedish Equestrian Federation, 2014; Thomson und Mahaffey, (n.d.); Hobbs et al., 2014; Egenvall et al., 2013). Therefore it is central to understand the interplay between water and surface property (Peterson et al., (n.d.)). Imagine walking on dryer beach sand is more exhausting than on wet less deformable sand (Swedish Equestrian Federation, 2014; Dreyer-Rendelsmann, (n.d.); FORUM Zeit-schriften und Spezialmedien GMBH, 2013). For horses applies the same: performing in dry deep sand need extra forces in every stride as proven (Ahrren and van Doorn, 2014; Heinrich and Hemker, 2012; Peterson et al., 2012; Ratzlaff et al., 1997). Watering alters surface's condition from dry to wet, so air is replaced by water in the pores between the sand grains (Swedish Equestrian Federation, 2014). Wet surface generally supports equine movement, reduces penetration depth (Ahrren and van Doorn, 2014) and loads due to damping effect (Barrey et al., 1991). Also equal surface properties are crucial for lower injury risk, so the surface should be filter stable (transfer water without de-mixing) (FLL, 2014), absorb and drain surplus water (FORUM Zeitschriften und Spezialmedien GMBH, 2013).

First Steps in Quality Assessment

In the racing industry precise monitoring of changes in moisture content over time were used to record the targeted humidity for turf and dirt racing tracks level into words (Peterson et al., 2012).

Turf Racing Track		**Dirt Racing Track**	
Firm	dry or slight moisture	**Fast**	Dry
Good	good amount of moisture	**Good**	some residual moister
Yielding	very wet course → slower racing times	**Muddy**	very moist due → high water content
Soft	Water-logged course → very slow racing times	**Sloppy**	Slippery due to excessive water content

Table 3: Surface characteristic of racing tracks based on estimated water content (Maeda et al., 2012).

Watering Goals

Watering should be goal orientated and constantly adjusted to the uncontrollable weather factors: sun, wind, and rain (FLL, 2014). The superficial goals for watering is to keep an uniform moisture level to improve surface's quality especially firmness with penetration security and penetration depth, elasticity and dust control to protect animal's and human's health (FLL, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013; Gilbert, (n.d.); Miller, 1994), since dust stresses the lungs of both (Dreyer-Rendelsmann, (n.d.)) (more details chapter 3.1.6.). For grass surfaces additional watering goals are the prevention of drought damages and the sward recovery support (FLL, 2014). A deeper look into this subject shows that surface quality parameters such as impact resistance, energy return, shear strength (Heinrich and Hemker, 2012) and friction damping capacity values are affected by moisture content (Barrey et al., 1991) consequently are also watering goals. A comparison of two humidity level and impact resistance measurements by the University of Applied Science Osnabrück (2008 humidity level: 15%; impact resistance: 33%; 2010: humidity level: 8%; impact resistance: 42%) initially shows that humidity level is a snapshot. Moreover it displays that impact resistance, which should be rather low (Setterbo et al., 2011), decreases when humidity level increases while energy return increases as well (Heinrich and Hemker, 2012; Ratzlaff et al., 1991) which is definitely desired (Setterbo et al., 2011) to let horse perform more easily. The values for both impact resistance and energy return approximate each other by raising water level, it is assumed to go on until the 'ideal' humidity level is gotten (Heinrich and Hemker, 2012). If the water level onwards increases the values will drift apart and the total riding property will decline (Heinrich and Hemker, 2012). Also for maximum shear strength parameter is a certain water content range required, above or below this rage the values will decrease again (Peterson et al., 2012) which is not preferable. It was researched that at 18% water content the shear strength values were relatively low and the maximum shear strength was reached at 14% (Mahaffey et al., 2013). Finally it is known that low (4%) and high (12%) moisture level created higher peak forces than moderate (8%) (Hobbs et al., 2014).

Watering Management

Watering is part of equestrian sport surface maintenance (FORUM Zeitschriften und Spezialmedien GMBH, 2013). The art of watering management is complex and requires fundamental knowledge and experience (Swedish Equestrian Federation, 2014). The amount and times of watering are always dependent on material and composition, particle size and pores size as well as regional and discipline requirements (FLL, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013; Peterson et al., 2008; 2012; Malmgren et al., 1994; Barry et al., 1991; Hobbs et al., 2014). Since different disciplines have different requirements to the surface, also moisture requirements differ (Hobbs et al., 2014). To meet these requirements water level adjustments lead to alter penetration depth with compacting and loosening the surface (Gilbert, (n.d.)). So surfaces for show jumping tend to have higher humidity level (Heinrich and Hemker, 2012) as it is aspired to be harder to allow a clear jump off (Strickland (n.d.))**.** Dressage surfaces seeks to be rather soft to gain lightness in the gaits (Strickland (n.d.)) so require less water (Heinrich and Hemker, 2012). For grass-based surface watering should be carried out during recovery and wilted times as well in increased quantities and time intervals to avoid root flattening (FLL, 2014). For outdoor surface and especially in summertime it is wise to water during the night because of less wind, lower evaporation rate and increased pressure in the public power supply (FLL, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013). Again there is no ideal receipt for the right water amount but scientific literature gives rough advices (FORUM Zeitschriften und Spezialmedien GMBH, 2013). For example the chamber of agriculture recommends to water 0.5mm per m² and minute (FORUM Zeitschriften und Spezialmedien GMBH, 2013). Other proposals are that the surface's humidity level should be between 8% and 12% (Gilbert, (n.d.)) or between 8% and 17% (Barrey et al., 1991). For racing tracks researchers recommend for dirt surfaces, between 9% and 11% water contents (Setterbo et al., 2011; 2012a; 2012b), and for synthetic surface humidity level of 0% up to 0.4% (Setterbo et al., 2012b) or 5.4% to 6% (Setterbo et al., 2011) (different values for synthetic surface may be due to unlike compositions and influence factors). For organic surfaces the average humidity level ranges between 11% and 15% (Peterson et al., 2008). Consequently the required water amount values need to be individually adjusted. When measuring water level it must be considered that the values may increase up to 66% in 5 cm depth (Heinrich and Hemker, 2012).

Problems

A clear problem in watering management is the unequal water distribution, shown in diverse color impressions in the surface (FLL, 2014). These wetter and dryer spots lead to unequal surface quality (Heinrich and Hemker, 2012; Swedish Equestrian Federation, 2014; FLL, 2014), which makes horse's performance more difficult and rise injury risk (FLL, 2014; Dreyer-Rendelsmann, (n.d.); Hobbs et al., 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013). Helpful for equal moisture distribution over the total surface is entirely evenness (FORUM Zeitschriften und Spezialmedien GMBH, 2013; Swedish Equestrian Federation, 2014). Another problem could be suffusion the relocation of fines in the surface by water, lead to only coarse structures are retained (FLL, 2014). As result the clogged separating layer hinders water drainage (FORUM Zeitschriften und Spezialmedien GMBH, 2013).

Watering Systems

→ Different Systems

Crucial for the watering quality is next to equal water distribution the water droplet size and jet's pressure (Heinrich and Hemker, 2012). All three parameters are influenced by the watering system, the most commons are: water hoses, water trucks, rainfall simulator or sprinkler, accumulation system (FLL, 2014; Swedish Equestrian Federation, 2014)***.*** The water trucks are in the majority of cases liquid manure spreader or tank trailers which are connected to tractor or maintenance device (FORUM Zeitschriften und Spezialmedien GMBH, 2013; FLL, 2014). Watering in this way is a short term solution and preferably used on events since it consumes much time and water, besides there is a great risk of spreading too much water (FORUM Zeitschriften und Spezialmedien GMBH, 2013).

Sprinkler systems are distinguished into fixed and moveable sprinklers (FORUM Zeitschriften und Spezialmedien GMBH, 2013; FLL, 2014). Two common movable sprinklers systems are sprinkler on tripods with hoses (tripod sprinkler) or pipelines out of quick coupling pipes (FLL, 2014). Both systems requires a large amount of time and human resources (FLL, 2014). There are also different types of fixed sprinklers: for outdoor arenas concealable or non-concealable sprinklers are advisable (FLL, 2014). Concealable sprinkler's covers rise when pressure releases while non-concealable sprinklers need to be installed outside the riding area (FLL, 2014). Both require less time and human resource compared to mobile sprinklers (FLL, 2014). In indoor arenas mainly fixed sprinklers connected to a supporting structure are used (FLL, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013).

→ Operation Possibilities

There are also three options for the system control: The hand operation when sprinklers are manual operated (FLL, 2014), the semiautomatic operation with time locker (FLL, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013) and the fully automatic operation controlled by a computer system with weather station (FLL, 2014). Beneficial for surfaces which require diverse amounts due to shadow areas is manual operation (FORUM Zeitschriften und Spezialmedien GMBH, 2013).

→ Accumulation System

Another watering option is the accumulation system with controllable water level (FLL, 2014; Swedish Equestrian Federation, 2014). Also called Ebb and Flood system imitates it the beach sand (Swedish Equestrian Federation, 2014). This system is very complex and sensitive so requires a specialist for installation and sand type selection based on the "flow-point" (Swedish Equestrian Federation, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013). This system meets the individual requirements of all disciplines (FORUM Zeitschriften und Spezialmedien GMBH, 2013) as varying water level changes total surface properties (Swedish Equestrian Federation, 2014; FLL, 2014). The total arena is placed in a sealed tub to avoid ground water insert and drainage of system intern water (FORUM Zeitschriften und Spezialmedien GMBH, 2013; FLL, 2014). The key element is the pipe systems in the lower layers of the surface (FORUM Zeitschriften und Spezialmedien GMBH, 2013), pipes with at least DN 100 are advisable for equal moisture distribution (FLL, 2014). The water use in an accumulation system is based on individual natural rainfall, evaporation and feeding in water (Heinrich and Hemker, 2012). The positive aspect of an accumulation system is that the daily maintenance effort is reduced, because watering is omitted (FORUM Zeitschriften und Spezialmedien GMBH, 2013). If the weather is dry and insolation increases, water evaporates via the face of the surface, consequently the system feeds the relevant water amount in (Heinrich and Hemker, 2012; FORUM Zeitschriften und Spezialmedien GMBH, 2013). Moreover the accumulation system pumps surplus water of rainfall off (Heinrich and Hemker, 2012; FORUM Zeitschriften und Spezialmedien GMBH, 2013). To ensure a well working system works regular pipe maintenance with a camera to locate problems is necessary (FLL, 2014). A problem could be unevenness in the pipe systems which result in dissimilar water levels within the system and thus the surface (Heinrich and Hemker, 2012).

Watering Supply

Water supply need be planned before installing an equestrian sport surface (Swedish Equestrian Federation, 2014). Many stables, have insufficient water supply (Swedish Equestrian Federation, 2014). Therefore Karsten Koch an expert for riding surface disagrees arena installation requests as long as the water supply is not clarified, because later complains about too deep surface property, will have its origin in too dry surface condition (Swedish Equestrian Federation, 2014). For insufficient water access solutions could be: use water from public resources (with approval) (FLL, 2014), install water tanks, collect rain water or an accumulation system (Swedish Equestrian Federation, 2014).

Drainage

Outdoor arenas are additionally required to handle rainwater and drain it, considering the Water Resources Law (FORUM Zeitschriften und Spezialmedien GMBH, 2013). There are equestrian sport surface with a horizontal or a vertical drainage or a combination of both (FLL, 2014; Heinrich and Hemker, 2012). The vertical drainage uses the interplay of barring and lower layers (FORUM Zeitschriften und Spezialmedien GMBH, 2013). The horizontal drainage, natural drainage, operates over the surface's face (FLL, 2014). Horizontal drainage surfaces have the highest point in the centre and slight slope of up to 2% to the sides (Swedish Equestrian Federation, 2014). Drainage systems are quite recent as the one under the surface at the Olympic Games in London 2012 (Hobbs et al., 2014).

Moisture Level is a Snapshot

The moisture degree is dynamic as it varies dramatically in short time (Peterson et al., 2012) affected by rainfall, evaporation, water holding capacity (Hobbs et al., 2014) and water permeability (Peterson et al., 2012). While the surface properties water permeability and water holding capacity can be changed by material adjustment (FLL, 2014; Heinrich and Hemker, 2012; FORUM Zeitschriften und Spezialmedien GMBH, 2013), the weather is uncontrollable so requires adjustments in watering or drainage (FLL, 2014). The higher the water permeability of an installed sand structure the higher the water proportion which seeps vertically (Heinrich and Hemker, 2012). Water holding capacity and water permeability or seepage behaviour meet each other on the same base: the pore sizes (Heinrich and Hemker, 2012) determined by the grain size distribution (Swedish Equestrian Federation, 2014). A surface with small pores is better in water holding capacity and lower seepage ability than one with rough pores (Heinrich and Hemker, 2012; Dreyer-Rendelsmann, (n.d.)). The pore size and therewith surface's reply to watering can be altered by surface treatment or material adjustment. It is known that pure sand surfaces have less seepage ability than sand surfaces with additives (Heinrich and Hemker, 2012). Water holding capacity improvement requires additives as fleece or fines considering grain size distribution (Heinrich and Hemker, 2012; FORUM Zeitschriften und Spezialmedien GMBH, 2013). Incline enlarging up to 2% alter water permeable or seepage (Heinrich and Hemker, 2012).

Conclusion

Finally the parameters impact resistance, energy return, humidity level and evenness need to be considered together to assess equestrian sport surface’s quality (Heinrich and Hemker, 2012).

2.4 Firmness

What is Firmness

→ Introduction

Essential for horse's security are the sport functional properties such as penetration-, slip- and jump security (FLL, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013). Therefore the penetration layer should be elastic and stable to offer enough grip without loading horse's joints and tendons (FORUM Zeitschriften und Spezialmedien GMBH, 2013; Swedish Equestrian Federation, 2014). However firmness as sport functional quality parameter for equestrian sport surfaces is complex since it is challenging to characterise optimal firmness.

→ Definition

• Firmness is the "quality of not being soft, but not completely hard" (*Cambridge Dictionaries Online*, 2014).

• Firmness means "resistant to externally applied pressure" (*The Free Dictionary by Farlex*, 2014).

• Firmness is the resistance behaviour of a material against elastic or plastic deformation (Wikipedia, 2014; *University of Bayreuth,* (n.d.); Heinrich, 2001; Argerer, 2009).

A harmonious combination of these three definitions will hit the nail right on the head for firmness as parameter of equestrian sport surface quality. So the surface's firmness degree determines the sliding behaviour and so-called stop effect which results from the interplay between horse's hoof and surface (Peterson et al., 2012). Firmness is indispensable for equestrian performance especially in turns and the phases of hoof landing and propulsion (Swedish Equestrian Federation, 2014).

→ The Right Amount

The sliding behaviour of the equine hoof into the top of the surface is crucial for the horse's security (Swedish Equestrian Federation, 2014) because the right amount decides between performance support or injury risk. A surface with low firmness degree is slippery and result in excessive sliding behaviour (Dreyer-Rendelsmann, (n.d.); Swedish Equestrian Federation, 2014). Which represents an insecurity and therewith soft-tissue injury risk for the horse especially at high speed performances (McClinchey et al., 2004). Additionally tendons and muscles need to work harder to compensate the extra loads and avoid slippage (Dreyer-Rendelsmann, (n.d.)). Also a very firm surface is undesirable, because it tend to be dull consequently shortened the sliding performance so the stop arises early (Dreyer-Rendelsmann, (n.d.); Swedish Equestrian Federation, 2014). Although a high degree of firmness supports high speed performances (Swedish Equestrian Federation, 2014) bones, tendons and muscles experience overload (Dreyer-Rendelsmann, (n.d.)).

So both too less and too much firmness increase the loads for the equine athlete (Swedish Equestrian Federation, 2014; Dreyer-Rendelsmann, (n.d.)). Consequently optimal injury prevention need a surface with a right balanced firmness degree so that horse's hooves get the ability to slide slightly and experience the impact absorption therewith the horse get supported (Swedish Equestrian Federation, 2014). To reach this desire is challenging for all involved parties such as equestrian sport surface manufacturer, stable owner and employees, riders and trainers (Swedish Equestrian Federation, 2014). Since various influence factors come together such as material and composition (Murray et al., 2010), maintenance, hoof landing speed and angle (Swedish Equestrian Federation, 2014). It was for example found out that surfaces with woodchips were 12.7 times more likely to cause slipping than other surface materials (Murray et al., 2010). So a strict individual management plans adjusted to surface material and circumstances (Dreyer-Rendelsmann, (n.d.); Heinrich und Hemker, 2012; FLL, 2014) is crucial for injury prevention.

Firmness Development

Generally firmness, or partly termed as grip, depends on surface's friction and the surface's ability to develop an interlock between penetration and lower layers to offer traction or grip (Swedish Equestrian Federation, 2014). Looking back to the previous chapter (3.1.2 Humidity) demonstates that water is an indispensable and irreplaceable resource for equestrian sport surface (Swedish Equestrian Federation, 2014; FLL, 2014) since it strongly influence the total surface behaviour (Setterbo et al., 2012 a; Heinrich and Hemker, 2012; Peterson et al., (n.d.); Schweizerischer Verband für Pferdesport, 2014; Swedish Equestrian Federation, 2014; Thomson und Mahaffey, (n.d.); Hobbs et al., 2014; Egenvall et al., 2013). To understand the development of firmness in an equestrian sport surface it is of important to explain the physical processes when merging sandy surfaces with water: A liquid is physically only a liquid because the particles attract each other,stick together (Dreyer-Rendelsmann, (n.d.)). The outside located particles are only attracted by the forces of the inside located particles (Dreyer-Rendelsmann, (n.d.)). An upper face tension or professionally termed as cohesion of, in this case, the liquid (Dreyer-Rendelsmann, (n.d.); Heinrich and Hemker, 2012) is responsible for droplet formation (Dreyer-Rendelsmann, (n.d.)). So cohesion is the particle attraction of a substance such as a solid, a liquid or a gas (*Kohäsion und Adhäsion*, (n.d.)). Adhesion is however the particle attraction between two dissimilar in type substances such as solid and gas (Dreyer-Rendelsmann, (n.d.); *Kohäsion und Adhäsion*, (n.d.)). So merging the equestrian sport surface sandy substance with water means adhesive forces which act between environment and water, and cohesive forces responsible for the cohesion of the droplets meet each other (Dreyer-Rendelsmann, 2013). So sandy surface consists of a multitude of sand grains consequently the pores between the grains build together a kind of pipe system (Dreyer-Rendelsmann, (n.d.); Kapilliarität, (n.d.)). In this very small pipes is the attraction of the solid walls (adhesion) greater than the attraction between the water droplets (cohesion) (Dreyer-Rendelsmann, (n.d.)). Consequently water rises, as long as the capillarity (adhesion and cohesion) is greater than the gravity (Dreyer-Rendelsmann, (n.d.)). This means the pores which are filled with air in dry constitution are filled up with water (Dreyer-Rendelsmann, (n.d.)). So cohesion and adhesion are together responsible for the interplay between sand and water which function as a kind of glue to result in cohesion to keep the sand grain mix together (Dreyer-Rendelsmann, (n.d.); Heinrich and Hemker, 2012). So cohesion is a key for a suitable firmness degree to ensure the horse penetration security and slip resistance (Dreyer-Rendelsmann, (n.d.)).

Influence Factors on Firmness

Firmness itself is an inconstant parameter, it varies with the degree of compaction as well as the humidity level as explained above (Heinrich and Hemker, 2012). However both are tightly related since adding water leads to increased compaction degree (Dreyer-Rendelsmann, (n.d.); Gilbert, (n.d.)). For compaction degree it is useful to know that the more a surface is compacted the more loadable the surface is, due to the fact that each volume unit of the surface fabric develops an increased number of contact points (Heinrich and Hemker, 2012). Grain composition as well as grain shape and face influence strongly the surface's firmness (Heinrich and Hemker, 2012) since those three parameters determine the pore sizes (Dreyer-Rendelsmann, (n.d.); Heinrich and Hemker, 2012). Pores sizes are crucial for compaction level since the smaller the pores the more compacted the surface is (Eden, 2010; Heinrich and Hemker, 2012). So a widely classed grain compositions possess a higher compaction degree and therewith definitely more contact points compared with a narrowly classed grain compositions (Heinrich and Hemker, 2012). For the reason that within a widely classed grain mix the pores might underlie a diminishment when smaller grains fill the pores between bigger ones (Eden, 2010; Heinrich & Hemker, 2012). The contact points are indispensable for equine performance since these contact points ensure the required penetration security and slip resistance (Dreyer-Rendelsmann, (n.d.)).

2.1.5 Elasticity

Definition and Desire

In physics elasticity is defined as A: “the property of returning to an initial form or state following deformation” and as B: “the degree to which this property is exhibited” (*The Free Dictionary by Farlex,* 2014). Furthermore is elasticity in the context of equestrian sport surface defined as energy return which is a proportion of the initially input kinetic energy (Heinrich and Hemker, 2012; FLL, 2014). So with other words the measured values for then parameter energy return express the surface’s degree of elasticity (Setterbo et al., 2011). The ideal elastic surface absorbs and consumes the force of the hoof which is contacting and interacting with the surface to reduce concussion, “both the downward and the upward shock of impact” (Strickland (n.d.)).

Elasticity will probably be one of the most frequently named desirable character of the perfect surface (FORUM Zeitschriften und Spezialmedien GMBH, 2013), directly followed by resilient feeling and cushion, energy return to support horse’s performance (Setterbo et al., 2011; Strickland (n.d.); Hobbs et al., 2014). However at the end of the day the safety must be the central focus (FLL, 2014) so an elastic penetration layer is highly important to minimise the loads on the horse’s legs especially the lowest parts: the distal phalanx (hoof), middle phalanx and proximal phalanx – figure 3 (Heinrich and Hemker, 2012) and therewith diminish the long term injury risk.

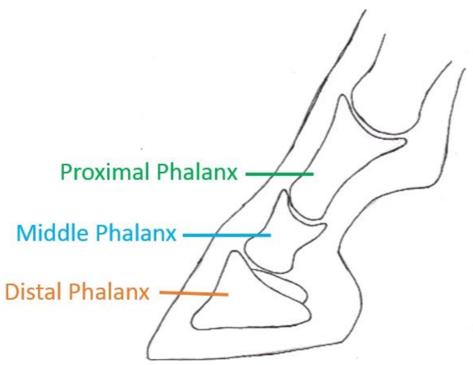

Figure 3: Visual explanation of proximal, middle and distal phalanx – Drawing by Helene Koch

That there are immense force differences for the equine limb based on surface properties was demonstrated comparing equine performance on steel and rubber surface (Heinrich and Hemker, 2012; Hobbs et al., 2014). Hoof acceleration was measured and expressed as multiple of g - acceleration of gravity (9.81 m/s²) (Heinrich and Hemker, 2012). The measurement results in table 5 demonstrate that already a slight elasticity in the surface results in reduced loads of hoof, phalanx r Hemker, 2012).

	Steel Surface	*Rubber Surface*
Hoof	74.0 x g	14.6 x g
Phalanx Media	17.8 x g	11.0 x g
Phalanx Proximal	6.1 x g	5.0 x g

Table 4: Absorption of a front limbs shock: acceleration measured in g = acceleration of gravity: 9.81m/s² (Heinrich and Hemker, 2013).

Elasticity Creation

The surface’s elasticity is created by the size of pores in between the grains (Swedish Equestrian Federation, 2014). Small pores, due to small grains, are more likely to create an elastic surface (Swedish Equestrian Federation, 2014). But then again the pore size is as well as an inconsistent parameters (Dreyer-Rendelsmann, (n.d.)) since usage let the grains underlie abrasion and result in wear (Dreyer-Rendelsmann, (n.d.); Heinrich and Hemker, 2012). As sand itself is poor in elasticity property (Ahrren and van Doorn, 2014) it may be created with additives as mentioned in chapter 3.1.2 (Additives), commonly used additives increases the surface's sport functional property of elasticity since are wood (Kruse et al., 2012; Dreyer-Rendelmann, (n.d.)) or are rubber additives (Murray et al., 2010). However those additives need to be mixed very cautious, because too much support or 'bounce' can lead to immense performance decline or catastrophic injuries when change from training to competition surface (Gilbert, (n.d)).

Another option to improve surface's elasticity is to adjust the lower layers with for example a rubber elastic pad (Heinrich and Hemker, 2012). Since measurements have shown that it has a significant effect on surface properties, less influence on impact resistance but significantly on energy return, penetration depth and compaction degree (Heinrich and Hemker, 2012).

Energy Return and Impact Resistance

Elasticity as measurable parameter is the combination of several parameters such as energy return and impact resistance. These both parameters cannot be evaluated alone as explained in chapter 3.1.3 Humidity various moisture levels lead to one increased and one decreased parameter (Heinrich and Hemker, 2012). That impact resistance only contributes to an elastic surface character proves the example sandy beach with dry deep sand which is a surface which has cushioning without elasticity (Swedish Equestrian Federation, 2014). So to set equal knowledge for further description it is helpful to look at the definitions in the context of sport surfaces. Impact resistance is the ability to reduce the impact or impact force of a falling body (FLL, 2014; Hobbs et al., 2014; Swedish Equestrian Federation, 2014). Energy return is, as mentioned above, the percentage of input energy that is returned (Heinrich and Hemker, 2012; FLL, 2014). So during this collision between horse's hoof and surface energy gets lost (Hobbs et al., 2014). Ideally the horse's hoof gets in contact with the surface, then penetrates and loads the same (Hobbs et al., 2014). This loading can be visualised as pushing the surface down, **deformation** by the horse's weight comparable with a trampoline (Swedish Equestrian Federation, 2014; Hobbs et al., 2014). Afterwards the trampoline gives energy back, which is also called responsiveness (figure 4) (Hobbs et al., 2014). So in the ideal case the surface reacts with pushing upwards to its original shape, as soon as the horse's weight decreases, and therewith supports the horse's pushing off into the next stride (Swedish Equestrian Federation, 2014; Hobbs et al., 2014; Heinrich und Hemker, 2012). Energy return is the desired 'bounce' effect or respond of the surface which supports horse to show active, light and sprightly performance as long as timing and proportion are correct (Strickland (n.d.); Roepstorff and Peterson, (n.d.); Hobbs et al., 2014). This

	Impact Resistance	Energy Return
Show Jumping	30% - 35%	15% - 35%
Dressage	35% - 55%	10% - 35%

Table 5: Rough range for common impact resistance and energy return values of an equestrian sport surface (FLL, 2014)

right momentum is crucial for the athlete's performance since required energy input will be reduced as shown in a human running track research (Hobbs et al., 2014). The rebound timing depends on surface's properties, a very compacted surface for example may respond too quickly consequently imposes extra loads for the horse (Hobbs et al., 2014). This kind of surfaces feel stiff or 'dead' and make it more difficult for the horse to perform instead of supporting (Swedish Equestrian Federation, 2014; Hobbs et al., 2014). Also a too slow rebound is undesirable and let the surface feel 'dead' as well (Hobbs et al., 2014). Next to timing deformation is crucial for horse's safety. Impact resistance, or partly termed as cushioning (figure 5) or force reduction, is reaction of the total surface construct (all layers) to the peak loads applied by the horse (Swedish Equestrian Federation, 2014; Hobbs et al., 2014). So ideally the surface react to the horse's penetration with a deformation to reduce the loads (Hobbs et al., 2014). There are three options for a surface to deform: the elastic, the plastic and the viscoelastic deformation (Hobbs et al., 2014). Elastic deformation means as soon as the load or pressure which triggers the deformation is reduced the surface recovers to the original shape (Hobbs et al., 2014). This kind of deformation is definitely desired since the recovery is the energy return which pushes the horse into the next stride (Swedish Equestrian Federation, 2014; Hobbs et al., 2014; Heinrich und Hemker, 2012). Also plastic deformation takes place in the interaction between horse and equestrian sport surface as hoof imprint (Roepstorff and Peterson, (n.d.); Peterson et al., 2012). The hoof imprint is important for shock absorption (Swedish Equestrian Federation, 2014) and penetration security (Hobbs et al., 2014) consequently a well-balanced combination of plastic (hoof imprint) and elastic (energy return) deformation is preferred (Roepstorff and Peterson, (n.d.)) (more details chapter 3.1.8 Hoof Imprint). So required is a surface that allows deformation so far that the loads are reduced (Heinrich und Hemker, 2012) to keep the injury risk low (Hobbs et al., 2014). Because a very compacted surface allows only a little deformation so creates high peak loads (Hobbs et al., 2014).

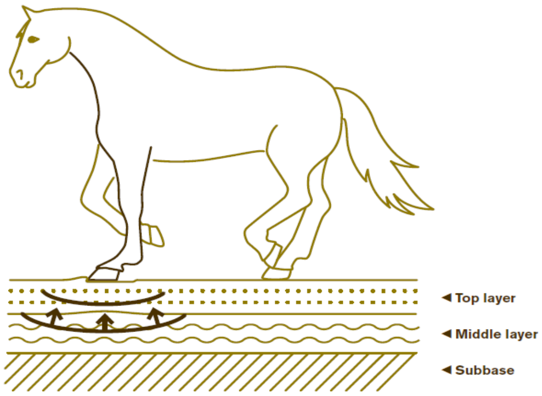

Figure 4: Responsiveness pictorial representation by Elin Hernlund and Linda Eriksson (Swedish Equestrian Federation, 2014)

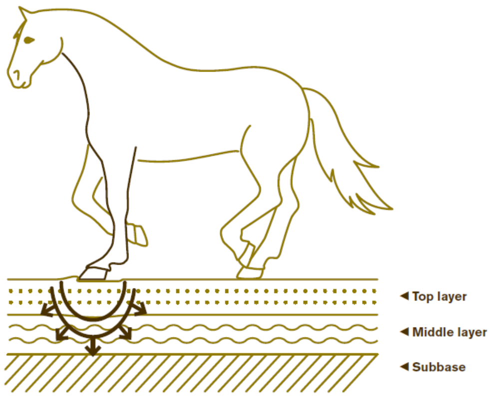

Figure 5: Cushioning pictorial representation by Elin Hernlund and Linda Eriksson (Swedish Equestrian Federation, 2014)

2.6 Dust

Definition and Formation

Dust are “fine, dry particles of matter” (*The Free Dictionary by Farlex,* 2014). Equestrian sport surface’s dust formation starts with grain abrasion, the breakdown of the grains into very small particles (Dreyer-Rendelsmann, (n.d.)), due to mechanical loads by the equine athlete, by maintenance device traffic (Heinrich and Hemker, 2012; Peterson et al., 2008; Hobbs et al., 2014) or ultra-violet light influences (Swedish Equestrian Federation, 2014). This applies next to sand also for the additives’ material (Heinrich and Hemker, 2012; Hobbs et al., 2014). However inorganic surface materials such as sand create significantly higher amounts of dust in than organic surface materials, mostly wood products (Dreyer-Rendelsmann, (n.d.); Hobbs et al., 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013). Furthermore dust of beech and oak wood are proven to be carcinogen (Dreyer-Rendelsmann, (n.d.)), thus dangerous.

The Danger of Dust

Both animal and human do sports on the surface (Dreyer-Rendelsmann, (n.d.)) consequently implement larger quantities of air (Dreyer-Rendelsmann, (n.d.); Hobbs et al., 2014), especially in indoor arenas (Hobbs et al., 2014). Although there not yet any scientific proven statements about the horse and human lug’s reaction to fine dust particles (Dreyer-Rendelsmann, (n.d.); FORUM Zeitschriften und Spezialmedien GMBH, 2013) it is assumed that it causes respiratory disease, airway damages and consequently reduced oxygen availability (Hobbs et al., 2014; Swedish Equestrian Federation, 2014) and irritation and lugs bleeding (Dreyer-Rendelsmann, (n.d.)). Researches have shown that the fine dust loads of equestrian sport surface can be critically high in comparing with limits for house dust (Dreyer-Rendelsmann, (n.d.)).

Solutions

Solutions to handle (Dreyer-Rendelsmann, (n.d.)) and prevent dust formation especially fine dust (FORUM Zeitschriften und Spezialmedien GMBH, 2013) can be watering (Miller, 1994; Dreyer-Rendelsmann, (n.d.); Gilbert, (n.d.); Hobbs et al., 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013), mixing additives such as wood products (Gilbert, (n.d.)), salt (Hobbs et al., 2014) or add wax or oil cover (Dreyer-Rendelsmann, (n.d.)). Water and salt are used to bind the dust (Hobbs et al., 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013) while waxed or oiled surface are used to reduce dust formation (Dreyer-Rendelsmann, (n.d.); Mahaffey et al., (n.d.)).The problem with binding dust is that it doesn’t solute the origin and may lead to additional problems such as de-mixing (Dreyer-Rendelsmann, (n.d.)) increased compactability and clogged drainage (Heinrich and Hemker, 2012; Hobbs et al., 2014).

2.7 Droppings

In the Context of Equestrian Sport Surfaces

The reminding words 'remove droppings in the arena are nowadays familar within the equine society as it is indispensable for surface's quality and durability (FLL, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013). In general droppings are organic material which changes the surface structure and property (Swedish Equestrian Federation, 2014; FORUM Zeitschriften und Spezialmedien GMBH, 2013; FLL, 2014). Only organic matter is a measurable parameter of equestrian sport surfaces but it may have its origin in droppings, leaves, natural or synthetic additives, watering- or rainfall water (Heinrich and Hemker, 2012) organic matter entries are not totally avoidable but minimisung is necessary considering its negative effects.

Effects on the Equestrian Sport Surface

Droppings entry on surface materials will shorten the lifetime dramatically as Oliver Hoberg, a German equestrian sport surface specialist stated "Manure kills all riding surfaces, no matter what material" (Swedish Equestrian Federation, 2014). Certainly this statement relates to the long term view since it is known that no dropping remove leads to a crumbling surface and increased dust formation (FORUM Zeitschriften und Spezialmedien GMBH, 2013). Especially natural and synthetic additives highly affect values for organic substance (Heinrich and Hemker, 2012). When droppings are merged with a sand-wood mixture: wood and droppings create together to a compost-like organic material (Swedish Equestrian Federation, 2014). This may have initially a positive resilient effect because it is comparable with a forest surface (FORUM Zeitschriften und Spezialmedien GMBH, 2013). But the composting process continues and the positive effect turns into negative, so the surface gets hard, deep (FORUM Zeitschriften und Spezialmedien GMBH, 2013 and slippery due to a lack of grip (Swedish Equestrian Federation, 2014). To leave droppings on wax-coated surface influences the wax behaviour (Swedish Equestrian Federation, 2014). Also on grass based surfaces dropping remove is necessary to avoid grass damage (FLL, 2014).

Measurements have shown that already small proportions of organic matter led to worsening in surface's water permeability (Heinrich and Hemker, 2012) and greater entries to plugged or damaged drainage (Schweizer Pferde Verband für Pferdesport, 2014).

Background Knowledge

As mentioned above droppings mixed into the equestrian surface is one form of organic matter entry. What kind of nutrients will be entered is listed in the following table published by the Saxon State Office for environment, agriculture and geology:

	nutrient content in %				
	organic mass	N Nitrogen	P Phosphor	K Potassium	CaO Calcium Oxide
horse's droppings	23	0.55	0.13	0.28	0.23
horse's urine	7	1.20	0.02	1.25	0.15

Table 6: Nutrient content of fresh horse droppings (Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, 2002).

To leave horse's droppings on the surface results in inconvincible masses (Swedish Equestrian Federation, 2014). The following example will draw a clear picture: If it is assumed that a stable hosts 50 horses which are all trained on the same arena surface, every horse drops on average once per training. This dropping unit is on average approximately 2kg with a content of 11g nitrogen. , Calculating for a 20m x 40m arena, 800m² surface would mean 25g nitrogen per m² per year:

Horses	50	
Arena/surface size	800m²	
1 unit droppings	2kg	
Nitrogen content of 1 unit droppings	0.55%	0.0055 • 2000g = 11g
Nitrogen excretion per day (all horses)	55g	
Nitrogen excretion per year (all horses)	20075g	~ 20kg
Nitrogen excretion per year and per m² (all horses)	25g	
Phosphor content of 1 unit droppings	0.13%	0.0013 • 2000g = 2.6g
Phosphor excretion per year and per m² (all horses)	59g	
Potassium content of 1 unit droppings	0.28%	0.0028 • 2000g = 5.6g
Potassium excretion per year and per m² (all horses)	128g	
Calcium Oxide content of 1 unit droppings	0.23%	0.0023 • 2000g = 4.6g
Calcium Oxide excretion per year and per m² (all horses)	105g	

Table 7: Calculations of organic matter entries based on droppings for one year (Heinrich et al., 2012; Swedish Equestrian Federation, 2014).

Effects for Environment and Groundwater

It was assumed that yard's and surface's waste water of would have, due to its organic matter entries, a toxic effect for environment and groundwater (Heinrich et al., 2012), which could be disapproved in a long-term study 2012 by FLL, FN (Meyer et al., 2011; Heinrich et al., 2012).

Conclusion

To reach the goal avoid as much organic matter entries as possible should include constant to remove droppings right after training (FORUM Zeitschriften und Spezialmedien GMBH, 2013; FLL, 2014), awareness that tractor tyres and horse's hooves are free from manure before entering the arena and in the outdoor arena leaves removing (Swedish Equestrian Federation, 2014). Otherwise the penetration layer need to be removed regularly after shorter time frames for example every three years (Swedish Equestrian Federation, 2014).

2.8 Hoof Imprint

Introduction

The sub chapter hoof imprint has an elementary right to exist in the context of equestrian sport surface property since the interaction between horse's hoof and surface is assumed to play a crucial role for horse's injury risk, so that especially in the racing sectors more researches are focused on this specific subject (Riggs*,* 2010). Additionally it was found out that the hoof-ground interaction also known as ground reaction force (GRF) – vertical and horizontal motion (Northrop et al., 2013) – is a key element in surface property researches (Vos and Riemersma, 2006). Since the hoof-surface interplay is how as the surface respond to loads by the horse and how this surface respond influences horse's performance (Hobbs et al., 2014).

Hoof Mechanism

To start with the basics: hoof mechanism is defined as the elastic reaction of the hoof to loads from above, in the form of the horse's body weight and from below the surface's pressure by deformation of the hoof capsule (Heinrich and Hemker, 2012); Swedish Equestrian Federation, 2014). As seen in figure 6 the hoof capsule deformation does not affect the total hoof (Heinrich and Hemker, 2012). Consequently it is clear that the hoof surface interaction including the hoof mechanism is a rather a complex dynamic process (Setterbo et al., 2011). Dynamic because it underlies a continuous changing, active progress (*The Free Dictionary by Farlex*, 2014), also because vertical and horizontal motion components are combined (Hobbs et al., 2014; Swedish Equestrian Federation, 2014). Complex because this interaction is always an indivual process based on horse's individual biomechanics in the equine gaits (Peterson et al., 2008). Moreover this process is very difficult to replicate (Setterbo et al., 2011) which is crucial for research. Since dynamic and natural hoof function are indispensable for horse's well-being and excellent performance (Salo et al., 2009).As long as the hoof surface interface is not better researches surface performance tests need to replicate horse's accelerations and loads (Peterson et al., 2008).

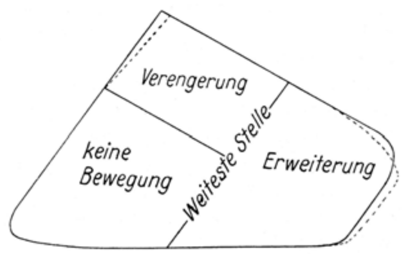

Figure 6: Hoof adjustment when loads are applied (Heinrich and Hemker, 2012).
Verengung = contraction; keine Bewegung = no motion; weiteste Stelle = widest part; Erweiterung = extension

Hoof-Surface Interaction Phases

An equine stride is determined from the time point when the hoof hits the ground until it hits the ground again (Swedish Equestrian Federation, 2014). The stride can be divided into the period the hoof touches the ground, with other words the hoof-ground interaction, and the period the hoof swings in the air (Swedish Equestrian Federation, 2014). The hoof-ground interaction or landing and take-off period is again divided into several phases (Peterson et al., 2012; Hobbs et al., 2014; Swedish Equestrian Federation, 2014). Regrettably there are no standardized terms available but the terms in figure 7 are a logical and easy to understand. The hoof-ground interaction starts with the primary impact, this phase includes moving downwards at a high speed and moving relatively slow forwards (Peterson et al., 2012). The secondary impact describes the performance slide and stop (Peterson et al., 2012; Peterson et al., (n.d.)). The third phase is the support phase which is also termed as stance phase or midstance (Hobbs et al., 2014). Characteristically for this phase and a key element for the interplay of hoof and surface, is the rest-moment when the hoof is completely loaded – vertical peak loads (Hobbs et al., 2014; Barrey et al., 1991; Peterson et al., 2012; Swedish Equestrian Federation, 2014; Peterson et al., (n.d.); Peterson et al., 2008). Measurements have shown that this phase started and ended with a period of vibration and in between the moment rest takes place (Barrey et al., 1991). This support phase overlaps with the secondary impact and is directly followed by the rollover phase (Peterson et al., 2012; Hobbs et al., 2014). The rollover is the final phase and is the last contact between hoof and surface, right before the take-off is carried out (Peterson et al., 2012; Peterson et al., (n.d.)). It is described that hoof lifting takes initially place at the heels followed by the 'roll over' (Swedish Equestrian Federation, 2014; Hobbs et al., 2014). So it is additionally termed as unloading, break-over or take-off phase (Peterson et al., 2012; Hobbs et al., 2014; Swedish Equestrian Federation, 2014).

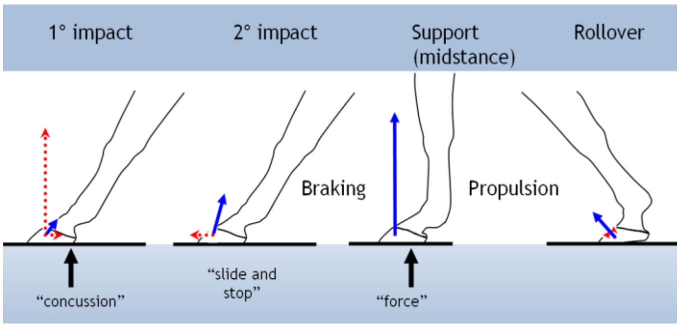

Figure 7: The hoof-ground interaction phases. Accerlation is marked in red and ground reaction force (GRF) is marked in blue. (Peterson et al., 2012; Hobbs et al., 2014).

Hoof Landing

Right before the hoof touches the ground – pre-impact – (Hobbs et al., 2014) it moves with a maximum speed of 5m/s downwards to the surface (Peterson et al., 2008), although this phase is associated with decreased velocity compared to the previous swing phase (Hobbs et al., 2014). During the initial impact of the hoof with the surface the hoof experiences deceleration which produces breaking forces (Northrop et al., 2013; Hobbs et al., 2014; Swedish Equestrian Federation, 2014; Peterson et al., (n.d.)). This sliding behaviour contains higher vertical than horizontal deceleration, because of high deceleration (rapidly to zero velocity) in the limbs while the horse's body still moves, so the loaded leg is pushes forward (Northrop et al., 2013; Hobbs et al., 2014; Peterson et al., (n.d.)). Finally the first hoof ground contact (primary impact) is directly followed by hoof sliding until it comes to completely halt (secondary impact) (Ahrren and van Doorn, 2014; Peterson et al., 2012; Hobbs et al., 2014; Swedish Equestrian Federation, 2014; Northrop et al., 2013). So contrary to primary impact, the secondary impact is indicated with less deceleration but higher forces (Hobbs et al., 2014).

Sliding

Then again the right amount plays again an essential role since the right sliding amount is rated to be beneficial for the horse's performance in the form that it decreases the forces (Hobbs et al., 2014; Swedish Equestrian Federation, 2014; Northrop et al., 2013). Both too less and too much sliding behaviour are undesirable since it means preventable increased forces (Hobbs et al., 2014). The sliding amount therewith force intensity and injury risk are affected by surface's resistance to horizontal movement (Ahrren and van Doorn, 2014; Peterson et al., 2012; Hobbs et al., 2014; Northrop et al., 2013). Furthermore the speed of horse and landing limb are crucial for the amount of sliding (Hobbs et al., 2014). Tightly coupled to sliding performance is the penetration depth, since the same may affect the sliding behaviour (Hobbs et al., 2014; Northrop et al., 2013). So it is desirable to get a surface which offers a well balance between grip and slide ability (Swedish Equestrian Federation, 2014).

Plastic Deformation

Directly after the sliding performance the motion comes to a halt and the limb is totally loaded (Hobbs et al., 2014; Barrey et al., 1991; Peterson et al., 2012; Swedish Equestrian Federation, 2014; Peterson et al., (n.d.); Peterson et al., 2008). As mentioned above ideally the hoof slides into the surfaces. When the limb is completely loaded it can be visualised as pushing down the surface or surface deformation by the horse's weight comparable with a trampoline (Swedish Equestrian Federation, 2014; Hobbs et al., 2014). As soon as the loading is removed the surface shows a reaction which indicates what kind of deformation was operated either an elastic, plastic or viscoelastic deformation (Hobbs et al., 2014). Ideally the surface's respond is a combination of elastic and plastic deformation (Roepstorff and Peterson, (n.d.)). The elastic deformation is desirable in the form of energy return to support equine performance and the plastic deformation will be the hoof imprint (Roepstorff and Peterson, (n.d.); Peterson et al., 2012). For the reason that every hoof which lands onto an equestrian sport surface will cut in the same (Strickland (n.d.)).

Influencing Factors

The hoof surface interaction is influenced by several factor such as surface composition and properties, horse's conformation, shoeing, gait, speed and direction (Swedish Equestrian Federation, 2014; Hobbs et al., 2014; Northrop et al., 2013; Peterson et al., (n.d.); Herlund et al., 2010). In general surface properties which is among others strongly influence by water content so both affect penetration and sliding ability of the hoof in the surface (Ahrren and van Doorn 2014; Mahaffey et al., (n.d.); FLL, 2014). Impact resistance and shear strength are part of surface properties (Northrop et al., 2013). Consequently shear strength, consisting of horizontal and vertical vector, is in combination with the surface's cohesion responsible for the penetration depth of the hoof into the surface and sliding performance (Hobbs et al., 2014). Because imagine the vertical force is higher than the horizontal, may be due to low level of cohesion, it comes to a deep hoof imprint and a shortened sliding behaviour (Hobbs et al., 2014; Peterson et al., (n.d.)). Additionally it is known that a surface which doesn't allow penetration in the rollover phase, maybe due to only low shear strength property, let the hoof may slide backwards during the movement (Ahrren and van Doorn, 2014). Also the toe grab shoe has a negative effect on the sliding performance since it decreases the capability of the hoof to slide (Peterson et al., 2008). Obviously maintenance management which affects surface properties would also have an influence on hoof surface interaction. But literature doesn't confirm this conclusion because it is stated that common surface treatment such as harrowing or rolling do not alter hoof mechanics (Northrop et al., 2013). This researches were based on the fact that hoof rotation is recommended to be a reliable indicator for surface's capability to deform during the equine's stance phase is carried out (Northrop et al., 2013). After all trials it was concluded that possibly a single load of one equine limb return the surface's constitution as before treatment was operated (Northrop et al., 2013). Also measurement adjustment treating the surface after every trial did not lead to different results (Northrop et al., 2013). Nevertheless this research is not representative for all surface because only one synthetic surface was tested (Northrop et al., 2013). Confirming the hypothesis: it was measured, in the long term research of the University of Applied Science Osnabrück, that penetration depth do alter when comparing values before and directly after the maintenance operation such as harrowing was operated (Heinrich and Hemker, 2012). Before harrowing the penetration depth is generally up to 4cm lower than after harrowing (Heinrich and Hemker, 2012). Consequently the shape of the hoof imprint was altered as well, as it can be seen in figure 8 (Heinrich and Hemker, 2012). Parallel it was found out that various surface compositions result in different amounts of hoof displacement and rotation (Northrop et al., 2013). However it is fact that an appropriate

Figure 8.1 Equestrian sport surface at location Hardinghaus: hoof imprint before (left) after (right) (Heinrich and Hemker, 2012)

Figure 8.2: Equestrian sport surface at location Werth: hoof imprint before (left) after (right) (Heinrich and Hemker, 2012)

maintenance management is indispensable for equal surface properties over the total surface area to minimise injury risk and support equine performance (Peterson et al., (n.d.)).

Injury Risk

Equestrian sport surface property has an unrestrained influence on equine performance (Swedish Equestrian Federation, 2014; Hobbs et al., 2014; Peterson et al., (n.d.)). Performance and injury risk are closely related since the following surface properties affect the forces for the hoof and be potential injury risk to bones and soft tissue of the whole limb (Peterson et al., (n.d.); Herlund et al., 2010):

- Vertical Stiffness or Hardness of the Surface
- Horizontal Slide or Shear Respond of the Surface
- Dynamic Tuning or Bounce of the Surface

  (Peterson et al., (n.d.)).

That various surface properties lead to immense forces differences for the equine limb, especially for the hoof, was demonstrated comparing horse performing on steel and rubber surface (Heinrich and Hemker, 2012; Hobbs et al., 2014). More details can be found in chapter 3.1.5 Elasticity.

To prevent heavy loads and therewith minimise the injury risk it is indispensable to allow the hoof to slide **into** the surface to (Swedish Equestrian Federation, 2014). Parallel it was found out that the hooves which were landing on hard surface oscillate before the hooves came to rest (Salo et al., 2009). So repeated landing on hard surface may result in injury (Salo et al., 2009) due to missing surface deformation there is no load reduction (Hobbs et al., 2014). Furthermore a hoof sliding into the top of the penetration layer is stopped at a certain point due to surface's cohesion and firmness for the hoof (Hobbs et al., 2014; Peterson et al., (n.d.)) which again reduces the loads for the horse in the form of stability (Dreyer-Rendelsmann, (n.d.)). This can be supported by a research which has shown that softer surfaces reduce the oscillate behaviour and therewith decrease the repetitive hoof injury risk (Salo et al., 2009). Parallel it is known that softer surface also reduces the horse's velocity (Salo et al., 2009) which is detrimental for some disciplines such focuses on speed as racing. Finally too less penetration depth and sliding behaviour may be injury causing as well as too much. The amount of sliding need to be limited since both as well as excessive sliding (slippage) and tripping are associated with abrupt loss of balance and rhythm thus may cause soft tissue injuries (McClinchey et al., 2004; Murray et al., 2010). Additionally excessive sliding performance is associated to be risky for the digital flexor muscular (Hobbs et al., 2014).

Too deep penetration would take place a deep loose sandy surface (beach), consequently the horse has to apply more muscular force which is exhausting (Hobbs et al., 2014; Heinrich and Hemker, 2012). Subsequently fatigue will occur earlier and is increased potential for traumatic injuries such as damage from overstraining especially for joints, tendons and ligaments (Heinrich and Hemker, 2012; Hobbs et al., 2014). Consequently it is logic that researches have shown a correlation between penetration depth and energy return (Heinrich and Hemker, 2012). At the same time there were measured high values for both parameters (Heinrich and Hemker, 2012), which confirms that it is more exhausting to perform in a deeper surface. Furthermore deep penetration in an equestrian sport surface may mean that the horse gets in touch with lower layers especially when penetration layer thickness is insufficient (FLL, 2014; Mahaffey et al., 2013). This is of course not desired since the lower layers are mainly compacted which means extra loads for the horse.

Facts and Values

To create a clearer picture of equestrian sport surface quality and its effects on equine performance several measurements were conducted.

Phase	Injury Potential
First and Second Impact Phase (Landing, Breaking, Touch Down)	Hoof and Distal Parts
Support Phase (Full Contact and Load)	Tendons, Ligaments, Joints and Bones

Table 8: Injury potential during the phases (Swedish Equestrian Federation, 2014).

penetration depth	2.8cm and 5.4cm dressage surfaces 2.8cm – 4.1cm show jumping surfaces 2.8cm – 3.9cm	(Heinrich and Hemker, 2012)
	racing tracks 100mm-150mm	(Mahaffey et al., 2013)
	dependents on individual construction material and composition → average advise 1cm-6cm	(FLL, 2014).
hoof ground contact	at racing speed up to 38mph (~61.155km/h) → 150/minute	(Peterson et al., (n.d.)).
experienced loads during gallop	2.5 times the horse's body weight = 1500 kilograms	(Swedish Equestrian Federation, 2014)
hoof contact area	9500mm²	(Peterson et al., 2008).

Table 9: measured values in the context of hoof surface interaction - each references seen in the right column

Chapter 3

• *Methodology* •

This chapter methodology - how the research is carried out - will be guided along the research questions.

1. What measurement parameters are available to establish equestrian sport surface's quality?

This question will be answered by using desk research. It is a literature review. Literature is collected reached by using the search engine provided by the webpage of Wageningen University Research Centre's (WUR) library.

Research question three will be evaluated as following:

2. What simple and low cost concept can be established to measure equestrian sport surface quality and durability?
   2.1 What measurement methods are simple and cheap but establish surface quality and/or durability?
   2.2 What questions should stable owners be asked to establish surface's quality?
   2.3 What questions should riders be asked to establish surface's quality?

Question two is partly a literature review and partly experienced based. All available measurement methods, are collected through literature research and listed. Appropriate, measurement methods are selected from this list using the following criteria:

- measuring surface quality
- low measuring costs
- simple to measure

Easy and cheap measurements mean professional measurement devices as described in chapter 3.2 are excluded for the reason that they are not available for everyone and the operation is not necessarily easy. For replication it is essential that the measurement methods are easy to operate and require only cheap measurement devices. So it is only material and measurements resources used which are part of every household or cheap to buy such as folding rule, water level and kitchen scales. The judgement whether these criteria were yes or no fulfilled, were made by the researcher. The selection takes place out of all available measurement methods, named in literature.

The second and third sub question will be answered using findings from literature. One will be developed for the stable owners/managers (2.2) who fundamentally control constitution and maintenance and a second one will be designed for the riders (2.3) who pay attention to ride-ability and desired characteristic. In addition special questions (2.4) are formulated for special surfaces such as surfaces with wood additives.

Research question three will be evaluated as following:

3. What can be said about the quality of the developed measurement concept?

   3.1 Do assessors measure parameters consistently when measuring the same parameter more than once?
   3.2 Do different assessors produce the same result when measuring the same parameter?
   3.3 Where the questionnaires understandable to all?

For the answer of these sub questions the developed measuring concept is executed by four persons. The four persons participated in a short introduction unit about project objectives and the measurement concept presented by the researcher.

Furthermore four stables with different surface types and material are selected in the surrounding of Meerbusch, North Rheine Westphalia, to save travel expenses. At preferably one or possibly two days the selected four person will travel to the five different selected surface locations and carry out the measurements as explained in the measurement concept. Every person gets measurement concept sheets clipped onto a clipboard to fill in the measured results. The designed sheet can be found in the annex as part of the measurement concept. To answer questions and ensure correct measurement performance the author of this research report will be present as well.

Testing the measurement concept will be performed in two different ways: an impression of the intra (within) and the inter (between) repeatability is produced in graphical form. Intra repeatability tests if the same person doing the same measurements several times, to what extent delivers the same result. The inter repeatability tests if different people doing the same measurements, to what extent delivers the same results. To get an impression of the intra and inter repeatability of the developed measurement concept the following system shows which person has to perform how many measurements at what location:

	Person 1	Person 2	Person 3	Person 4
Surface 1	☆☆☆	☆	☆	☆
Surface 2	☆	☆☆☆	☆	☆
Surface 3	☆	☆	☆☆☆	☆
Surface 4	☆	☆	☆	☆☆☆

→ each star stands for one measurement cycle

The results produced by the different assessors on the different surfaces will be presented in tables and graphs to produce an impression of inter and intra repeatability. The results of the questionnaires were not analysed systematically within the framework of this thesis. They are used to get a first impression what kind of answers for the questionnaires can be expected.

Chapter 4

• *Results* •

4.1 Available Quality Measurement Methods

4.1.1 Introduction

To introduce this chapter it may be helpful to ask for the existence reason. To give an objective statement about constitution and quality of an equestrian sport surface measurements have to be executed (Swedish Equestrian Federation, 2014; Hobbs et al., 2014). The assessment of the total quality constituent can only be made if several measurable parameters create a sum of properties which basically is the quality constitution since quality can be defined: "quality is the sum of all properties of an item" (Wyssling, 2012). Further it is essential to explain why measurements are important in the quality evaluation and future development of the equestrian sport surface sector. Measurements have the potential to significantly improve the constitution (Peterson et al., 2012) of equestrian sport surfaces. Optimally the surface measurements procedures take place regularly (Peterson et al., 2012) to control several parameters and to rework at particular parameters such as refill penetration layer. However measurement methods need to be adjusted to individual surface type and material (Peterson et al., 2012).

When discussing about equestrian sport surface measurements, much attention must be paid to standardised and validated equipment (Swedish Equestrian Federation, 2014; Hobbs et al., 2014). Unpretentiously are measurement procedures from other sports such as soccer a suitable guide (Swedish Equestrian Federation, 2014). Nevertheless the focus has to be on the fact that the equine athlete has simply a greater weight and an incomparable motion (Swedish Equestrian Federation, 2014) which leads to a highly complex horse-hoof-surface interaction (Hobbs et al., 2014) which is extremely difficult to replicate (Setterbo et al. 2011).

The following chapter is divided into different measurement opportunities.

4.1.2 Sieve Curve

The sieve curve is a standardized method to determine grain sizes of soil samples (Kruse et al., 2012; Technische Uni München (n.d.) a). The standard code is DIN 18123 (Kruse et al., 2012; Heinrich and Hemker, 2012) and was determines at the German Institute for Standardization in Beuth in 2011 (Kruse et al., 2012). The sieve curve is created due to sieving the soil sample with several sieves with determined mesh size (Dreyer-Rendelsmann, (n.d.)). Afterwards a sieve curve is created (Dreyer-Rendelsmann, (n.d.)). In equestrian sport surface quality measurements sieve curve is used to find out about the percentage of clay and silt, the fines since it affect the surface properties (Peterson et al., 2012; Swedish Equestrian Federation, 2014). Thus the grain size distribution determines the gaps between the grain sizes which are filled with air in dry constitutions and with water in wet constitutions (Dreyer-Rendelsmann, (n.d.)) as explained the chapter 3.1. The gap sizes affect penetration and slippage security (Dreyer-Rendelsmann, (n.d.)). The steeper the curve the more homogeneous the materials, so a vertical line would mean that all grains have exactly the same size (Dreyer-Rendelsmann, (n.d.)).

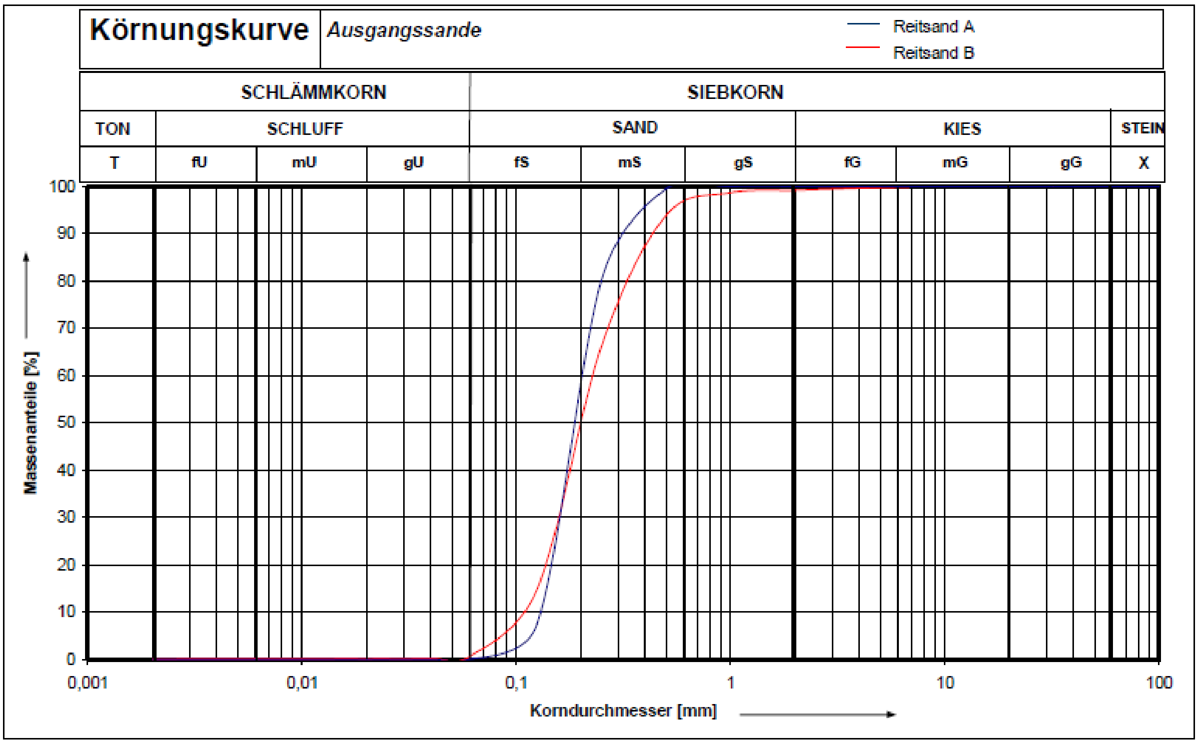

Figure 9: A sieve curve carried out with two equestrian sport surfaces within the long term research if University of Applied Science Osnabrück (Heinrich and Hemker, 2012)

4.1.3 Hydrometer

The hydrometer is a composition test with the standardized code ASTM D422, 2007 (Peterson et al., 2012). When using the hydrometer for an equestrian sport surface the objective is to determine particle sizes and percentage of fines, clay and silt (Peterson et al., 2012). Composition testing is important since it has a strong influence on total surface properties (Peterson et al., 2012). Hydrometer test procedure is very time consuming since it takes approximately 4 days (Mahaffey et al., (n.d.)). The hydrometer is able to determine particles as fine as 0.002mm but it doesn't accurately distinguish between silt and clay (Mahaffey et al., (n.d.)). It is indeed a very complex measuring method and is not as reliable as the wet sieve test (Mahaffey et al., (n.d.)). To ensure the repeatability when using a hydrometer strong temperature control is indispensable (Mahaffey et al., (n.d.)).

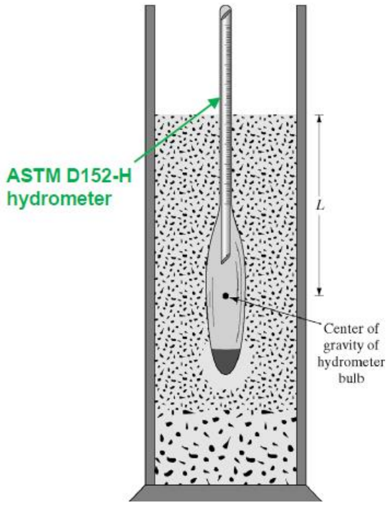

Figure 10: A Hydrometer (University of Massachusetts Lowell, 2013)

4.1.4 X-Ray Diffraction

This method is currently the only one which effectively gives a statement about percentage and type of clay within a surface or soil sample (Mahaffey et al., (n.d.)). Various clay types differ greatly in their character and reaction to water and loading (Mahaffey et al., (n.d.)). Consequently with greater percentage it has a greater influence to total surface properties and performance (Mahaffey et al., (n.d.)). So X-Ray Diffraction is useful to improvement of equine athlete's safety as well as surface maintenance management (Mahaffey et al., (n.d.)). Therefore regular operation is recommendable (Mahaffey et al., (n.d.)).

4.1.5 Slurry Test

As already mentioned in previous chapters about sand as main material it is clear that assumed pure sand is not pure sand. The slurry test is a very simple method to determine the rough ratio of sand, fines and other substances such as additives (Gilbert, (n.d.); Hellberg-Rode, 2002 b). A glass jar is needed preferably long and straight for example baby food glass (Hellberg-Rode, 2002 b). A fresh surface sample of about a quarter height of the glass may be 5cm is placed into the glass jar *(*Gilbert, (n.d.); Hellberg-Rode, 2002 b). Then fill water on it so that there is only 1cm to the top then either mix strongly or close the lid and shake it both for about a minute (Gilbert, (n.d.); Hellberg-Rode, 2002 b). In the following 60 seconds the sand grains will sink down (Gilbert, (n.d.)). By measuring the height of sand particles the percentage of sand in the surface can be calculated easily (Gilbert, (n.d.)). So if the sand height is 3.75cm means 75 percent of the surface will be sand and 25 percent other materials (Gilbert, (n.d.)). The colour of the water gives an indication of high or low amount of fines (Gilbert, (n.d.)). Brown or yellow stands for higher amount (Gilbert, (n.d.)). Several hours later the fines will sink as well on and build an extra layer on top of the sand grain (Gilbert, (n.d.)). This extra layer can be measures and calculated as well as described above for the sand amount (Gilbert, (n.d.)).

Figure 11: (Gilbert, (n.d.)).

4.1.6 Clegg Hammer

The Clegg Hammer is a typically in-situ testing device (Peterson et al., 2012). The Clegg Hammer is probably the most commonly used measurement device for surface performance in North America (Peterson et al., 2012) and parallel quick and easy to use (Hobbs et al., 2014; McAuliffe, 2012). Originally the Clegg Hammer was developed to measure the compaction degree on roadways (Peterson et al., 2012). Today it is used for sports surfaces in the various disciplines such as football, golf, cricket (McAuliffe, 2012) and equestrian.

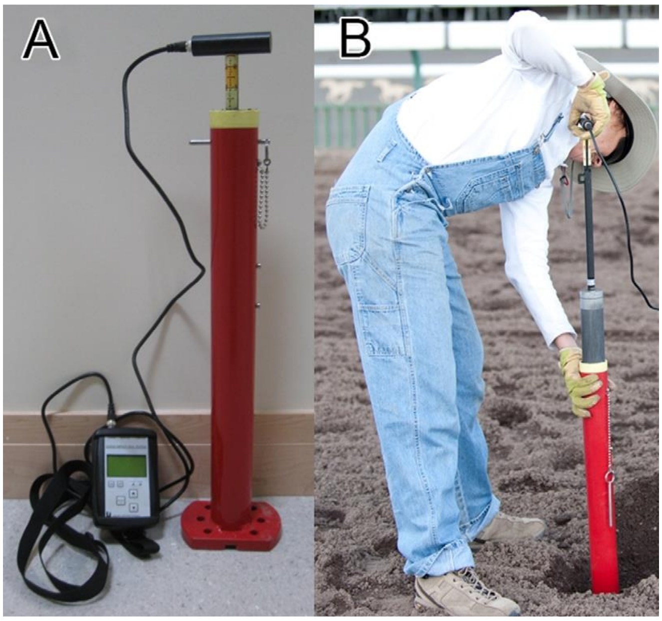

Figure 12: A: a Clegg Hammer; B: The Clegg Hammer in action (Setterbo et al. 2012 a).

In the equestrian sport surface measurement sector the Clegg Hammer is mainly used to measure the **compactability** considering moisture content measurement (Peterson et al., 2012; Setterbo et al. 2012 a; Hobbs et al., 2014). For the reason that moisture content and compactable behaviour of a surface have a strong interaction (Peterson et al., 2012). Additionally the Clegg Hammer is used to give a statement about surface's degree of hardness (Setterbo et al. 2012 b; Hobbs et al., 2014) and shock absorption (McAuliffe, 2012).

However the Clegg Hammer doesn't deliver useful information regarding the peak load which the horse's hoof will experience during performance on the measured surface (Peterson et al., 2012). About the Clegg Hammer's weight there are different values in the literature: 2.25kg (Peterson et al., 2012; McAuliffe, 2012) or 4.5kg (Setterbo et al. 2012 a; Setterbo et al. 2012 b). These dissimilar values may come due to missing standards. The 4.5kg Clegg Hammer for examples is describes as cylindrical Clegg Hammer with a diameter of 5cm and a Model Code is added: Model 95050A, Lafayette Instrument Co., Lafayette, IN (Setterbo et al. 2012 a; Setterbo et al. 2012 b). The 2.25kg Clegg Hammer relates to the standard test number ASTM F1702 (McAuliffe, 2012). Next to varying drop weight also drop height can vary (McAuliffe, 2012).

Still the negative aspects about the Clegg Hammer are it only measures vertical properties and it doesn't replicate the speed and geometry of the equine gait (Hobbs et al., 2014) as well as the weight of the athlete (McAuliffe, 2012).

4.1.7 Time Domain Reflectometer (TDR)

The Time Domain Reflectometry (TDR) is a device to measure the surface's moisture content (Thomson und Mahaffey (n.d.)). In literature it is declared as best surface's condition measurement possibility (Peterson et al., 2012). The device main components are two spokes which are pushed into the surface with one hand (Thomson und Mahaffey (n.d.)). The surface's moisture content is measured due to the transit time of the electromagnetic wave over the length of the spikes (Thomson und Mahaffey (n.d.)).

Figure 13: Time Domain Reflectometer (Krzic et al., 2010)

4.1.8 Moisture Meter

The water content in the surface can be assessed using a moisture meter (Maeda et al., 2012). There are divers types of moisture meters for example the infrared moisture meter with the code FD-720, KETT Chemical Electric Laboratories, Ohta-ku, Tokyo, Japan (Maeda et al., 2012) or digital moisture meters (Vegetronix, 2008). The moisture content is measured via a probe which is put into the soil or surface (Vegetronix, 2008). This probe is waterproof and doesn't corrodes (Vegetronix, 2008). The moisture meter's advantages are the ease of use, the pocket sizes and the low pricing (Vegetronix, 2008).

1

2

3

Figure 14:
1: Moisture Meter (amazon.com)
2: Moisture Meter scale (amazon.com)
3: a digital Moistre Meter (vegetronix (n.d.)).

4.1.9 Drying Procedure

A very simple method to find out about the moisture content is the drying procedure (Richter, 1993). The first step is to take surface samples of about 150–300g (Setterbo et al. 2011). Then if necessary synthetic additives are filtered out by sieving and weighed (m_4) (Kruse et al., 2012). Following the surface samples are weight in the same constitution as they were taken (m_1) (Kruse et al., 2012). The next step is the drying in a drying cabinet for 24 hours with a temperature of 105°C (Kruse et al., 2012). After the drying procedure the samples are weighed for the second time (m_2) (Kruse et al., 2012). If additionally the organic substance want to be obtained it will be necessary to further go on with the dried sample (Kruse et al., 2012). This samples has to be a minimum of 45 g (Kruse et al., 2012). This sample is taken and burnt out in a muffle furnace for 3 hours with a temperature of 550°C and afterwards weighed for the third time (m_3) (Kruse et al., 2012).
The determinations of the water content, the organic substance, and the synthetic substance were calculated by the following expressions:

Water content = $\frac{(m_1 - m_2)}{m_1} \times 100$

Organic substance = $\frac{(m_2 - m_3)}{m_2} \times 100$

Synthetic substance = $\frac{m_4}{m_2} \times 100$

(Kruse et al., 2012).

As well here are differentiations in procedure and calculation available. A standardized test method with the code ASRM D 2216-05 uses drying at 110°C (Setterbo et al. 2011). If devices such as drying cabinet and muffle furnace can’t be used the following simplified method is available (Setterbo et al. 2011). Drying in a commercial oven with a temperature at 65°C (Setterbo et al. 2011). The oven temperature used was lower than the standard drying temperature based on the reason to prevent destroying synthetic surface components (Setterbo et al. 2011).

4.1.10 Penetrometer

The penetrometer device measures penetration resistance (Thomson und Mahaffey (n.d.)) as well as deformation resistance in general (Richter, 1993). For equestrian sport surfaces the penetrometer measures the penetration depth, so how far the hoof is allowed to penetrate into the surface (Peterson et al., 2012) parallel this measurement results gives a statement about surface's degree of hardness (Maeda et al., 2012; Richter, 1993).
The penetrometer's main constituents are a dropping weight onto a rod with the thickness 1-2cm which ideally penetrates into the surface (Thomson und Mahaffey (n.d.)). The penetration depth can be read off of the shaft (Thomson und Mahaffey (n.d.)).

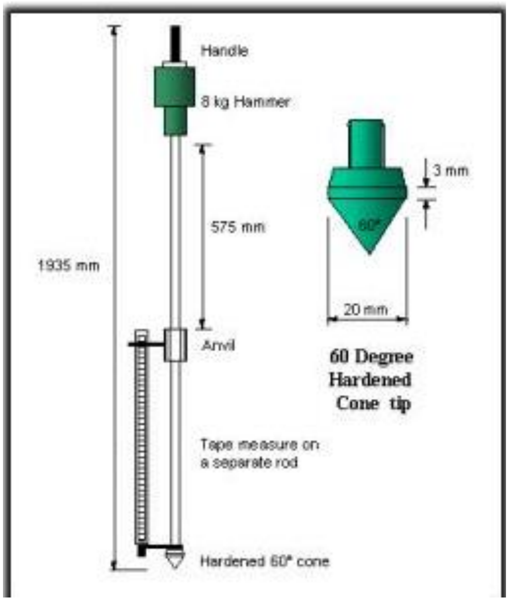

Figure 15: Dynamic Penetrometer (Pavia Systems, 2009)

Especially for racing tracks the penetrometer is commonly used (Peterson et al., 2012). Mainly used in equestrian sport surface measurements is the dynamic penetrometer (Peterson et al., 2012). The negative aspect about the penetrometer as device for equestrian surface measurements is that the falling weight is small so it doesn't replicate the horse's weight (Peterson et al., 2012).

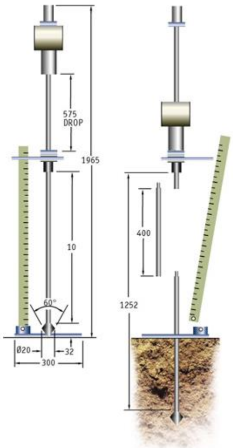

Figure 16: Dynamic Cone Penetrometer (Controls Srl, (n.d.))

4.1.11 Going Stick

The Going Stick is a measurement device which was initially used by British Horse Racing and is now a days also used in other countries (Thomson und Mahaffey (n.d.)). The Going Stick measures the force which is required to penetrate into the surface with flat blade (Peterson et al., 2012). So the Going Stick is used to measure about the equestrian sport surface's quality parameter: penetration resistance and shear strength (Peterson et al., 2012; Thomson und Mahaffey (n.d.)). These two measured parameters lead to two evidences one is about the surfaces firmness and one about the traction or grip the horse experiences during performance on the surface (TurfTrax Ltd (n.d.)). The Going Stick's blade is pushed into the surface supported by a foot on the device and following pulled back so that a 45 degree angle is developed from the vertical (Peterson et al., 2012; Thomson und Mahaffey (n.d.)). Afterwards the top of the Going Stick rotates about the base (Peterson et al., 2012; Thomson und Mahaffey (n.d.)).

Figure 17: The Going Stick in action (Sky Ltd., (n.d.))

Figure 18: The Going Stick (Peterson, (n.d.))

The problem with the Going Stick as measurement device for equestrian sport surfaces is that the probe is smaller than a horse hoof (Peterson et al., 2012). Furthermore it is critical that the insert of the device into the surface is carried out manually (Peterson et al., 2012) which may influence the result and is negative for the repeatability.

4.1.12 Shear Vane

The Shear Vane Tester is used as equestrian sport surface measurement method to evaluate the horizontal properties (Setterbo et al. 2012 a; Setterbo et al. 2012 b). The key element of the Shear Vane is a torque load cell (Setterbo et al. 2012 a; Setterbo et al. 2012 b). The Shear Vane consists of a stainless steel ring with the dimension of inner diameter of 6cm and outer diameter of 10cm (Setterbo et al. 2012 a; Setterbo et al. 2012 b). Attached to this ring are 12 1cm high and 1mm thick rectangular grousers which have equal space of 2cm to each other (Setterbo et al. 2012 a; Setterbo et al. 2012 b). To estimate the surface's shear strength weights are applied onto the Shear Vane and it slowly rotates until the sample fails (Setterbo et al. 2012 a). Using the Shear Vane in situ it rotates about 100° in 30-60 seconds and in a laboratory test it rotates about 110° in 90-150 (Setterbo et al. 2012 a).

Figure 19: The Shear Vane device in action so weights are applied. (Setterbo et al. 2012 a).

The formula background for the Shear Vane test is: τ_{max} = c + σ tan ϕ. (Setterbo et al. 2012 a; Setterbo et al. 2012 b).

τ = shear stress → τ_{max} = maximal shear stress

c = cohesion

σ = normal stress

ϕ = internal friction

Since the shear interface is applied to tested surface arena in the form that shear vane's force and torque are converted to normal stress (σ) and shear stress (τ) (Setterbo et al. 2012 a; Setterbo et al. 2012 b).

2.2.13 Triaxial Test Cell

The Triaxial Test Cell was developed as technical device to measure surface's shear strength. Basically it is used to determine the triaxial shear strength of racing track penetration layers (Peterson et al., 2012). In figure 20 is the construction of this Triaxial Test Cell demonstrated (Peterson et al., 2012).

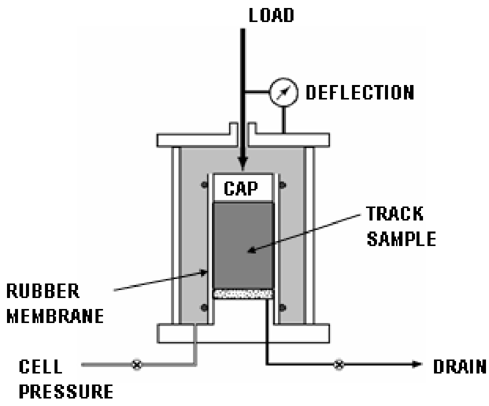

Figure 20: Construction Triaxial Test Cell to determine traixial shear strength of a racing track surface (Peterson et al. 2012).

To the parameter of shear strength it is important to explain that in general the strength of a material is always the maximum stress it can endure (Lui, 2007). Shear strength in soil in general develops due to two issues (Lui, 2007):

- Cohesion between particles (independent to stress)
    - Cementation between sand grains
    - Electrostatic attraction between clay particles
- Frictional resistance between particles (stress dependent component)

(Lui, 2007).

Shear strength is in the context of equestrian sport surface defined as material's resistance to slipping when load is applied in the form of horse's weight (Roepstorff and Peterson, (n.d.)). The to be tested material is vertically loaded as with the weight of the horse (Roepstorff and Peterson, (n.d.)). If the material slides the test result is failure, and imitates the sliding behavior of the surface during the propulsion phase. For this kind of measurements a Triaxial Shear Test is used. (Roepstorff and Peterson, (n.d.)).

In the cylinder of the Traxial Test Cell is a surface sample which is encircled by pressurized fluid (Peterson et al., 2012). Due to loading the top of the cylindrical test specimens the deflection of the sample is measured (Peterson et al., 2012). Until the sample shows failure at this point shear strength is connected to a particular limited pressure (Peterson et al., 2012).

ASTM D4767 is the code for this almost standardized procedure used for equestrian sport surfaces (Hobbs et al., 2014). However the problem is that this test is an in vivo test which basically means under laboratory conditions (Hobbs et al., 2014). This test can be carried out with drained and undrained surface samples (ASTM International, 2011). Undrained samples replicate the field conditions (ASTM International, 2011).

4.1.14 Artificial Athlete

The Artificial Athlete was originally developed to replicate the athlete human's impact on the ground (Kruse et al., 2012) to measure the elasticity of sport coverings (Heinrich and Hemker, 2012). Through a guided falling weight (3) the following three parameters: shock absorption (SA), energy restitution (ER), and vertical deformation (VD) can be measured (Kruse et al., 2012).

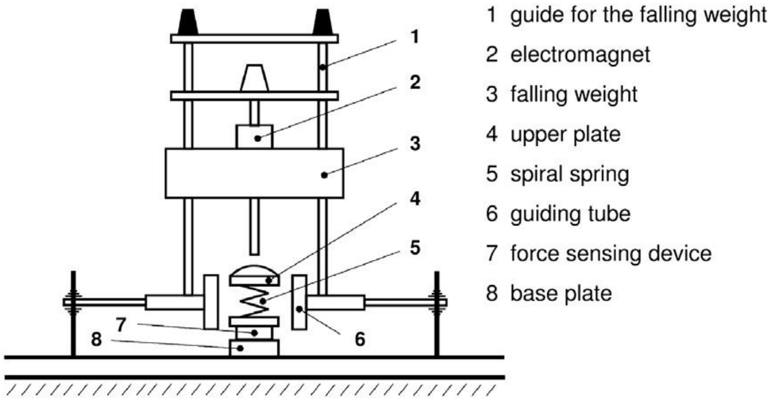

Figure 21: the Artificial Athlete and its construction (based on DIN) (Kruse et al., 2012)

Looking back to the parameter explained in the chapter 3.1 SA (= Shock Absorption) stands for parameter impact resistance, elasticity, energy restitution is just a different term for energy return and vertical deformation is basically what it is.
The construction of the Artificial Athlete can be seen in figure 21 and how it operates will be explained in the following sentences: The guided falling weight (1, 3) has a mass of about 20kg (± 0.1kg) and is dropped form a height of about 55mm (± 0.25mm) vertically to the testing foot (4, 5, 7, 8) (Kruse et al., 2012; Heinrich and Hemker, 2012). The testing foot consists of circular steel base plate (8) with a diameter of 70mm (± 0.1mm) (Kruse et al., 2012). On the top of this steel base plate is a force sensing device installed (7) (Kruse et al., 2012). Located over these both items are a spiral spring (5) which damps the impact of the dropped falling weight with a spring rate of 2000 ± 60 N/mm (Kruse et al., 2012). A hardened upper plate (4) is at the top of the spiral spring.

As mentioned above the Artificial Athlete is able to measure three different parameters, how these parameters are calculated will be explained at the following paragraph.

The parameter **SA** is formulated with the following formula: $SA = \left(1 - \frac{F_t}{F_r}\right) \cdot 100;$

the result is expressed in % (Kruse et al., 2012).
F_t = the testing surface's measured maximum peak force, expressed in Newton (N) (Kruse et al., 2012).
F_r = is the reference force, measured on a concrete surface, the value is about 6.2kN (Heinrich and Hemker, 2012) or 6.6kN (Kruse et al., 2012).

The parameter **ER** is formulated with the following formula: $ER = \frac{E_a}{E_b} \cdot 100$;

the result is expressed in % (Kruse et al., 2012).

E_a is the energy *after* the impact, expressed in J and is itself calculated as: $E_a = 0.5 \cdot m_{fw} \cdot {v_a}^2$.

m_{fw} = the mass of falling weight (20kg)

v_a = the take-off velocity (m/s)

E_b is the energy *before* the impact, expressed in J and is itself calculated as: $E_b = 0.5 \cdot m_{fw} \cdot {v_b}^2$.

m_{fw} = the mass of falling weight (20kg)

v_a = the initial impact velocity (m/s)

(Kruse et al., 2012).

The parameter **VD** is formulated with the following formula: $VD = -1 \cdot (D_{fw} - D_s)$;

the result is expressed in mm (Kruse et al., 2012).

D_{fw} = the displacement of the falling weight (mm)

D_s = maximum deformation of the spring and is itself calculated as: $D_s = \frac{F_i}{R}$

F_i = the impact force (N) measured by the Artificial Athlete

R = the spring rate of the spring (2000 N/mm)

(Kruse et al., 2012).

During a research based measurement procedure at the equestrian centre of Holsteiner Verband in Germany in 2013 the results of the hoof acceleration measurements in trot and the Artificial Athlete were assumed to be similar (Kruse et al., 2012). Against the expectations the Artifical Athlete was evaluated as inappropriate as measurement device for equestrian sport surface (Kruse et al., 2012). The first questionable point when using the Artificial Athlete to assess an equestrian sport surface is that human sport coverings offer a relative stable face which cannot be asserted about equestrian sport sandy surfaces (Heinrich and Hemker, 2012). This leads to displacements and therewith large variances between different test procedures (Kruse et al., 2012). Essentially the research based measurements results for shock absorption (SA) showed large variances between the measurements with the hoof-acceleration and the Artificial Athlete (Kruse et al., 2012). For the reason that the Artificial Athlete is not able to replicate the horse's shock absorption behaviour (Kruse et al., 2012). Additionally another research has shown that the force development on a concrete surface differs about 22% comparing the Artificial Athlete with 6.2kN and the trotting horse with 5.1kN (Heinrich and Hemker, 2012). Only for the parameter vertical deformation (VD) both measurement procedures showed similar result values (Kruse et al., 2012).

4.1.15 Trailer-Mounted Track Testing Device (TTD)

Figure 22: TTD presented on a portable frame (left) and inlaboratory frame (right). (Setterbo et al., 2012 a).

The Trailer-Mounted Track Testing Device is used to assess the dynamic surface properties (Ratzlaff et al., 1997; Setterbo et al. 2011; Setterbo et al., 2012 a; Setterbo et al., 2012 b). With the TTD it is possible to determine the surface's impact resistance and percentage of energy return (Ratzlaff et al., 1997). The TTD replicates the vertical force as a trotting or galloping horse (Ratzlaff et al., 1997; Setterbo et al., 2011; Setterbo et al., 2012 a; Setterbo et al., 2012 b). Essential for this device is the 27.8 (61.3 pound) or 36.3kg (80 pound) dropping weight, which drops in form of a free fall from divers adjustable heights (f.e.: 12.7cm, 20.3cm, 30.5cm, 40.6cm) (Ratzlaff et al., 1997; Setterbo et al., 2011; Setterbo et al., 2012 a; Setterbo et al., 2012 b). The body which is dropped is a stainless steel disc with 12.7cm (5 inches) diameter (Ratzlaff et al., 1997; Setterbo et al., 2011; Setterbo et al., 2012 a; Setterbo et al., 2012 b). Based on measured hoof landing velocities in trot and canter of 2-3m/s (Setterbo et al., 2011) also the velocity (1.91, 2.30, and 2.63 m/s) and the impact angle (0° (vertical), 20°-angle) of the TTD are adjustable (Setterbo et al., 2011; Setterbo et al., 2012 b).

The TTD is a unique device since it better replicates the equine's gaits, forces, velocities and impacts than comparable devices such as the Clegg Hammer (Setterbo et al., 2011; Setterbo et al., 2012 b). This is of high importance due to the surface related injury risk (Setterbo et al., 2011). Furthermore it is able to assess vertical and horizontal aspects (Setterbo et al., 2011). Although the TTD mimics the horse better than other used devices it is not capable to replicate the equine hoof motions and impacts in its total extent (Setterbo et al., 2011; Setterbo et al., 2012 b). When comparing the horse's and the TTD's impact onto the surface the result is that the TTD's impact is shorter and more intense ((Setterbo et al., 2011; Setterbo et al., 2012 b).

The TTD can be used as in-situ device and in laboratory frame (Setterbo et al. 2011; Setterbo et al. 2012 a).

4.1.16 Drop Hammer

The Drop Hammer device is in general used to asses equestrian sport surfaces based on respond to impact (Malmgren et al., 1994). More precisely the Drop Hammer is capable to evaluate several equestrian surface quality parameters: cushion depth or penetration depth moisture content, hardness and particle size distribution (Malmgren et al., 1994). The Drop Hammer delivers only limited information about surface's vertical properties and doesn't replicate equine's gaits and velocities (Hobbs et al., 2014).

Using the Drop Hammer as test device for equestrian sport surfaces requires high time investments such as when using the cone penetrometer (Maeda et al., 2012).

4.1.17 Biomechanical Hoof/Surface Tester

In some references it is called Biomechanical Hoof Tester in others Biomechanical Surface tester, however both terms mean the same apparatus type.

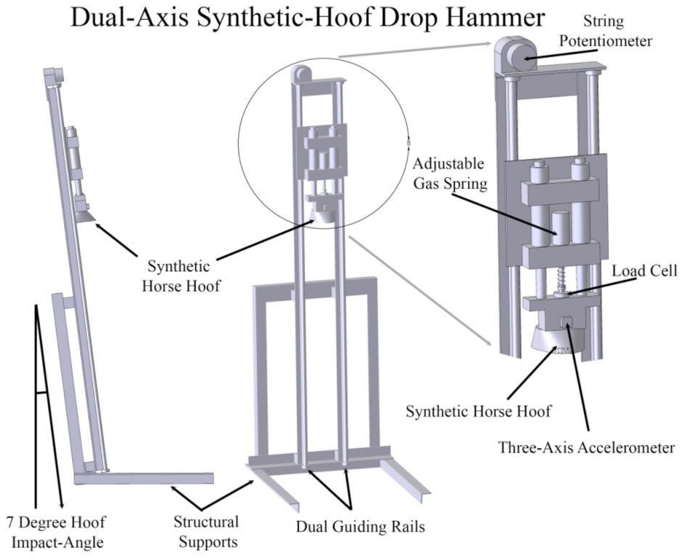

Figure 23: The Biomechanical Hoof Tester used to mimic the horse's speed and loading by the hoof on the racing track (Peterson et al., 2008; 2012).

Since devices such as the Clegg Hammer, the dynamic Penetrometer and the Going Stick limited in measuring equestrian sport surface considering equine athlete replication the Biomechanical Hoof Tester was developed (Peterson et al., 2012). The development for this device was based on surface's risk potential to cause catastrophic injuries which may result in ending horse's career (Peterson et al., 2012). The Biomechanical Hoof Tester is different to other devices since it is able to load the surface with comparable rates and loads as applied by a horse at gallop (Peterson et al., 2012; Mahaffey et al., 2013; Hobbes et al., 2014) with a hoof shaped projectile (Swedish Equestrian Federation, 2014). This system imitates the equine gait period when the forelimb gets in contact with the surface and the horse's weight is transferred from body to hoof (Peterson et al., 2012; Swedish Equestrian Federation, 2014). This particular time point is essential for equestrian sport surface measurements because both the highest vertical loads and the highest shear strength are applied to and affect the surface (Peterson et al., 2012; Mahaffey et al., 2013). So the equestrian sport surface quality parameters shear forces or grip, impact forces and responsiveness are measured when the Biomechanical Hoof Tester (Peterson et al., 2008; 2012; Swedish Equestrian Federation, 2014; Hobbes et al., 2014). In a broader perspective surface's elasticity, firmness and friction are evaluated (Tranquille et al., 2013).




Figure 24.1, 24.2, 24.3, 24.4 The Orno Biomechanical Hoof Tester in action (Crook (n.d.)

The Biomechanical Hoof Tester itself consists of two non-orthogonal axes drop tower (Peterson et al., 2008; 2012; Tranquille et al., 2013). Elementary is that the movable axes imitates the sliding behaviour into the surface as the horse's the hoof performs it (Peterson et al., 2008; 2012; Mahaffey et al., 2013). The drop mass has a weight of 30kg which impacts energy of approximately 540J (Peterson et al., 2008; 2012).

4.2 New Measurement Concept

Suitable Measurements Methods

Suitable measurement methods mean in the context of this research that they need to easy in operation, cheap and certainly measure the surface's quality based on the parameter description in chapter 3.1. In this paragraph is checked if the measurement methods comply with the criteria

- Measuring surface quality
- Low measuring costs
- Simple to measure.

In the following table + +, +, 0, - and - - are used to rate to what extend the measurement methods comply with each criteria.

Based on that table, the following parameters will be part of the measurement concept:

- material and grain size
- grain face
- material wear
- water content
- water permeability
- evenness/height differences
- penetration depth/hoof imprint

Measurement Method	Criteria 1: Measuring Quality Parameter	Criteria 2: Cheap	Criteria 3: Simple to operate
Sieve Curve	+ +	**0**	- -
Hydrometer	+ +	+ +	- -
X-Ray	+ +	- -	- -
Slurry Test	+ +	+ +	+ +
Clegg Hammer	+ +	- -	+ +
Time Domain Reflectometer (TDR)	+ +	- -	+ +
Moisture Meter	+ +	+ +	+ +
Drying Procedure	+ +	- -	+ +
Penetrometer	+ +	- -	+
Going Stick	+ +	- -	+ +
Shear Vane	+ +	- -	-
Triaxial Test Cell	+ +	- -	- -
Artificial Athlete	+ +	- -	- -
Trailer- Mounted Test Device	+ +	- -	- -
Drop Hammer	+ +	- -	- -
Biomechanical Hoof/Surface Tester	+ +	- -	- -
First Impression	+	+ +	+ +
Height Measurements/Incline	+ +	+ +	+
Taking Surface Samples	+ +	+ +	+ +
Firmness	+	+ +	+ +

Measurement Method	Criteria 1: Measuring Quality Parameter	Criteria 2: Cheap	Criteria 3: Simple to operate
Penetration Depth/Hoof Imprint	**+ +**	**+ +**	**+ +**
Grain Face and Appearance	**+ +**	**+**	**+ +**
Material Alteration – Stressed/Loaded	**+ +**	**+**	**+ +**
Water Permeability	**+ +**	**+ +**	**+ +**
Water Content	**+ +**	**+ +**	**+ +**
Slurry Test	**+ +**	**+ +**	**+ +**

Table 10: What measurement method complies to what extend with the determined criteria

Information from the stable owner

As background information for the measurement operation it is important to get the following key information about the surface by the stable owner:

- construction
- surface material
- surface price and producer
- time point of installation and refill
- penetration layer height
- watering system
- maintenance management and plan: how often harrowing, watering, track levelling, etc.
- number horses hosted which are regularly trained on the surface (f.e. mares with foals are excluded)
- main disciplines of clients
- average satisfaction of clients
- are injuries which could be based on overload known (tendon, ligament)

These information will be asked inform of a questionnaire.

Information from the riders

Parallel to the information by the stable owner also several riders are asked to fulfil a questionnaire with the following content:

- discipline
- education level
- maintenance management and plan: how often harrowing, watering, track levelling, etc.
- subjective feeling about surface's quality
- injuries which could be based on overload (tendon, ligament)

Measurement Manual

Essential for this measurement concept is the simplicity and artlessness character, to ensure an easiness and correctness in operation. Ideally only a brief precise introduction paper should enable everyone to operate this measurement concept. Furthermore no measurement devices are included so only devices or tools everyone has or can get easily such as a folding rule.

1. First Impression

To get a first impression about surface's constitution – wet or dry – and grain shape some surface mass is felt between fore finger and thumb. For this method are no measurement devices required. On the measurement sheet is record if the surface is rather dry or rather wet. Furthermore is the grain smooth or rough and is it round or angular.

2. Height Differences/Incline

As described several times in the previous chapter surface evenness is crucial for horse's security. To measure height differences the following material is needed:

- 6 Iron Nails/Obstacle stands
- Hammer/Rubber Hammer
- Water Level
- Small Ropes
- Folding Rule
- Measurement Sheet

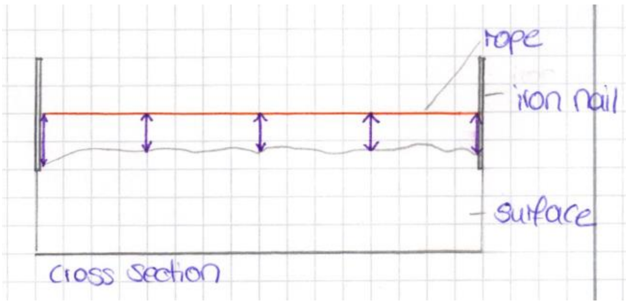

Figure 25: how to measure height differences/evenness

Each two iron nails are positioned and inserted into the penetration layer with the hammer. The rope is fixed on both iron nails and altered with the water level so that it is horizontal. Then every few meters starting at one iron nail doing two steps into the direction of the other nail, the height between surface and rope is measured and the value filled in into the measurement sheet.

3. Taking Surface Samples

To get a clear total overview to assess the average surface properties and quality it is highly important to take surface samples at different spots. As seen in figure xx it is wise to choose sports which are used intensively like on the track and those which are used less intensive for example in the corners outside the track.

Needed Material:

- Pipe Section of 150mm length and 50mm width with Cover
- Hammer/Rubber Hammer
- Adhesive Labels
- Permanent Marker
- Small bags

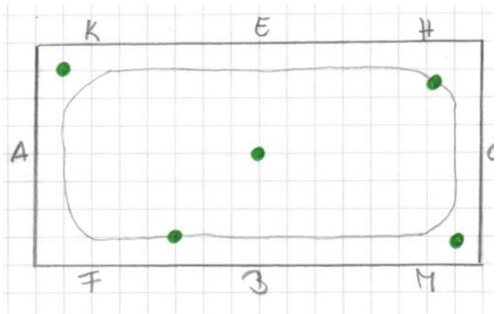

Figure 26: example how to mark the surface sample taking spots

Before starting with taking samples the small bags are prepared with adhesive labels and sample code. The pipe section is inserted 5 to 10cm into the surface by light strokes with the rubber hammer. Afterwards the pipe section will be carefully pulled out and the surface sample is filled into the small bag with probe's name on the label.

4. Firmness

Take some surface into the hands and from a ball out of it. Push the surface material as hard as possible to create a very stable ball. Afterwards take the ball in one hand and use the thumb of the other hand to destroy the ball. Then record the easiness of ball creation and ball destroying on the measurement sheet.

5. Penetration Depth

Needed Material:

- Tile, Glass Plate or Plexiglas Plate
- Folding Rule
- Optimal Treated Surface
- Measurement Sheet

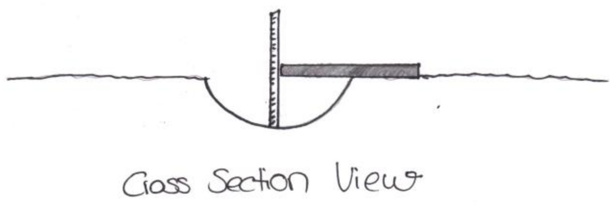

Figure 27: how to measure the hoof imprint depth

A horse is lead or written in walk straight way through the arena. The general impression is it a deep, medium or shallow penetration will be written on the measurement sheet. Next the plate is applied to the hoof imprint as seen in figure 2. With the folding rule the height between imprinted surface and lower edge of the plate will be measured at the deepest point in centimetre. This will be operated on three different spots per measurement procedure. Afterwards the same will be operated for a straight line in trot and in cater and later on the hoof imprints when a horse cantered several rounds on a circle.

6. Grain Face and Appearance Determination

Needed Material:

- A 'Normal' Microscope which is also Available for Children
- Surface Samples
- Measurement Sheet

Only a few grains out of every taken sample will be taken out to put under the microscope. Face, roundness and general appearance are evaluated which will be written in a measurement sheet. This measurement method will be also the basis for the next one.

7. Material Alteration Due to Stress or Loads

The precondition for this measurement is the measurement 'Grain Face and Appearance Determination'.

Needed Material:

- A simple mortar
- Surface Samples
- Measurement Sheet
- A 'Normal' Microscope which is also Available for Children

The surface sample is taken into the mortar. To pestle the surface sample replicates the mechanical loads by horse's hoof. Afterwards some grains are selected and put again under the microscope. Face, roundness and general appearance are compared to the previous microscope session before the sample was treated with the pestle.

8. Water Permeability

Needed Material:

- Transparent Small Tube Ø 2,5cm and about 25cm long
- Water
- Surface Samples
- Some Net Curtain
- Measuring Glasses
- Calculator
- Measurement Sheet

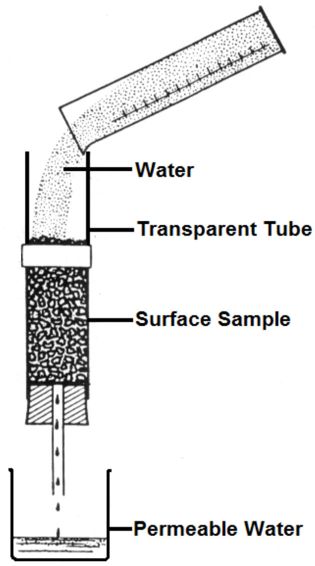

Figure 28: Experimental Set-Up (Hellberg-Rode, 2002c)

The tube is closed on one site the net curtain. Then a few grams dry surface sample is filled into the tube. Then 60ml water is splashed over or through the tube with surface sample. The water which is passed through directly and in one hour is measured and based on this the water permeability is calculated in percent. Imagine 53ml water go through the surface sample:

60 ml = 100% 53ml = ??? % $\frac{100}{60}$ x 53 = 88,3%

9. Water Content

Needed Material:

- A Common Oven
- Ovenware Small Bowl
- Kitchen Scales
- A Sieve
- Calculator

150g of surface sample are weight and sieved. Then filled into the ovenware small bowl and put into the oven by 110°C for several hours to dry it. Afterwards the sample is again weight. And at the end the following calculation leads to the water content of the sample.

weight before drying - weight after drying = loss of water

$$\frac{100 \text{ x weight before drying}}{\text{loss of water}} = \square \text{ \% of water content}$$

10. Slurry Test – Rough Particle Size Determination

This measurement is to determine the average amount of different particle size groups.

Needed Material:

- *A* Glass Jar (preferably long and straight for example baby food glass)
- Folding Rule
- Measurement Sheet

A fresh surface sample of about a quarter height of the glass may be 5cm is placed into the glass jar Then water is filled on it so that there is only 1cm to the top. Next either strongly mixing or shaking with closed cover is operated both for about a minute. In the following 60 seconds the sand grains will sink down. By measuring the height of sand particles the percentage of sand in the surface can be calculated easily. So if the sand height is 3.75cm means 75 percent of the surface will be sand and 25 percent other materials. The colour of the water gives an indication of high or low amount of fines. Brown or yellow stands for higher amount. Several hours later the fines will sink as well on and build an extra layer on top of the sand grain. This extra layer can be measures and calculated in the same way as described above for the sand amount.

The developed measurement sheet that will be used by the test persons as well as the developed questionnaires for stable owner/manager and for riders can be found in annex.

4.3 Quality of the new Measurement Concept

The objective was to find out if the measurement concept is reliable. Therefore it was looked at every parameter singly. Following graphs were drawn to show indications about the inter- and intra-repeatability. Only a selection of graphs is presented in this chapter, all graphs in systematically order can be found in the annex. For the inter repeatability different persons did the same measurement method on the same surface at the same constitution. For the intra repeatability the same person did the same measurement methods three times on the same surface at the same constitution. Four surfaces with different material composition were tested.

4.3.1 First Impression

The first section of measuring sheet addressed the first impression that the test persons noted down. This measurement method contains three tested parameters: constitution, grain shape and grain size. As seen in table 10 the collected values for the intra repeatability were for all three parameters and for all three measurement procedures identical. This is also visible in the graphs as seen in figure 29. This graph stands in representation of all three measured parameters and let assume that this measurement method is intra repeatable.

		1.Measure	***2.Measure***	***3.Measure***
Surface 1/ Person 1	Wet/Dry Constitution	medium	medium	medium
	Grain Shape	sharp angular	sharp angular	sharp angular
	Grain Size	fine	fine	fine
Surface 2/ Person 2	Wet/Dry Constitution	dry	dry	dry
	Grain Shape	round	round	round
	Grain Size	fine	fine	fine
Surface 3/ Person 3	Wet/Dry Constitution	medium	medium	medium
	Grain Shape	round	round	round
	Grain Size	fine	fine	fine
Surface 4/ Person 4	Wet/Dry Constitution	medium	Medium	medium
	Grain Shape	sharp angular	sharp angular	sharp angular
	Grain Size	fine	Fine	fine

Table 11: Results for triple tests in the measurement method 'first impression'

For the inter repeatability test the results were not equal for all three measured parameters. For the parameter grain size the measurements were again identical as. However all assessors were convinced that all surfaces had fine grains. In figure 30 is again the graph for the parameter constitution which is comparable with the graph for the parameter grain shape, based on small deviation. For constitution assessor 2 and 3 scored all 4 surfaces identical. Assessor 1 differed from these two assessors one point in two cases and assessor 4 differed from them one point in one case. For the grain shape again assessor 2 and 3 scored all 4 surfaces identical. Assessor 1 and assessor4 differed from these two assessors one point in two cases, assessor 1 at surface 1 and surface 4 and assessor 4 at surface 3 and surface 4. Based on these small deviations it seem to be that also the inter repeatability for all three parameter seems to be reasonable.

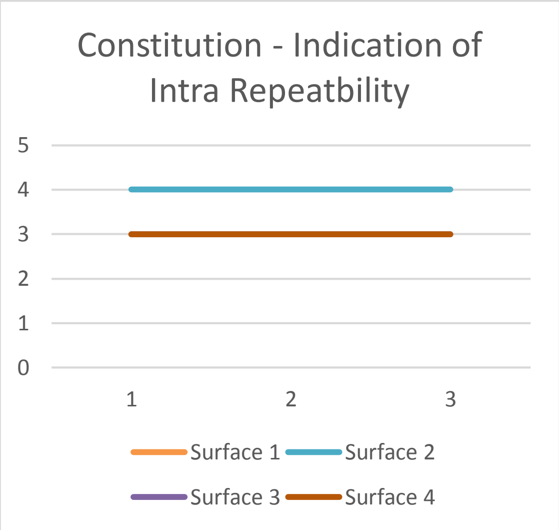

Figure 29: Constitution wet or dry was the first measured parameter, which seem to be intra repeatable

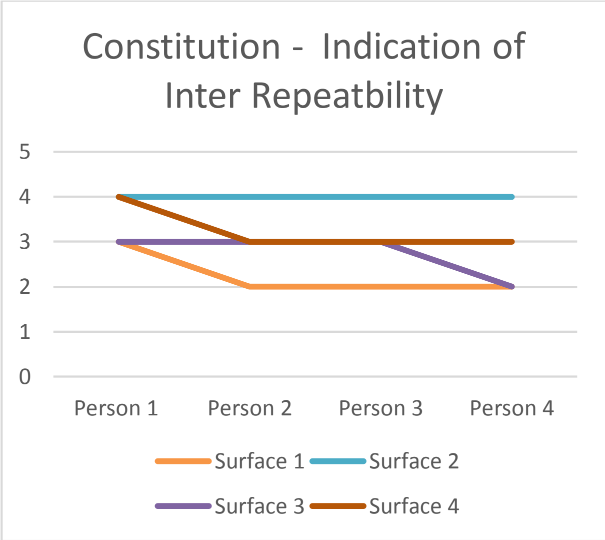

Figure 30: Constitution wet or dry was the first measured parameter, which seem to be not inter repeatable

4.3.2 Height Measurements/Incline

Based on the large number of collected values, on each surface three tightened ropes were measured, the drawn graphs differ from all other measurement methods. Representative for all intra repeatability test is the graph in figure 31 is which illustrated the indication of repeatable values. Representative for all inter repeatability test is the graph in figure 32 which as well shows the indication of repeatable values. To keep it simple it is to say that all value deviations are rather small.

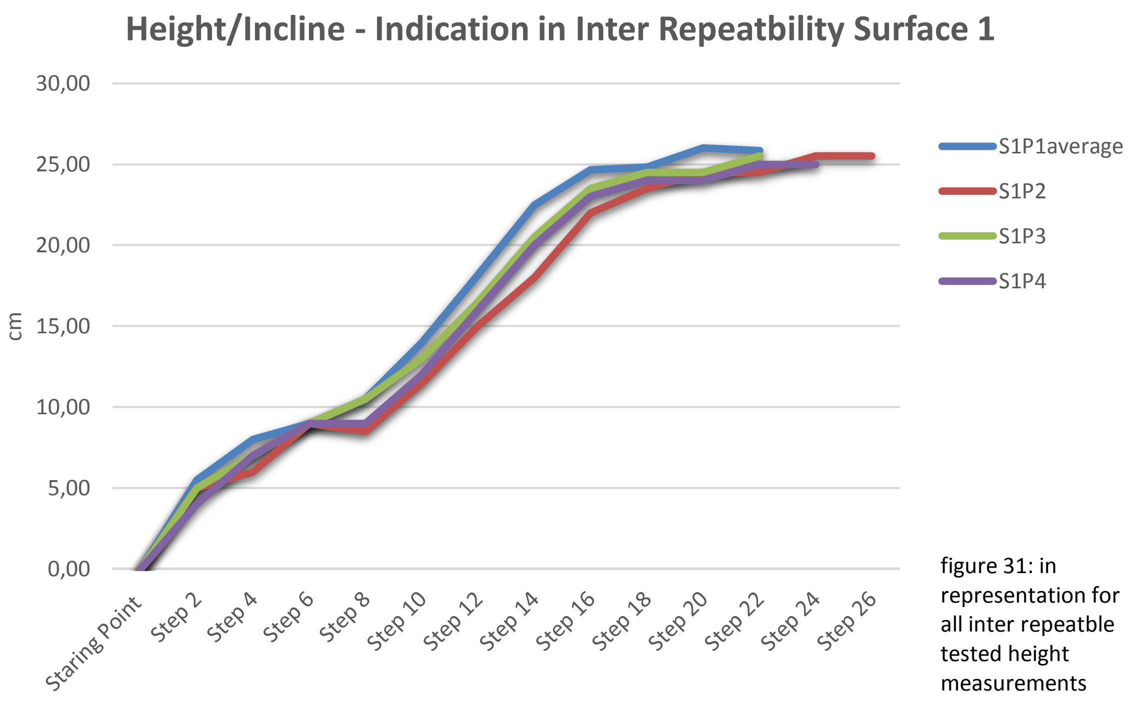

figure 31: in representation for all inter repeatble tested height measurements

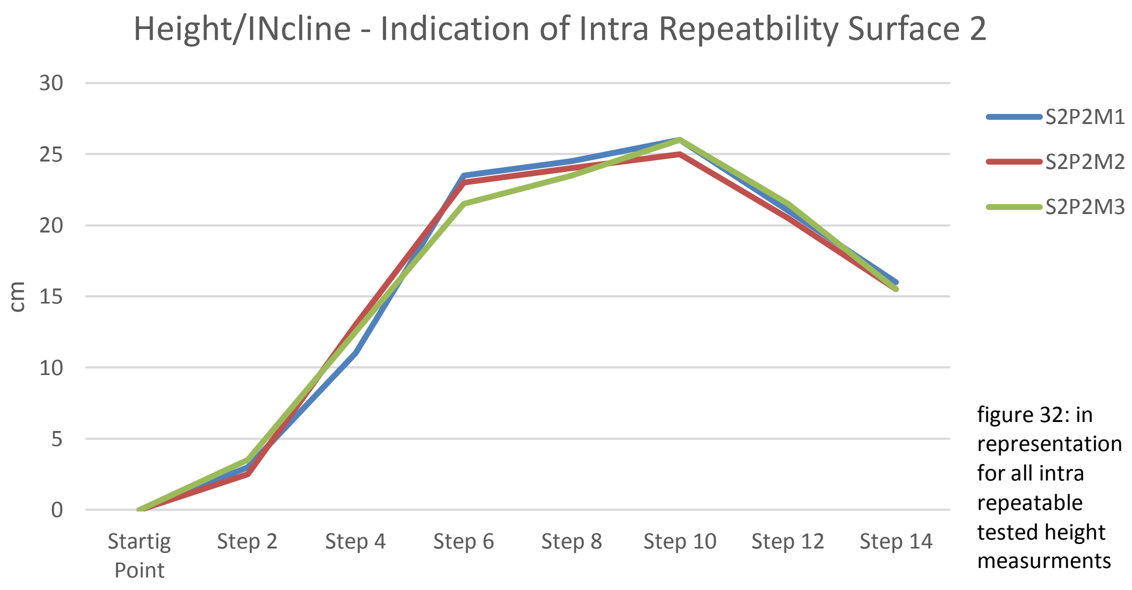

figure 32: in representation for all intra repeatable tested height measurments

4.3.3 Firmness

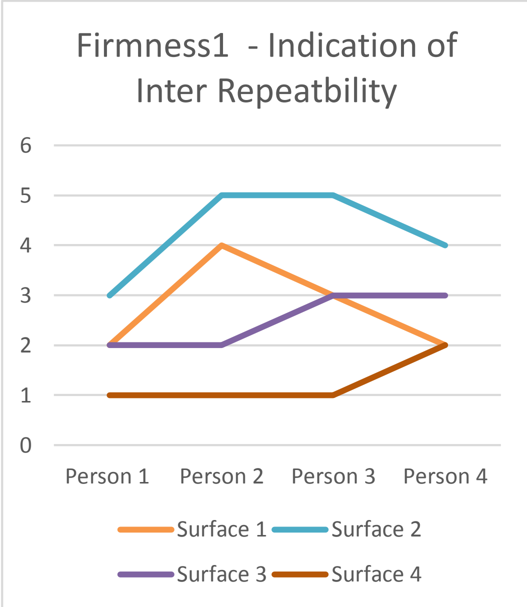

Figure 33: illustrated indication

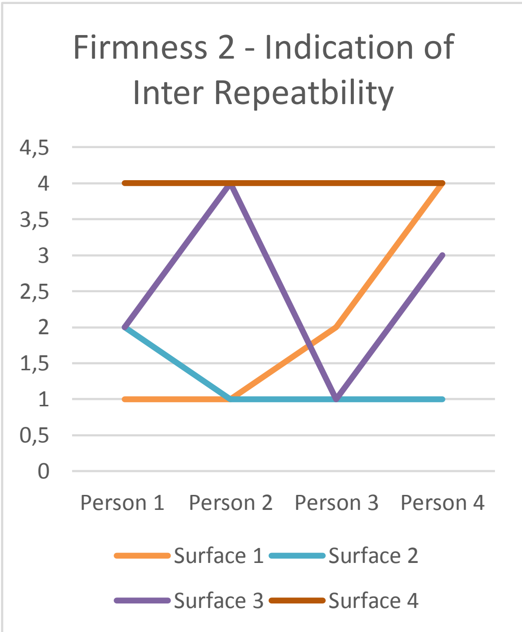

Figure 34: illustrated indication

For the firmness measurement method two tests were included, initially the ball creation were rated and afterward the easiness of destroying the ball. To start with the indication of the intra repeatability analysis applies the same as for the 'first impression' method. This means every person had identical observations in all three measurement executions. So it gives an indication that this measurement method seem to be intra repeatable.

In the indication analysis of inter repeatability the rated values between the different assessors deviate as seen in figure 33 and 34. For the first parameter assessor 1 and assessor 4 had identical values at the surface 1. Assessor 2 and assessor 3 had the same value for surface 2. At surface 3 the values of assessor 1 and assessor 2 were identical and with one point deviation the values of assessor 3 and assessor 4 were as well identical. At the last surface (4) assessor 1, assessor 2 and assessor 3 had the same value and the value of assessor 4 deviate with one point. All in all also small deviations up to two points per surface. Comparable are the results for indication of inter repeatability for the second parameter. Identical values were observed by assessor 1 and assessor 2 for surface 1; assessor 2, assessor 3 and assessor 4 for surface 2 and all 4 assessors for surface 4. So based on these indications it is questionable if this measurement method is inter repeatable since in only 9 of 16 cases the values between the assessors were equal.

4.3.4 Hoof Imprint

The total number of collected values for the measurement method are 364, because it started with a general assessment of the imprint followed by three measurements per gait. But for canter there were two measurement procedures one for canter on straight line and one several times canter on circle.

To start with the indications of intra repeatability of the parameter general impression of the hoof imprint. The assessors could choose between shallow, medium and deep and again the rated values were identical. As seen in figure 35 there are for the indication of inter repeatability only really small deviations between the rated values can be observed for this parameter. At surface 1 assessor 3 and assessor 4 had identical values while assessor 1 and assessor 3 deviate with one point. At surface 2 and surface 4 all assessors had identical values. At surface 3 only assessor 4 differed with one point will all other three assessors had again identical values.

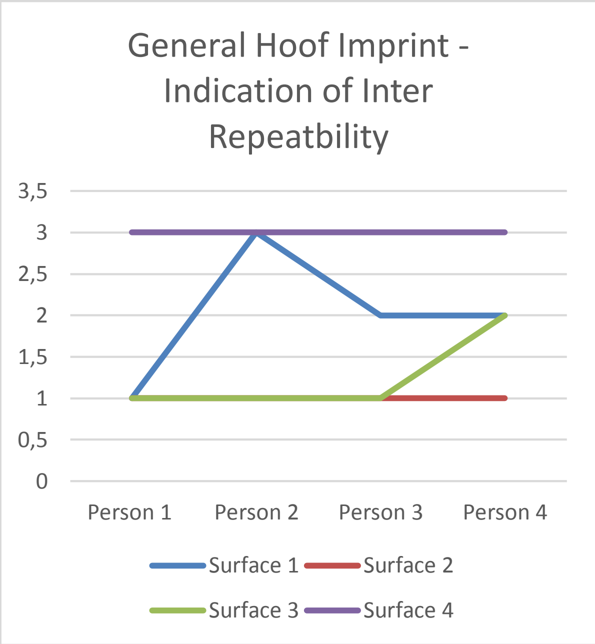

Figure 35: inter repeatable indication

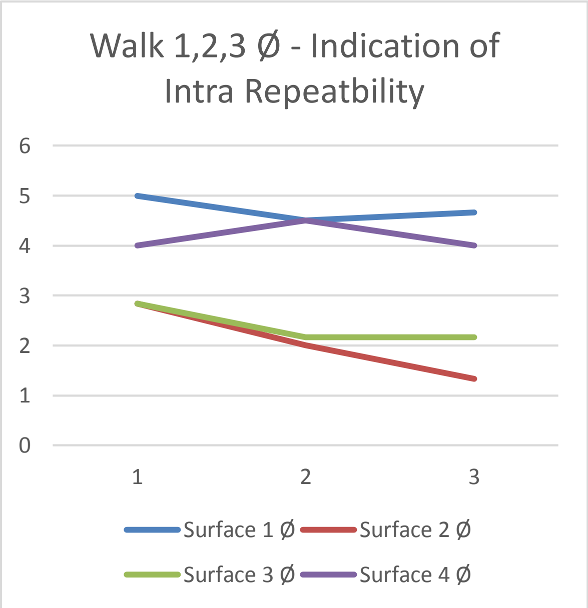

Figure 35: a positive indication of intra repeatability

For all gaits every measurement person or assessor measured three hoof imprints to keep it simple graphs based about the median values were drawn. The single graphs about every measured hoof imprint are found in the annex. As seen in figure 35 the graphs shows a indicate of intra repeatability measurement method in the median of parameter walk 1,2,3. The deviation between the measured values is maximal 0.8. Similar is the result for the indication of intra repeatability in the median of trot with maximal differences of 1.3, for the parameter canter with maximal deviation of 1. Greater deviations up to 2.67 could be observed for the indication of intra repeatability in the median of circle canter. Based on these rather small deviations the indication of intra repeatability seem to be reasonable.

Conversely are the deviation values between assessors up to 6 for the indication of inter repeatability for the median values of walk, up to 4.5 for trot, up to 4.2 for canter and up to 7.53 for circle canter. Of course these are only the peak points and as seen in figure 37 the graph stands in representation for all parameters the value ranges between assessors for each surface have different deviations. Important to mention is to take a look at the y-axis which is divided in greater steps compared to the graphs in figure 35 and 36. There it seem to be that the indications inter repeatability is not confirmed.

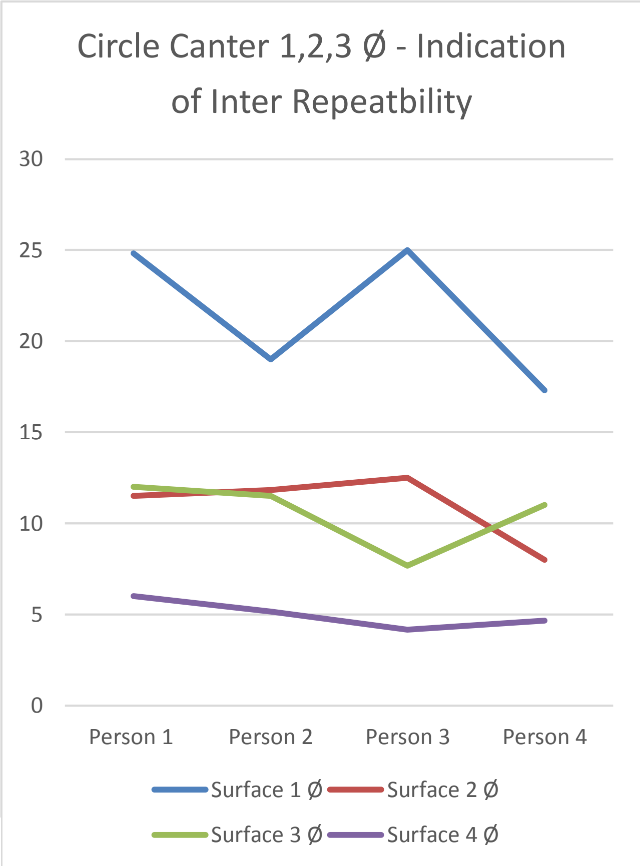

Figure 37: a negative indication of inter repeatability

4.3.5 Grain Face and Appearance

This measurement method contains three tests with the parameters grain face, grain shape and grain roundness. For the indication of intra repeatability of grain face the triple measured values of assessor 1 assessor 3 and assessor 4 are identical. Assessor 2 differed one point in one case. For the parameter grain shape the values of assessor 2 and assessor 3 were in all three cases identical, assessor 1 and assessor 4 differs one point in one case. For the parameter grain roundness all rated values are identical. Therefore based on the indications all three parameters are estimated to be intra repeatable.

For the indication of inter repeatability in the parameter grain shape assessor 1 and assessor 4 measured identical values for all four surfaces, assessor 3 differed one point in one case and assessor 2 differs one point in two cases and 0.33 in one case. Similar are the results for the parameter grain roundness: assessor 2 and assessor 4 measured identical values for all four surfaces, assessor 1 differed one point in one case and two points in another case, assessor 3 differed one point in one case. Conversely are the results for the inter repeatable indication of grain shape since only assessor 3 and assessor 4 for surface 1 and plus assessor 1 for surface 3 as well as assessor 1, assessor 2 and assessor 3 for surface 2 and assessor 1 and assessor 2 for surface 4 had identical values. As also seen in figure 38, 9 out of 16 cases showed identical values. Therefore for this parameter it is questionable if the inter repeatability can be confirmed. For the parameters grain shape and grain roundness seem to be inter repeatable.

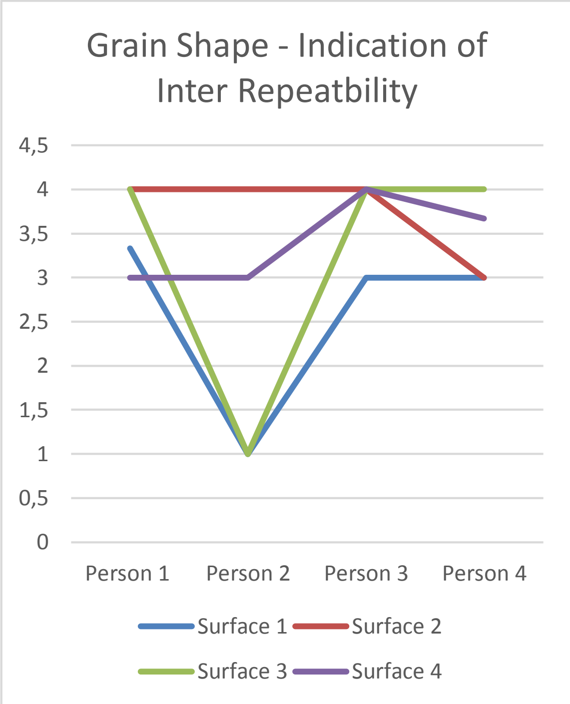

Figure 38: questionable indication of inter repeatability

4.3.6 Stress/Load

This measurement method is comparable with the previous one, also the parameters are the same with the difference that the surface samples is initially treated with the pestle in a mortar. The measured values for the parameter grain face indication of intra repeatability are identical for assessor 2 and assessor 4, assessor 1 and assessor 3 deviate one point in one case. Comparable results are for the parameter grain shape but here assessor 2 and assessor 3 have identical values. For the parameter grain roundness all rated values are identical. Therefore it seem to be an intra repeatable measurement method for all three parameters based on the indications. The measured values for inter repeatability for the parameter grain roundness showed very small deviations. All measured values were identical with two exceptions assessor 4 for surface 3 and assessor 1 for surface 4 differed one point. For the parameter grain face assessor 3 and assessor 4 for surface 1 also assessor 1, assessor 2 and assessor 3 for surface 2 and surface 4, assessor 2 and

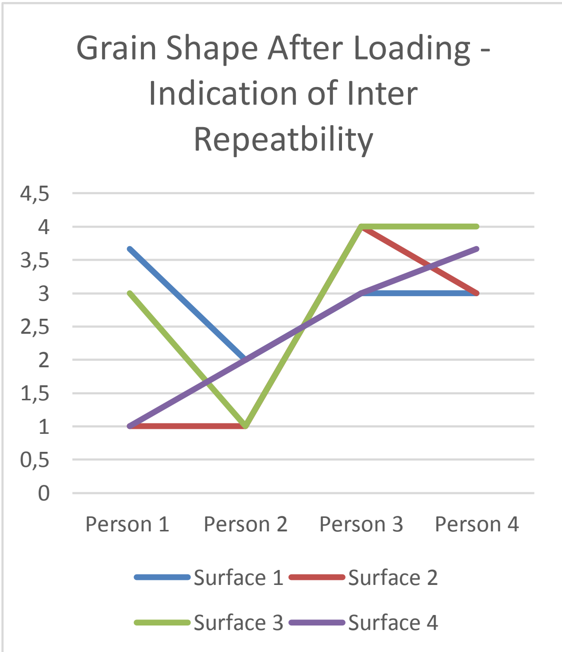

Figure 39: a negative indication of inter repeatable method

assessor 4 for surface 3 measured identical values. Surface 2 and surface 4 assessor 4 differed one point. For the parameter grain shape even less identical values occur only assessor 1 and assessor 2 for surface 2 and assessor 3 and assessor 4 for surface 1 and surface 4 measured the same. All in all considering the parameters singly lead to different estimations: for the parameter grain roundness it seem to be a inter repeatable test method, but for the parameters grain face and grain roundness it is rather not inter repeatable measurement method all based on the indications as representative shown in figure 39.

4.3.7 Water Permeability

This measurement method is again divided into three parameters: direct water permeability, water colouring and water permeability. To start with parameter colouring the values for intra repeatability are all the identical with one exception and the same applies for inter repeatability. So it is to assume that based on the indication seen in figure 39 this measurement method is intra und inter repeatable for this parameter.

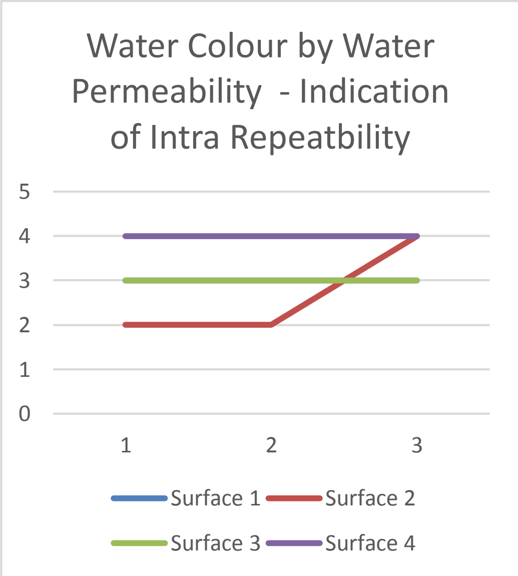

Figure 40: a positive indication of intra repeatability

The peak deviations for the parameter direct water permeability for the indication of intra repeatability are 59.18 and for inter repeatability 51.94 and for water permeability intra repeatability peak deviations are 49.17 and for inter repeatability 46.7. However in both parameters and both tested repeatabilities the values especially for surface 1 and surface 4 are more closely related which can be also observed in figure 41. Therefore it is still assessed to be reasonable repeatbilities based on the indications.

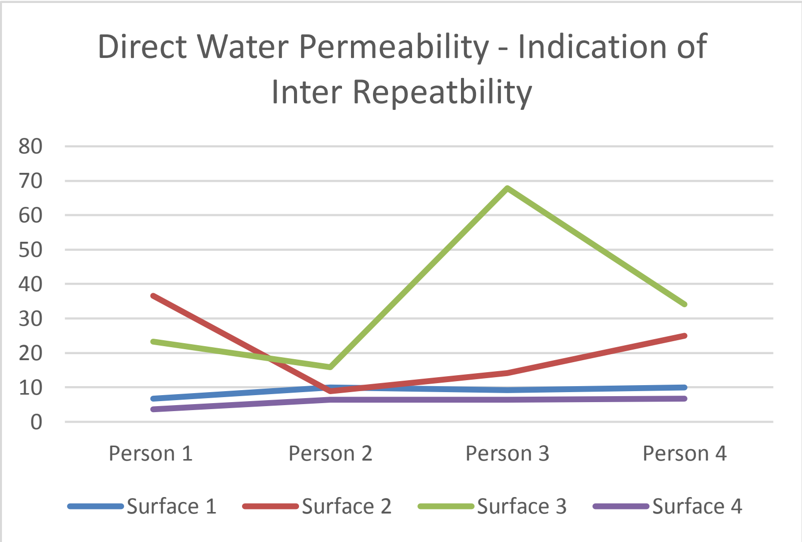

Figure 41: positive indication of inter repeatble measurement method

4.3.8 Water Content

This measurement method only contains one parameter. Based on the indications by the drawn graphs it is to estimate that this measurement method is an inter repeatable one. The different lines per surface seen in figure 42 are going all the same directions. The peak deviation is 10.4 but it is an exception, the average of the deviations between assessors a rather smaller.

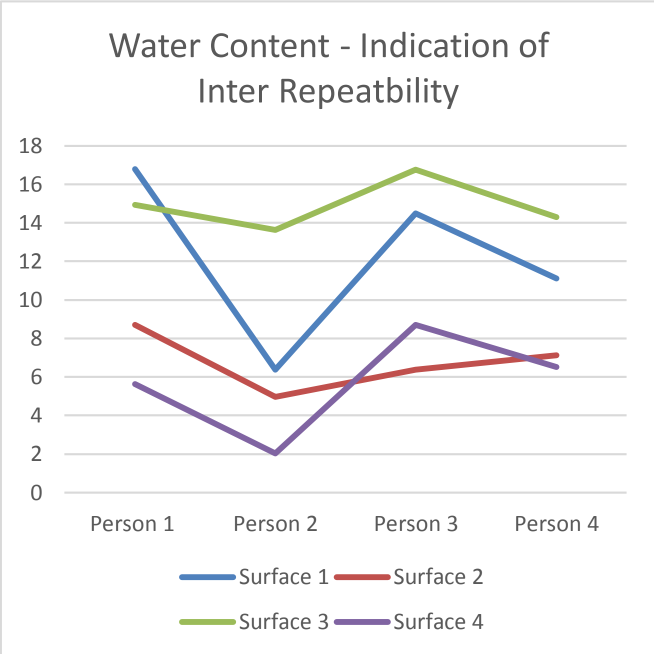

Figure 42: seem to be an inter repeatable measurement method

The deviations within rate assessors for the intra repeatable test are for surface 1: 8.49 and 7.01; for surface 2: 6.66 and 4.53; for surface 3: 4.11 and 2.77; for surface 4: 9.49 and 7.77. So it is questionable if this measurement method is intra repeatable.

4.3.9 Slurry Test

This measurement method is again divided into three parameters: sand amount, water colouring and fines amount. To start with parameter colouring the values for intra and for inter repeatability are all identical. So this measurement method seem to be intra und inter repeatable for this parameter.
The measured values for sand amount are two times identical for assessor 1 and assessor 2. Assessor 3 shows deviations of 8 and 22 and assessor 4 shows deviations of 14 and 2. Looking at the graph (figure 43) for the indication it still seem to be reasonable intra repeatability. For the inter repeatability tests the lines in the graph (figure 43) go almost the same direction without the line of surface 3. Looking at the values confirms that there are the greatest deviations for surface 3 with 28. However based on these indications it seem to be an inter repeatable measurement method.
Greater deviations can be observed for inter repeatability test for the parameter fines amount. The peak deviations per surface are: surface 1: 20; surface 2: 10; surface 3: 10; surface 4: 16, so it is questionable if this is an inter repeatable measurement method for this parameter. This applies also for intra repeatability indication for this parameter. Since the measured values are identical for surface 1 and almost identical for surface 3, but the peak deviations for surface 2 is 13.34 and for surface 4 is 32. So 50% of the indications as illustrated in the graph in figure 44 let assume an intra repeatable measurement method and 50% not.

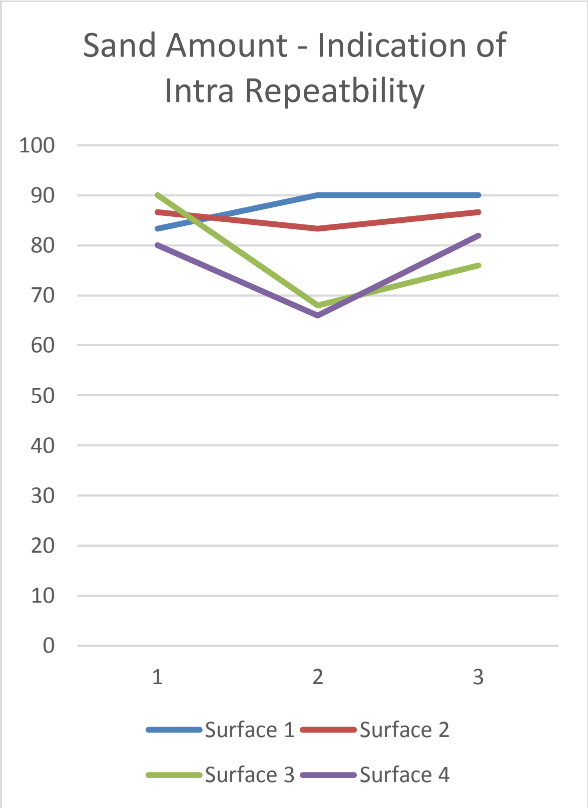

Figure 43: positive indication of inter repeatability

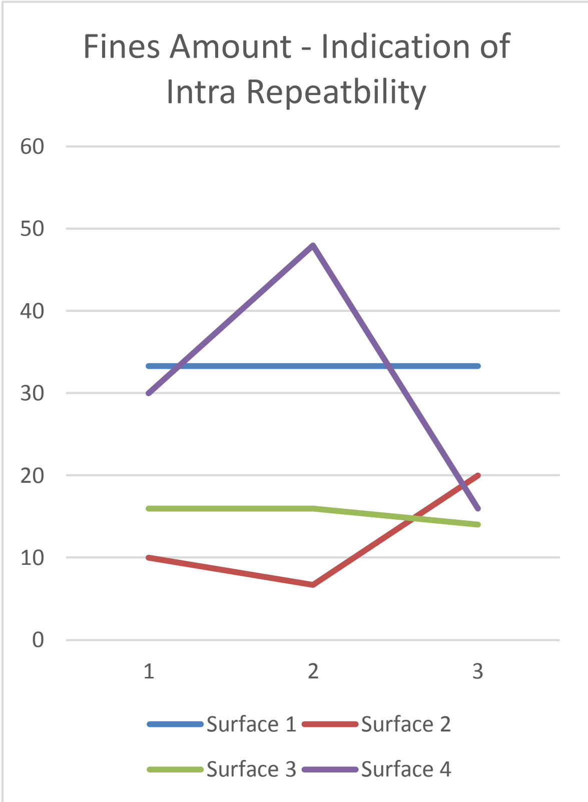

Figure 44: questionable indication of intra repeatability

Chapter 5

• *Discussion* •

5.1 Introduction

In the following chapter the results and source of errors within the testes measurement concept are discussed. Also possible improvements or unsuitability are illustrated.

5.2 First Impression

Although the measurement method 'first impression' is rated as reliable method in the previous chapter it should not fall out of the focus that this method is very subjective. Consequently if a person feels the first time a wet surface the same person would preferable not change its opinion in a minute. Since the repetition of the same measurement method for three times was executed without a determined break it is notable that the person still remembered what he or she rated a minute ago. Furthermore it was criticised by the measurement persons that experiences and comparative value were missing especially at the first surface. Since this measurement method did lead to comparable evidences about equestrian sport surface based on its strong subjectivity it is recommended to remove this method from the measurement concept.

5.3 Height/Incline

This measurement method translated form the building industry especially out of the road construction business lead to very reliable results. As explained in the previous chapter this method seem to be repeatable based on indications. Also the execution work out well as planned. However the first challenge was the insert of the iron nails or the positioning of the obstacle stands need to be plump-vertical (Richter, 1993). One of a measurement persons was experience with this and introduced the other ones. With some practice it is manageable. Furthermore the rope installing in point of tightening and get it vertically also requires some practice. The rope is attached to the first nail and wrapped around the second one. Then the end need to be pulled to tighten the rope. To keep the measurement devices simple and cheap it was planned to check rope's horizontally with the water level. Since the objective of this research was to test the concept about its repeatability, reliability and realistically it was decided to double check if the rope is 100% vertical additionally with a surveyor's level. Although the iron-nail-rope construction

	Rope 1	**Rope 2**	**Rope 3**
Surface 1	+3cm	+1cm	+5cm
Surface 2	+1cm	+0,5cm	+1cm
Surface 3	+1cm	+,06cm	+1cm
Surface 4	+3cm	-1cm	+1cm

Table 12: Results of measurements with the surveyor's level

was installed by and under guidance by an experienced road constructer with more than 20 years working experiences, the surveyor's level gained height difference of up to 5cm as seen in table xxx. The surveyor's level was used with a leveling rule on top of the rope right next to the both iron nails (Richter, 1993) as it is used in road construction businesses.

The measurement method determined to measure the height between rope and surface initially at the first iron nail and then every second step. First of all it is indispensable to determine a start side to ensure for each measurement run the same basis. The problem with measuring every second step is that everyone does different sized steps. This leads at the end to different number of values. One person did 22 steps another one at the same location 28. Anyway the results of this measurement method showed that this is a very reliable method intra and inter repeatability could be strongly confirmed. Therefore this test should be included in the measurement concept with some improvements. The prescription between measurement points should be more specific. Steps should be transferred into meters with a measuring tape. An improvement in rope installing would be either use a surveyor's level together with an experience person. However this would not necessarily comply with the criteria of cheap measurement concept. So a cheap alternative would be to use a water level as long as possible. Since the longer the water level the more precise the rope alteration. On the other hand it should be considered that only once there was a difference of 5cm which is a difference of 0.25%.

5.4 Sample Taking

The surface sample taking was translated for agricultural soil sample taking. Agricultural soil sample taking is distinguished between taking sample with a special device or by hand (LTZ Augustusberg, 2012). For agricultural background soil samples pipe with diameter of 18mm are inserted up to 90cm deep into the soil (LTZ Augustenberg, 2012). Considering the surface tests which were operated not at surface location and the fact that equestrian sport surface sample taking only focuses on the penetration layer which has a limited thickness. So it was determined to use pipes 50mm diameter. The first problem already occurred while taking the surface samples. Although a gummi hammer as described for soil sample taking (LTZ Augustenberg, 2012) was used not all surfaces allowed pipe inserted as easy as desired. Which means putting the pipe into the top of the penetration layer worked well. But stabilise it with one hand and with the other one hammer it into the penetration layer lead to problems in stabilisation to ensure a vertical insert of the pipe. However with some experiences it worked better. To keep it still simple but also to ensure vertical pipe insert it is advisable to do sample taking as partner work. One person is responsible for stabilising the pipe with two hands and the other one hammers the pipe into the penetration layer.

The other source of failure and even more crucial was that some surfaces did not allow the insertion

of the pipe. This applied especially for the driest surface (surface 2) and the most compacted surface (surface 3). Surface 2 was not in optimal maintenance constitution, so it was neither watered nor treated with some kind of maintenance device. Furthermore this surface is only used as alternative for heavy rain falls. Surface 3 was watered but not treated with harrow. So it is indispensable to prepare the measurement inform of optimal maintenance constitution to prevent very dry or compacted constitution, since surface treating counteracts compaction (Heinrich and Hemker, 2012; FORUM Zeitschriften und Spezialmedien GMBH, 2013). Additionally deep harrowing several days before measuring takes places is advisable to prevent compacted layer beneath the top of the penetration layer (Swedish Equestrian Federation, 2014).
During the test which were not operated at surface location such as water permeability, water content and grain evaluation, the problem of sample mass occurred. Sometimes it was not possible to carry out all tests with the determined requirements such as 150g sieved surface sample for the water content test. Again surface 2 and 3 made trouble. Since it was not possible to insert the pipes into the penetration layer of surface 2 the surface sample was collected by hands as deep as possible. At this point a small shovel as known from flower planting would have been helpful particularly to ensure also deeper surface from deeper parts. As mentioned above optimal maintenance constitution would solve this problem. Furthermore small planting shovel should be added to list of resources for surface sample taking in the measurement manual to prevent possible problems with pipe insertion. For surface 3 the problem with surface mass was that the additives had to be sorted out for the drying procedure. So it is advisable to take more samples on one spot to guarantee that all test can be carried out with the right surface mass.

5.5 Firmness

As shown by many surface manufactures to demonstrate the surface's firmness is to form a ball out of some surface mass as hard as possible. Next this ball is destroyed with the thump. At this point pumped up the same problem as explained under first impression. Measurement persons, all involved within the equestrian sports, did not have any experiences in surface quality assessment. Furthermore the same person rated the same surface for three times did probably remember his or her previous rated values. Additionally the values between person differ greatly which lead to not confirmed inter repeatability. Furthermore the measurement persons again all complained about lack in comparable values. This measurement method is subjectively based and does not deliver objective and comparable evidence about surface's quality constitution. Consequently it is advised to take this measurement method out of the measurement concept.

5.6 Hoof Imprint

Since this measurement method seem to be intra repeatable but not necessarily inter repeatable it is important to take a look at the set up and possible sources of errors. Although the possibility that the persons tested the intra repeatability may remember the previous measured values can be taken out since the collected data is too big to remember values. Nevertheless at this point it is indispensable to search for strong improvements within this measurement method to make it more reliable. First of all it is important to mention that 'hoof imprint creator' was on every surface a different horse. It is known that the imprint is dependent on many factors such as horse's weight, and biomechanical constitution, hoof shape and surface quality (Herlund et al., 2010; Hobbs et al., 2014). Therefore first improvement is to use always the same horse to eliminate the influence factors by the horse and keep the focus on surface's quality. Another source of error was probably the determination to measure the deepest point. Since the deepest point was determines by eye, it is an inaccuracy and may result in errors, also due to unevenness in the penetration layer the measured values are not as precise as desired (Heinrich and Hemker, 2012). Therefore it was decided test a different set up which allow more precise change the whole set up of this method. To get more accurate values it was decided to try out to do a negative imprint. Two possibilities were tried out one with and one without an interlayer. On top of this interlayer liquid cement was filled into the imprint. Drying phase took only 5 to 10 minutes and the gips imprint copy was ready and the height was measurable. The same was operated without interlayer. First of all it was noticeable that the more water was used to create the gips fluid the faster to started drying. The results were that the set up without interlayer worked out more precisely than with interlayer. The disadvantage is that some surface will stick on the negative probe which can be removed when the surface is dry as well, but again some material is lost.

5.7 Grain Face and Appearance

Since some indications for inter and intra repeatability lead to positive and some to negative assumptions it is again indispensable to take a look at possible sources of errors as well as possible improvements to make the method more reliable. It is generally know that sand grain evaluation is only possible underneath a microscope, since a sand grain is with grain size of 0.063mm to 2mm (Dreyer-Rendelsmann, (n.d.)) comparable with the size of the matchstick head and fines even invisible for the human's eye (Swedish Equestrian Federation, 2014). Based on the measurement concept criteria easy and cheap measurement methods, a cheap microscope available for children was used. The selectable grain properties on the measurement sheet were based on literature gained knowledge such as: for grain face: rough or smooth, for grain shape: round, flat, longish and cubic and for grain roundness: sharp angular, angular, angular-rounded, well rounded (Dreyer-Rendelsmann, (n.d.)). Although the results indicate a high chance of repeatability the feedback by measurement persons were relative negative. It was difficult to determine the grains face, as well as to distinguish between longish and cubic for grain shape, since it was often a mix of both. Obvious is that although there are four different grain shapes could be chosen, in 22 of 24 cases it was either longish or cubic chosen. In only two cases the grain shape was evaluated as round and this was in both cases the same person. Furthermore the steps between sharp angular, angular and angular rounded are very tightly was as well a difficulty. So it is strongly recommended to use a microscope which performs better in point of enlargement. The used microscope enlarged the objectives up to 200 times. However internet research showed that there are already microscopes available with 1200 times enlargement for 40 Euros which still would comply with the criteria cheap. The ease of use is also guaranteed since it is recommended for children aged 10.

Another issue is that it was challenging to put only very few grains onto the microscope slide because the sand grains stuck to each other. The origin idea was to put some sand between thumb and forefinger and trickle it onto the microscope slide. Since this did not work out very well it is better to lay a tablecloth or newspaper and on top the microscope slide and sieve a small amount of the surface probe over it.

5.8 Loads/Stress

As this measurement method is very similar to the previous one also the results were comparable. So due to the fact that some indications for inter and intra repeatability lead to positive and some to negative assumptions the key element is to discuss possible improvements to make the method more reliable. So to the facts, the base idea was to replicate mechanical loads for the surface material with a simple mortar. Small surface amounts were put into the mortar which was pestled about 50 times. This measurement method was translated form wear resistance test for additives carried out within the long term study by the University of Applied Science Onsabrück (Heinrich and Hemker, 2012). The first problem was that the weight determination of 50g sand (Heinrich and Hemker, 2012) could not be used because of the mortar's size. So there was no weight determination, but the outcome was that small amounts, such as 5-6g, worked the best. The background was to compare grain before this loading and afterwards. So again the microscope was used. Therefore also the same issued with putting grains onto the microscope slide and with struggling how to evaluate the grain apply here as well. Consequently also the same solutions should be also applied here.

The values and the feedback of measurement persons show that there was not always a difference in grain evaluation noted which could have different reasons:

- either the surface material is very durable and wear resistant which would be the most desirable one,
- a simple mortar was used instead of a mechanical mortar in the origin research (Heinrich and Hemker, 2012),
- the 50 pestles were not enough to replicate mechanical load,
- the surface sample within the mortar was chosen too high.

Possible is also a combination out of several reasons were the source of error. Therefore it is strongly advised to set a weight determination of 5g surface sample and to increase pestle treatment number to get more clear evidences about surface's quality.

5.9 Water Permeability

Figure 45: developed construction to measure the water permeability of all samples at once.

As seen in the result chapter the water permeability measurement method seem to be a repeatable method for all tested parameters. However there are still requirements to improvement this measurement methods based on gained experiences during the execution. The first question occurred by the determination, what is direct water permeability. Since the water permeability velocity differs strongly between the surfaces types, it was decided to equalise this method with the determinations by the slurry method. So direct water permeability was measured after one minute and total water permeability after one hour. To measure the water permeability of several samples at the same time a special frame was developed as seen in figure 45. Since it was very difficult to get glass tubes, they were replaced by plastic tubes, which were only available with an inner diameter of 16mm instead of required 30mm (Hellberg-Rode, 2002c). Based on change from glass to soft plastic tubes the required length had to be changed as well from 20-30cm to 10cm (Hellberg-Rode, 2002c). Consequently the next problem occurred the 60ml water could not be filled in once into the tube which was filled with 5cm (~10g) dried surface sample. Depending on water permeability velocity, it took some time to fill the 60ml into the tube. Additionally it was challenging to read the exact permeated amount of water. So finally it was decided to execute one time per each surface an enlargement with the relation of 1:7. Calculated by the volume:

$$small\ tube: \pi\left(\frac{d}{2}\right)^2 h = \pi\left(\frac{16}{2}\right)^2 100 = 20106.19298$$

$$294524.3113 : 20106.19298 = 14.6$$

$$big\ tube: \pi \left(\frac{d}{2}\right)^2 h = \pi \left(\frac{50}{2}\right)^2 150 = 294524.3113$$ 14.6 : 2 ≈ **7**

So the big tube was used with a surface sample 70g (= 7x 10g) and 240ml water (= 7 x 60ml). The permeated water amount could be read more accurate. Consequently the percentage value differed. So the recommendation is to do a larger version of this measurement method to result in better evidences about the surface's water permeability values.

5.10. Water Content

As explained in the previous chapter is the measurement method of water content classified as relative reliable since the indication shows an inter- but not intra repeatable measurement method. That let assume that the measurement execution may need some improvements. As in the measurement manual explain it was determined to sieve the surface samples before starting with the drying procedure to sieve additives out since the respond of additive material to heat is not clear. The sieving was the first obstacle which had to be overcome. A small kitchen sieve as it is used for did not work because of too fine mashes. The out with a try flour sifter result in a damaged flour sifter because of the wet sand. So a commercial children's sand box sieve with relatively wide mashes (~ 3mm x 3mm) were used and worked out. Additionally it was a lot cheaper that the flour sifter. The oven's heat had to be adjusted to 110°C instead of 105°C (Kruse et al., 2012) since the commercial ovens offer only 10°C steps. In literature it was required to dry the samples for several up to 24hours (Kruse et al., 2012). However during the drying procedure it was noticeable that the sieved samples dried relatively quickly. So the most reliable procedure was to put the samples into the oven when it is already on 110°C, stir it after 30 minutes and after 1hour it is completely dry. But it was independent if the oven was put on upper and lower heat or on recirculation air.
The following calculation work out easy and well:

$$Weight\ of\ the\ wet\ Sample - Weight\ of\ the\ dry\ Sample = Water's\ Weight$$

$$\frac{Water's\ Weight}{Weight\ of\ the\ dry\ Sample}\ x\ 100$$ (Richter, 1993).

The only improvement which could be necessary would be to increase the surface sample mass to gain more accurate results.

5.11. Slurry

As seen in the result chapter also the slurry test seem to be a relative reliable measurement method which could may be explained by some changes considering the original requirements. It was recommended to use 2inces/5cm surface sample (Gilbert, (n.d.)). Based on the fact that some samples were very roughly calculates in point of mass as explained above beneath the heading sample taking, 5cm was changed into 3cm. The observations worked out very well as explained in literature after 60seconds the sand layer was created and could be measured and the same for the second layer about fines (Gilbert, (n.d.); Hellberg-Rode, 2002b). Nonetheless staring the calculations it came out that the decision to take 3cm instead of 5cm soil sample was not completely overthought. To gain more precise percentages it is better to use 2,5cm surface sample. After calculation it was noticeable that in 50% of the cases the total value, sand amount and fines amount together are greater than 100%. This may come due to in accuracy in height measuring and rounding error due to the fact that the basic calculation result in a periodic number: $\frac{100}{3} = 33{,}3$. Therefore it is very important to execute this measurement method with either 2,5cm surface sample or even better 5cm as required in the literature (Gilbert, (n.d.); Hellberg-Rode, 2002 b).

5.12 Questionnaire Stable Owner/Manager

In this paragraph is the focus on the understandability of every question based on either the given answer or enquiry during fill in the questionnaires. The first and the second question are easy to understand since these are just basic questions of location, indoor or outdoor and arena size. The third question about the construction probably understand by three out of four answered persons, since one person selected 2-layer-surface and removed bearing layer and put instead separating layer. May be it would be advisable to add a short explanation about construction possibilities. The following three questions about material of bearing, separating and penetration layer seem to be answered right or let out if this layer is not part of the surface construction. Question 7 and question 8 are about the installation time point and the last refill. Based on the fact that one person answered with installation was 1999, but it is known that the penetration layer was totally renewed 2015, it is strongly advised to divide question 8 into the different layers. The question about surface manufacturer seem to be understand well. The following question about the pricing was only answered twice instead of fourth, this may have the reason that it is not known anymore or because of business secret. Question 11, 12, 13 and 14 seem to be understandable they focus on penetration layer thickness, watering system and maintenance management. The following question about how many horses train on the surface daily seem to be difficult to estimate if different surfaces can be used within the stable, for example the stable of surface 4 offers two indoor arenas (20x40m and smaller), an outdoor arena (20x60m) and one circle outdoor arena for longing and an roundpen and hosts about 50 horses. The question about mainly practised disciplines were one time miss understood because it was chosen eventing although it is known that there is no eventing rider in this stable, but in German language it is called 'Vielseitigkeit' (=versatility) and this person may thought yes the surface is used very versatile. This may happen if the stable owner's background does not lie in the equestrian sport. Question 17 if injuries which may be caused by constant overload such as tendon and ligament injury occur was always answered with no. But in one stable it is know that there were several injuries which could by caused by overload. Of courses this is always based on multi factors. In this case it could be that the stable owner has no idea that these injuries occurred. The last question is as well understandable but it is questionable if the stable owners really know what their clients think about the surface quality.

All in all the quality of the questionnaire is understandable with the remark of construction introduction. The problem is that not everyone is familiar the construction possibilities of surfaces.

5.13 Questionnaire Riders

The first six questions seem to be understandable and focus on activity with the horse (rider, trainer, etc.), the regular practiced discipline and class as well as surface location: indoor or outdoor and arena size. Question 6 is about the satisfaction about the surface quality. Notable is here that the opinions within one surface are very different for one surface. The same applies for the satisfaction with the watering system in question 8. The majority of persons also answered question 9 and did know what system is used, but for more inexperienced equestrian sport involved people it may be helpful to give a short explanation of available and common used watering systems. Also the opinions about satisfaction with maintenance management watering times and treatment with maintenance device was various responded. This may be based on the fact that several surfaces are used for various disciplines and everyone has different requirements and desired about the 'perfect' surface, so it is quasi never possible to get everyone satisfied. The lasts questions focus on injury occurrence, here again it may help to get clear answers especially from the beginners to give an explanation. To conclude this paragraph, adding some explanations and this questionnaire will help to evaluate surface quality, considering that fact that everyone desires the 'perfect' surface which is not possible as explained in the first chapters.

Chapter 6

• *Conclusion* •

At the end of this research it is essential to get a short precise answer on the research questions:

1. What measurement parameters are available to establish equestrian sport surface's quality?
   As described in chapter 2 the parameters surface materials: main materials and additives as well as humidity, firmness, elasticity, dust, droppings and hoof imprint are crucial for the equestrian sport surface quality. The development of the measurement concept with the criteria easy and cheap the led to the following measurable parameters:
   - grain face, shape and roundness
   - grain face, shape and roundness alteration due to mechanical loads
   - penetration depth
   - height differences/incline
   - water permeability
   - water content
   - sand and fines amount
   - firmness

   Another very important parameter would be shear strength, but it is as not possible to measure this in a cheap simple way.

2. What simple and low cost concept can be established to measure equestrian sport surface's quality and durability?

2.1 What measurement methods are simple and cheap but establish surface quality and/or durability

The measurement methods for the measurement concept as detailed explained in chapter 4.2 in the measurement manual all comply with the criteria:

- Measures the Surface's Quality
- Simple in Operation
- Cheap to buy

All measurement methods are only operated with measurement devices such as folding rule, commercial oven, cheap microscope, simple mortar, water level and more. To get a real answer in the following sentences the measurement concept is roughly explained.

The developed measurement concept includes nine different measurement methods. It starts with the first impression which is an estimation of surface constitution in point of wet or dry constitution as well as grain shape and roundness. All three methods are operated by feeling the materials between fore finger and thumb. The second measurement method is to measure height differences or incline. Therefore an iron-nail-rope construct is installed as known from road construction business. Three ropes per surface are tightened. The height between surface and rope is measured every second step. Afterwards surface samples are taken with a 50mm diameter pipe and a rubber hammer. The fourth method is called firmness and the requirement is to create a ball by hands as hard as possible and afterwards destroy it with the thumb. Following the easiness of ball creation and destroying should be estimated. The last measurement method which is executed at surface location is the measurement of the hoof imprints. Therefore a horse is lead through the arena in the different gaits and in-between the imprints depth are measured with a tile and folding rule. The other five methods are carried out in the kitchen. First of all a microscope is needed to assess grain face, shape and roundness. Afterwards a small surface sample is treated with the pestle in a mortar and the grains are again assessed underneath the microscope. To measure the water permeability glass tubes are closed with net curtain on one side and dried surface samples are filled in. Then 60ml water is splashed over it and direct (60sec.) and total (1h) water permeability is calculated based on the permeable water. For water content calculation sieved surface samples of 150g are dried in a commercial oven by 110°C. The sample is weight after drying to calculate the water loss as well as the percentage of water content. Finally a rough determination of sand amount and amount of fines is measured with the so-called slurry test. Therefore glass jars are filled 5cm with fresh surface samples and the jar is filled up with water so that there is only ca. 1cm space between water surface and cover. Then the cover is closed and the glass strongly shacked. In 1min a layer of sand will settle down and can be measured in height and the same will be with fines after an hour. Based on these height measurements the rough sand and fines amount can be calculated.

2.2 What questions should stable owners be asked to establish surface quality?

The questionnaire for the stable owner or manager focuses on construction, material type, age, penetration layer thickness. Furthermore about maintenance management especially watering systems and times and treatment times and injury occurrence. The detailed questionnaire is found in the annex.

2.3 What questions should riders be asked to establish surface quality?
The questionnaire for the riders, horse owners or trainers mainly focuses satisfaction with surface quality and in this context the maintenance management. Also a crucial point in this questionnaire is the injury occurrence especially tendon and ligament injuries which may be caused by constant overloading. The detailed questionnaire is found in the annex.

To the main question it is to conclude that all three parts the measurement concept, and both questionnaires are together a simple and low cost intensive research concept focusing surface quality and durability.

3. What can be said about the quality of the developed measurement concept?

3.1 Do assessors measure parameters consistently when measuring the same parameter more than once?
In almost all cases the assessor's triple measurements were identical or almost identical. One reason could be that the assessors still recognized what they have already measure because all three measurement procedures took place right after each other. On the other hand it could stand for precise measuring.

3.2 Do different assessors produce the same result when measuring the same parameter?
Not always, in about the half of cases the measured values were similar or identical.

3.3 Where the questionnaires understandable to all?
Both questionnaires are in general understandable. The question about construction in the questionnaire for stable owners/managers and the questions about maintenance management and watering systems explanations would be beneficial for better understandability.

To the main question is to conclude that if the mentioned improvements are implemented the measurement concept is under consideration of the criteria useful and beneficial its purpose.

Chapter 7

• Recommendation •

Finally it is to say that the measurement concept can be used for a long term research with the a few limits and changes. The measurement methods for first impression and firmness should be removed from the concept since they does not deliver accurate comparable values. The measurement method for height should be improved with accurate measurement points determined by meters. For the grain assessment a microscope with better zoom should be chosen. The measurement set up for penetration depth should be change totally and negatives with gips should be used. Also the water permeability measurement method should be improved in the form of enlarging sample amount as well as water amount to create a more precise method.

For the questionnairs some explantions should be added as mentioned in the chapter of discussion.

Chapter 8

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Cover	SA Since this moment – Photography (2015) Germany.
Figure 1	Heinrich, T. and Hemker O. (2012) Qualität und Dauerhaftigkeit von Reitplatzaufbauten - sportfunktionale und boden-mechanische Betrachtungen unter den Gesichtspunkten Nutzung, Alterung und Horizontbildung der Reitplätze. Hochschule Osnabrück University of Applied Science, Germany. p. 25 → enlarged with information: Dreyer-Rendelsmann, C. (n.d.) Reitplatzbau - kein Buch mit sieben Siegeln. Germany. Not yet published.

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Chapter 9

• Annex •

7.1 Measurement Sheet to Register

Surface ______________________________

Date ______________________________

Name ______________________________

1. First Impression

Take some surface between thumb and forefinger and evaluate what it feels like	
The surface is...	◯ very wet ◯ wet ◯ medium ◯ dry ◯ very dry
The grain is....	◯ round ◯ sharp angular ◯ other:
The grain is....	◯ fine ◯ coarse ◯ other:

2. Height/Incline

Introduction:
Position and insert each two iron nails are into the penetration layer with the hammer as seen in figure 27 and 28. Fix the rope is on both iron nails at the marker of 25cm. Then recheck if the rope is level with a water level. Next start at one iron nail measuring and then do always two steps into the direction of the other nail and measure the height between surface and rope. Fill in the measured values into this measurement sheet.

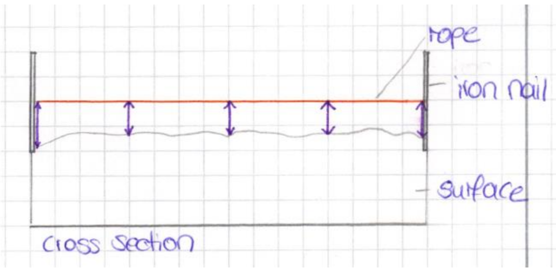


Figure 47: lateral view

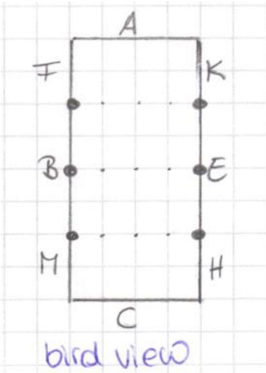
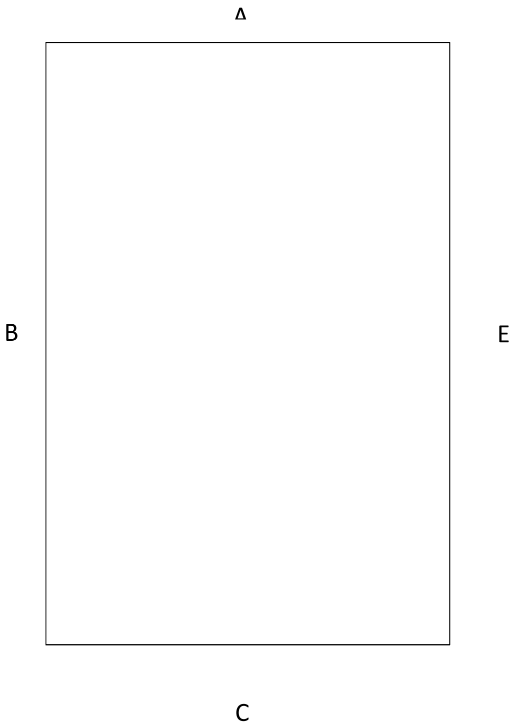


Figure 47: bird view

1. Rope		2.Rope		3.Rope	
Starting Point	cm	Starting Point	cm	Starting Point	cm
Step 2	cm	Step 2	cm	Step 2	cm
Step 4	cm	Step 4	cm	Step 4	cm
Step 6	cm	Step 6	cm	Step 6	cm
Step 8	cm	Step 8	cm	Step 8	cm
Step 10	cm	Step 10	cm	Step 10	cm
Step 12	cm	Step 12	cm	Step 12	cm
Step 14	cm	Step 14	cm	Step 14	cm
Step 16	cm	Step 16	cm	Step 16	cm
Step 18	cm	Step 18	cm	Step 18	cm
Step 20	cm	Step 20	cm	Step 20	cm
Step 22	cm	Step 22	cm	Step 22	cm
Final Point	cm	Final Point	cm	Final Point	cm
Comment:		Comment:		Comment:	

3. *Taking Surface Samples*



Please mark where
←surface sample taking was executed!

4. *Firmness*

Take some surface into your hands and create a ball as hard as possible. Take the ball in one hand and destroy it with the thumb of the other hand and note your observations (effort)!	
General	
Ball create was	◯ very easy ◯ easy ◯ medium ◯ hard ◯ very hard
Destroying the ball was	◯ very easy ◯ easy ◯ medium ◯ hard ◯ very hard

5. Hoof Imprint

General Impression of Hoof Imprint ◯ shallow ◯ medium ◯ deep Shape:	
Walk 1.	cm
Walk 2.	cm
Walk 3.	cm
Comment:	
Trot 1.	cm
Trot 2.	Cm
Trot 3.	cm
Comment:	
Canter 1.	cm
Canter 2.	cm
Canter 3.	cm
Comment:	
Circle Canter 1.	cm
Circle Canter 2.	cm
Circle Canter 3.	cm
Comment:	

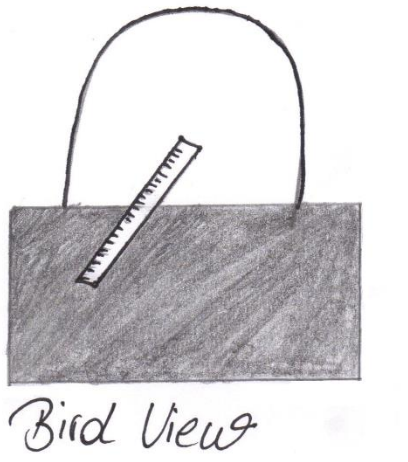


Figure 48: how to measure the hoof imprint

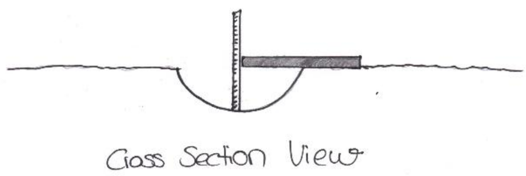


Figure 49: how to measure the hoof imprint

6. Grain Face und Appearance

Observations underneath the microscope : General observations
Grain Face: ◯ smooth ◯ rough
Grain Shape: ◯ round ◯ flat ◯ longish ◯ cubic
Grain Roundness: ◯ sharp angular ◯ angular ◯ angular-round ◯ well-rounded
Comment:

7. Stress/Loading

Observation during pestle treatment within the mortar:
Observations underneath the microscope : General observations
Grain Face: ◯ smooth ◯ rough
Grain Shape: ◯ round ◯ flat ◯ longish ◯ cubic
Grain Roundness: ◯ sharp angular ◯ angular ◯ angular-round ◯ well-rounded
Comment:

8. Water Permeability

Direct Water Permeability:

permeable water amount in ml: __________ = ***u***

$\frac{100}{60}$ x ***u*** = $\frac{100}{60}$ x _____________ **=** _____________***%***

Comment:

After 1h Water Permeability:

permeable water amount in ml: __________ = ***u***

$\frac{100}{60}$ x ***u*** = $\frac{100}{60}$ x _____________ **=** _____________***%***

Commment

9. Water Content

Weight before Drying ___________________g

Weight after Drying ___________________g

Weight before Drying – Weight after Drying = Lost Water: ________________g

$\frac{100\ x\ Lost\ Water}{Weight\ after\ Drying} =$ ________________$\%\ Water\ Content$

10. Slurry Test

Fill 5cm fresh surface sample into the jar. *Fill the jar with water so that ca. 1 cm space between water surface and cover.* *Close the cover and shake strongly. Then measure as follwong:*
General Observations:
Height oft he sand grains after 60 seconds ______________ cm **= u** $\frac{100}{5}$ ***x*** _________________ **=** ___________________***%*** amount of sand
Colour of the water ***:*** ◯ Brown ◯ Brownish ◯ between Brwon and Yellow ◯ Yellowish ◯ Yellow Comment:
Height of the fine grains after ____ hours ______________ cm **= u** $\frac{100}{5}$ ***x*** _________________ **=** ___________________***%*** amount of fines

7.2 Questionnaire Stable Owner/Manager

Stable Name & Location :____

Name: ____ Date:____________________

1) ____ **Where is the surface located?**

a) Indoor b) Outdoor

2) ____ **What is the size of the arena?**

a) 20x40m
b) 20x60m
c) other:______________m

3) ____ **What type of surface constructing do you have?**

a) Three layer: bearing, separating and penetration layer
b) Two layer: bearing and penetration layer
c) Penetration layer on top of a compacted ground

4) ____ **What materials are installed for the bearing layer?**

____

5) ____ **What materials are installed for the separating layer?**

____

6) ____ **What materials are installed for the penetration layer?***

a) sand
b) additives: ____
c) organic: ____
d) pure synthetic:____
e) grass
f) wax-coated
g) Salt
h) Other:____

7) ____ **When was the surface installed?**

____

8) ____ **If there was a refill, when was it? And refill of what?**

____

9) ____ **Where is the surface from? Manufacturer/Company Name**

____

10) ____ **What did you pay for the surface and installation?**

____

11) ____ **In which height was the penetration layer installed?**

a) 2-4cm
b) 4-6cm
c) 6-8cm
d) 8-10cm
e) 10-12cm
f) 12-14cm
g) Other:_______cm

12) ____ **What type of watering system do you use?**

a) water tank
b) mobile sprinklers
c) sprinkler system
d) accumulation system
e) Other: ____

13) ____ **How often do you water the surface?**

a) daily
b) every other day/2-3days per week
c) weekly
d) every 10-14days
e) other:____

13) ____ **How often do you treat the surface with a harrow or similar maintenance device?**

a) twice a day

b) daily

c) every other day/2-3days per week

d) weekly

e) every 10-14days

f) other:____

14) ____ **How many horses train regularly on the surface?**

_________________ horses

15) ____ **What disciplines are operated mainly?***

a) Dressage

b) Show Jumping

c) Eventing

d) Vaulting

e) Western

f) Endurance

g) Polo

h) Other: _________________________

16) ____ **Do you know about injury occurrence in your stable which may be caused by overload such as tendon or ligament injuries?**

a) Yes! What and how many ____

____

b) No!

17) ____ **What do you think is your clients opinion about the surface's quality?**

a) very satisfied, there are no complains

b) Satisfied

c) I don't know I never talk about it with them

d) not satisfied, they sometimes complain about___________________________________

____

e) not at all satisfied: they complain about

-

-

-

7.3 Questionnaire Rider/Horse Owner

Stable Name & Location :____

Age: ____ Date:____________________

Gender: ◯ female ◯ male

1) ____ **What are you?***

a) Rider
b) Horse Owner
c) Stable Owner
d) Trainer
e) Professional Rider
f) Vaulter
g) Others:____

2) ____ **What discipline you mainly do?*** *name at least three*

a) Dressage
b) Show Jumping
c) Eventing
d) Vaulting
e) Western
f) Endurance
g) Polo
h) Other: ______________________

3) ____ **What is your level?**

a) Leisure
b) competition beginner (E-A)
c) competition medium (M-L)
e) competition (S and more)
f) professional

4) ____ **Where is the surface located?**

a) Indoor
b) Outdoor

5) ____ **What is the size of the arena?**

a) 20x40m
b) 20x60m
c) other:______________m

6) ____ **What type of surface constructing is it?**

a) Three layer: bearing, separating and penetration layer
b) Two layer: bearing and penetration layer
c) Penetration layer on top of a compacted ground

7) ____ **What materials are installed for the penetration layer?***

a) sand

b) additives: ____

c) organic: ____

d) pure synthetic:____

e) grass

f) wax-coated

g) Salt

h) Other:____

8) ____ **Do you know when the surface was installed?**

____

9) ____ **Do you know if there was a refill, when was it? And refill of what?**

____

10) ____ **Do you know what type of watering system is used?**

a) water tank
b) mobile sprinklers
c) sprinkler system
d) accumulation system
e) Other: ___________________________
f) I don't know

11) ____ **Do you know how often do you water the surface?**

a) daily
b) every other day/2-3days per week
c) weekly
d) every 10-14days
e) Other: ___________________________
f) I don't know

12) ____ **Do you know how often the surface is treated with a harrow or similar device?**

a) twice a day
b) daily
c) every other day/2-3days per week
d) weekly
e) every 10-14days
f) I don't know
g) Other: ____

13) ____ **Do you know how many horses train regularly on the surface?**

a) _________________ horses b) I don't know

14) ____ **Did your horse has/had an injury which may be caused by overload such as tendon or ligament injuries?**

a) Yes! What and how many times ____

____

b) No!

15) ____ **Do you know if any horse in your stable has/had an injury which may be caused by overload such as tendon or ligament injuries?**

a) Yes! What and how many ____

____

b) No!

16) ____ **What do you think about the surface's quality?**

a) very satisfied, there is nothing to no complains

b) Satisfied

c) I don't know I never talk about it with them

d) not satisfied, they sometimes complain about___________________________________

____

e) not at all satisfied: they complain about

-

-

-

17) ____ **What do you think about the surface's maintenance management?**

a) very satisfied, there is nothing to no complains

b) Satisfied

c) I don't know I never talk about it with them

d) not satisfied, they sometimes complain about___________________________________

____

e) not at all satisfied: they complain about

-

-

-

Development of a Research Concept Concerning Equestrian Sport Surface Quality

For

Dr. agr. Cornelia Dreyer-Rendelsmann

Officially appointed by the Chamber of Agriculture of North Rhine-Westphalia and sworn experts for horse breeding and husbandry, riding- driving- and competition sport
Of the Commerce and Industry Chamber of Cologne publicly appointed and sworn expert for riding arenas
Institute for Applied Hippology

Hogeschool VHL University of Applied Sciences

Marie-Christine Koch

Equine, Leisure and Sports student

Table of Content

Preface

At this point it is highly important to mention that in the following research proposal for my bachelor thesis the term footing, riding surface and equestrian sport surface are used as technical term for the ground, horses are trained on or even compete on.

Background

Equestrian sport developed over years to an own standing industry. Constantly changing trends and researches as well as upcoming innovations lead to the evidence the equine industry is acting in a complex and dynamic environment. A lot of specialized sectors such as saddlery, equine nutrition and hoof care try to meet the variety of customers and their needs. The horse as sport partner has led to the consequence to set a higher focus to health and security. Next to genes and influences in the young age, the everyday used training equipment has a very high effect to constitution, performance and persistence. For training equipment it's not only meant saddle, bit and boots, also, and a frequently forgotten equipment, is the footing horses are trained on every day.
Equestrian sport is carried out in indoor as well as on outdoor arenas. Outdoor arenas have additional requirements due to weather conditions such as handle the individual amount of rainfall means on one hand store enough moisture to prevent the footing to get dry and dusty and on the other hand lead away too much amounts of rainfall and be frost-proof (Dreyer-Rendelsmann 2013).

Horticulturist and agriculturists frequently talk about excellent or poor surface. They mean, how well their plants are growing on this ground. For other parties the ground is excellent if the ground is as solide as possible, so you can play ball on it. How to assess the quality of the surface, ground or footing is depending on usage. (Hellberg-Rode, Otto 2012)
Of course riding and horse's locomotion have different requirements to the footing than for instance beach volleyball. So the desired characteristics for equine footing are formulated as a footing which is penetration secure or anti-slippy, plane and has a consistent characteristics with low care effort, further the footing should be elastic. A deeper look to these characteristics show they are controvert. A penetration secure or ant-slippy footing means a riding surface which offers hold, to reduce the load onto muscles and tendons. Problematic is that a footing with this characteristic has a stop effect, so the whole motion of the horse is stopped and therefore less fluent. If the stop effect increases which would mean better hold, the load on bones, tendons and muscles increases as well (Dreyer-Rendelsmann 2013). So this is already a non-agreement the principle to reduce the horse's load. This is only one example.

The conjecture that riding surface and the risk of injury stand in direct context is confirmed by the following statement by Peterson et al. The static and dynamic loads on the leg stress the materials of every anatomical structure in the leg including each bone, muscle, tendon and ligament. Furthermore it is essential to mention why the context between riding surface and risk of injury is not obvious. If the threshold stress on horse's anatomical structures is exceeded repeatedly tissue degeneration occurs which is a common response for performance horses. At a later stage failure of the locomotion system will occur (Peterson et al. 2012)

The rule of thumb for injury prevention of the locomotion system to train the horse and various footings and surfaces (Dreyer-Rendelsmann 2013) is confirmed with a lot of statements such as the following one. The documented risk for injury is when a well-trained horse changes from one type of surface to another and at the same time is expected to perform at maximum capacity (Perterson et al. 2012).

Since numerous of years horse are trained on sand footings. Sand is firstly a grain size designation and defines a grain mix with grains of sizes between 0.063 and 2mm (Dreyer-Rendelsmann 2013). This definition does not describe necessarily the sand as we assume it with the beach sand. So it can be every material in this sizes. The rage between 0.063 and 2mm is quite large. However the grain size of individual sand grains have multiple meanings for riding surfaces. They determine the density while storage and thereby the sand grain intermediate spaces. Those intermediate spaces develop a widely branched tube system which is filled with air during dry states and with water during wet states (Dreyer-Rendelsmann, 2013). Both states have different effects of the footing's characteristic, for example the firmness. For the reason that firmness is basically influenced by the interaction of water and sand grain mix (Dreyer-Rendelsmann, 2013).

So getting the perfect footing for equestrian sport is not as simple as it looks like at the first view to a riding arena, not at least because diverse disciplines have various requirements.

Problem Definition

If footing for equestrian sport becomes topic of conversation a bunch of smart statements will fly through the room. However hand on the heart the majority of these statements are based on experiences and not on scientifically proven results.

The problem is surface quality is a complex subject, furthermore to record quality special measurement devices are required which are expensive and difficult in operation.

Furthermore measurements of surface, soil and ground are only a snapshot of a particular moment.

Research Objective

Based on the above stated problem this research is conducted to be able to measure the equestrian surface several times to record quality. Therefore a measurement concept with simple and cheap measurement methods is strongly required. So the objective is to develop a measurement concept in line with questionnaires for stable owners and riders and to test this concept about repeatability.

Research Questions

Main Question
1. What measurement parameters are available to establish equestrian sport surface's quality?

Main Question
2. What simple and low cost concept can be established to measure equestrian sport surface quality and durability?
Sub Questions
2.1 What measurement methods are simple and cheap but establish surface quality and/or durability?
2.2 What questions should stable owners be asked to establish surface quality?
2.3 What questions should riders be asked to establish surface quality?

Main Question
3. What can be said about the quality of the developed measurement concept?
Sub Questions
3.1 Do assessors measure parameters consistently when measuring the same parameter more than once?
3.2 Do different assessors produce the same result when measuring the same parameter?
3.3 Where the questionnaires understandable to all?

Methodology

Research Design

The bachelor thesis research is carried out as desk and as field research. The desk research focuses on the literature review about equestrian sport surface quality parameter which are measureable as well as measurement methods and devices. This stands predominantly for reading scientific literature to gain knowledge about measurement methods, parameter and evaluations. Based on the literature review a development process is tied in. A research concept for a long term study is generated. This research concept contains measurement parameters with precise implement instructions together with a comprehensive question catalogue.
Subsequently this measurement concept as well as the questionnaires are tested to investigate and evaluate the quality of the generated research concept. On one hand to give a first impression what value ranges and what kind of answers can be expected. On the other hand and more important to give an evidence about the repeatability. This need to be conducted by a third party who is only involved for this reason.

Data Collection

As already mentioned the first part is to gain knowledge about appropriate measurement parameters and methods. Therefore mainly scientific literature be searched and studied. This is for the measurement concept. For the question catalogue also the brand new Minithesis of two Equine, Leisure and Sports students will be worked through, to get an overview what questions are appropriate to ask and which are not.
The following practical conduction of the previously developed research concept brings data in form of real values. These data is collected as it is instructed in the concept. Measurements are examined and question are asked to related people. This need to be conduct by four selected people to parallel collect data about the intra and inter repeatability. Therefore data is collected about the variances of results while measuring the same. Means is there a variance in results within (intra) and between (inter) different people. Consequently the following system should be applied to get collect data about the repeatability of the research concept for the reason that this concept will be conducted for the long term study always by diverse people.

	Person 1	Person 2	Person 3	Person 4
Surface 1	★★★	★	★	★
Surface 2	★	★★★	★	★
Surface 3	★	★	★★★	★
Surface 4	★	★	★	★★★

Each ★ stands for one measurement cycle

Data Processing

Entirely collected data will be discussed to get clear explanations about the reasoning for the particular measurement methods combined with accurate instructions. The same counts for the question catalogue which is designed within this research. So far about the desk research data processing.

Subsequently the data for the field research processed in the form of graphical illustration. Graphs for each parameter are drawn on for an indication about intra and one for the indication about inter repeatability. For the intra repeatability indication the triple measurements are compared. To assess the inter repeatability the measurements of all persons at the same surface are compared. Initially the median of the triple measurements is calculated and following all measured values of one location are compared.

Time Schedule

Week	Task
1	Understand the main topic (proposal for a title) Proposal: Background, Research Questions, Time Planning
2	Adjust proposal to feedback from Mr. Dreyer-Rendelsmann & Coach
3 4	Literature about how to measure what / what parameters describe quality aspects of footings for horses + Work through the results of the Minithesis Approvalform + Summary Meeting
5 6	Working through literature + Content structure Entry for implementation: how to develop a measurement of quality model
7	Practical tests and evaluation – complete the model
8 & 9	Literature Chapter (Background)
10	Adjust Background with Feedback
11 & 12	Methodology & Practical tests
13 & 14	Discussion + Results + Abstract
15	Writing the Article
Hand in Draft Report to all involved parties (Mrs Dreyer-Rendelsmann & Hans van Tartwijk)	
16	Format, References and Annex & Implement feedback
17	Implement Feedback
18	Print

Resources

To carry out this research a computer with internet connection is needed for scientific article as well as e-mail contact to involved parties (Mrs Dreyer-Rendelsmann & Coach: Hans van Tartwijk).

An additionally resource is an available car and money to pay petrol costs which are required to enable meetings with the contracting party and thesis coach. This is also important to ensure for the measurement day to get the measurement people as well as devices from stable to stable.

Furthermore for the measurement all cheap measurement devices are required therefore money is needed. Additionally a kitchen is required to execute the measurements which are not operated at the surface location.

References

Cover picture: provided by Querkant-Images.de – Melanie Block

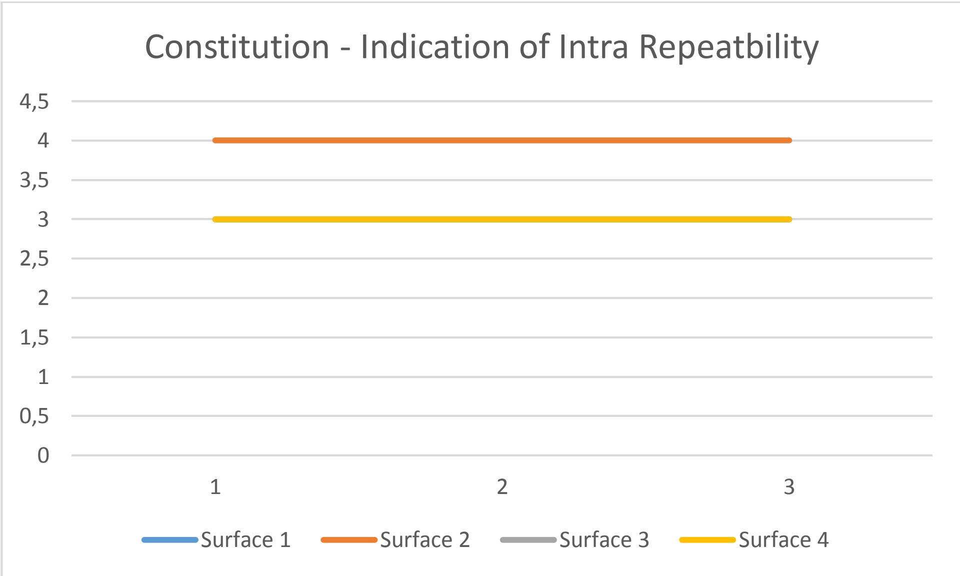
Dreyer-Rendelsmann, Cornelia (2013): *Reitplatzbau – kein Buch mit sieben Siegeln*. Literatur. Not yet published.

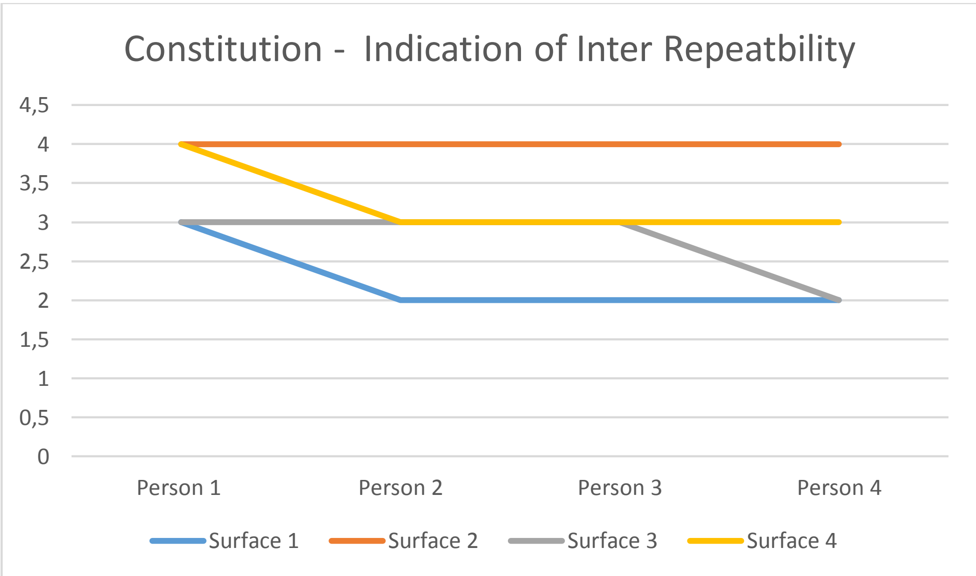
Helleberg-Rhode, Gesine; Otto, Karl-Heinz (2002): *HyperSoil – Entwicklung einer hypermedialen Lern- und Arbeitsumgebung zum Themenfeld "Boden" im (Sach-)Unterricht*. Online. Available: http://hypersoil.uni-muenster.de

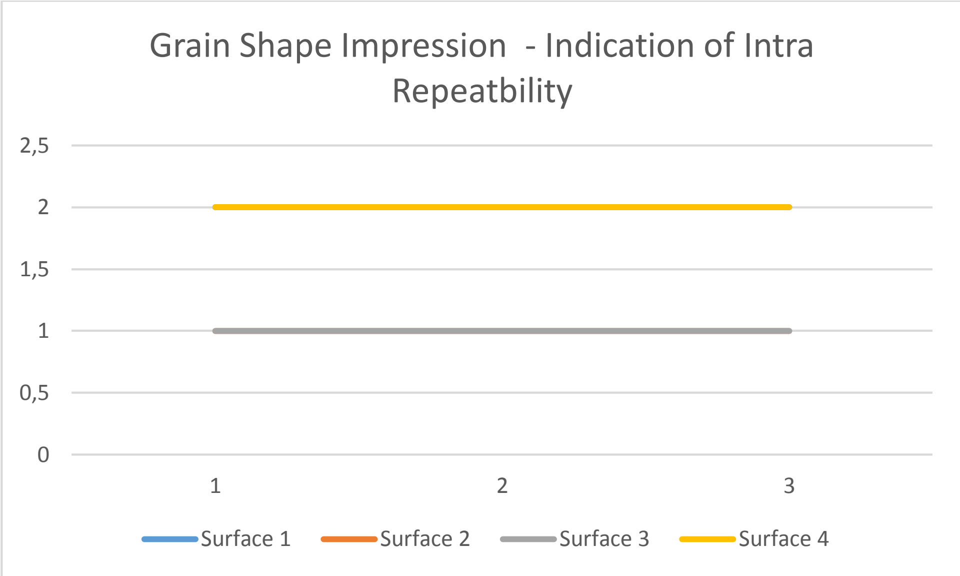
Peterson, Micheal; Roepstorff, Lars; Thomason Jeffery J.; Mahaffey, Christie (2012): *Racing Surfaces: Current progress and future challenges to optimize consistency and performance of track surfaces for fewer horse injuries.* Online. Available: www.grayson-jockeyclub.org/resources/White_Paper_04272012.pdf

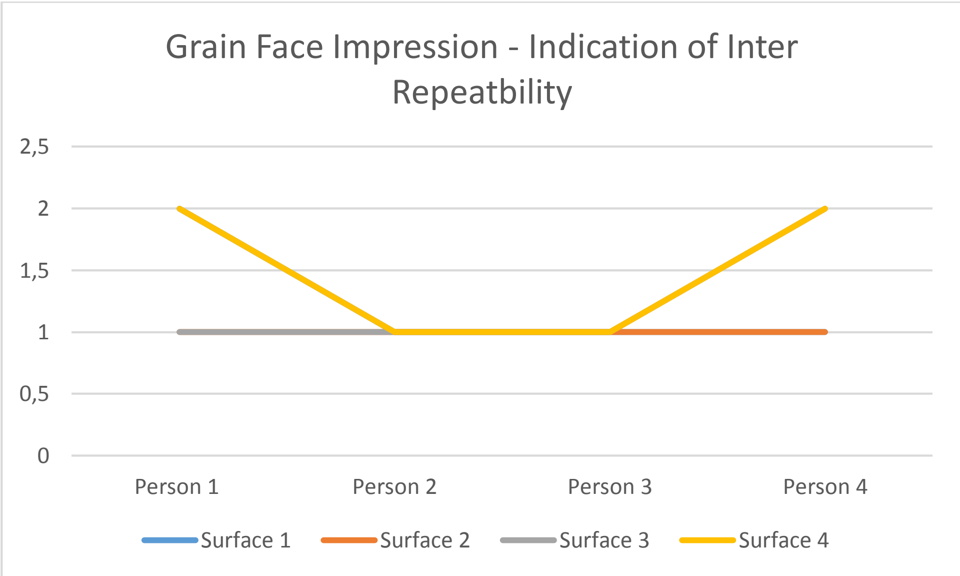
7.5 All Drawn Graphs for the Evaluation of the Measurement Concept

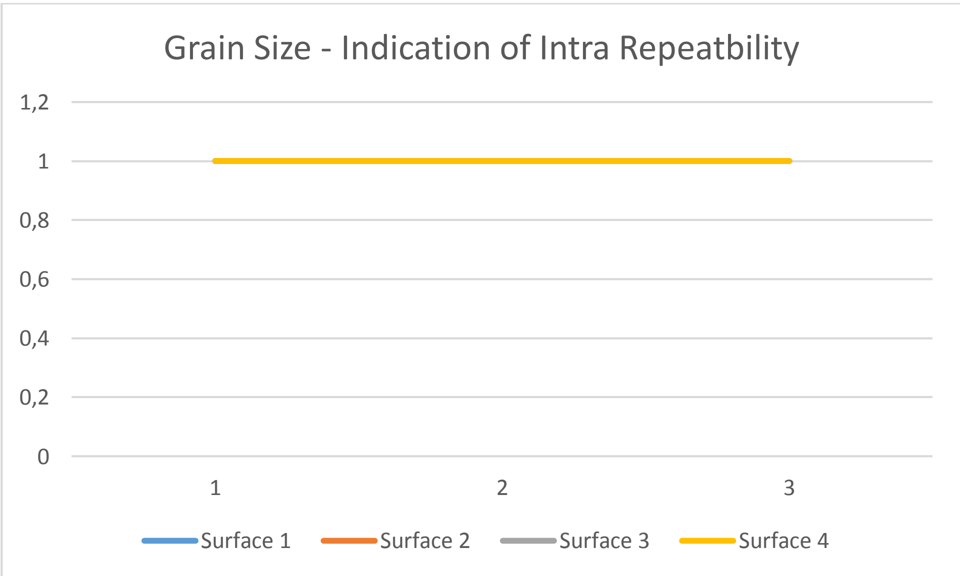
7.5.1 First Impression

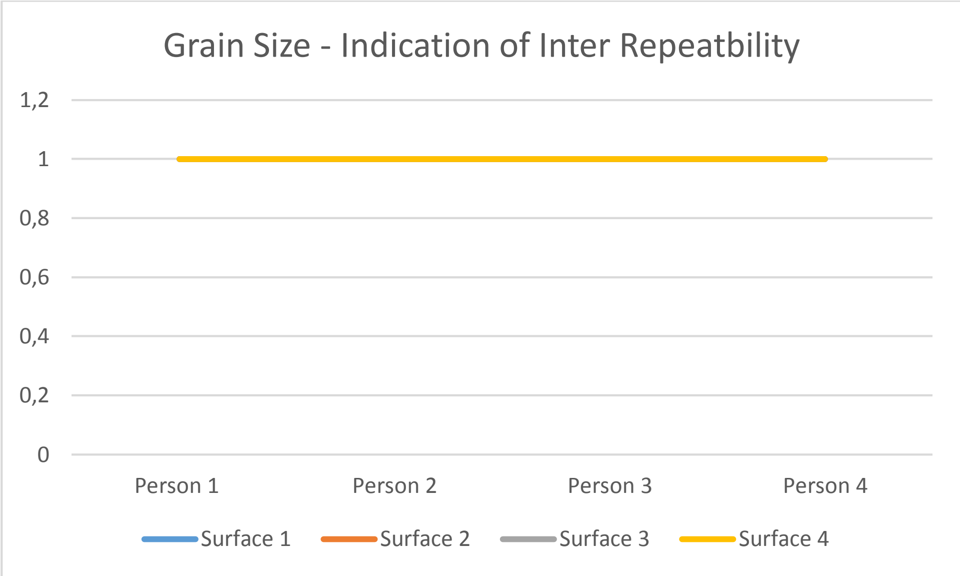




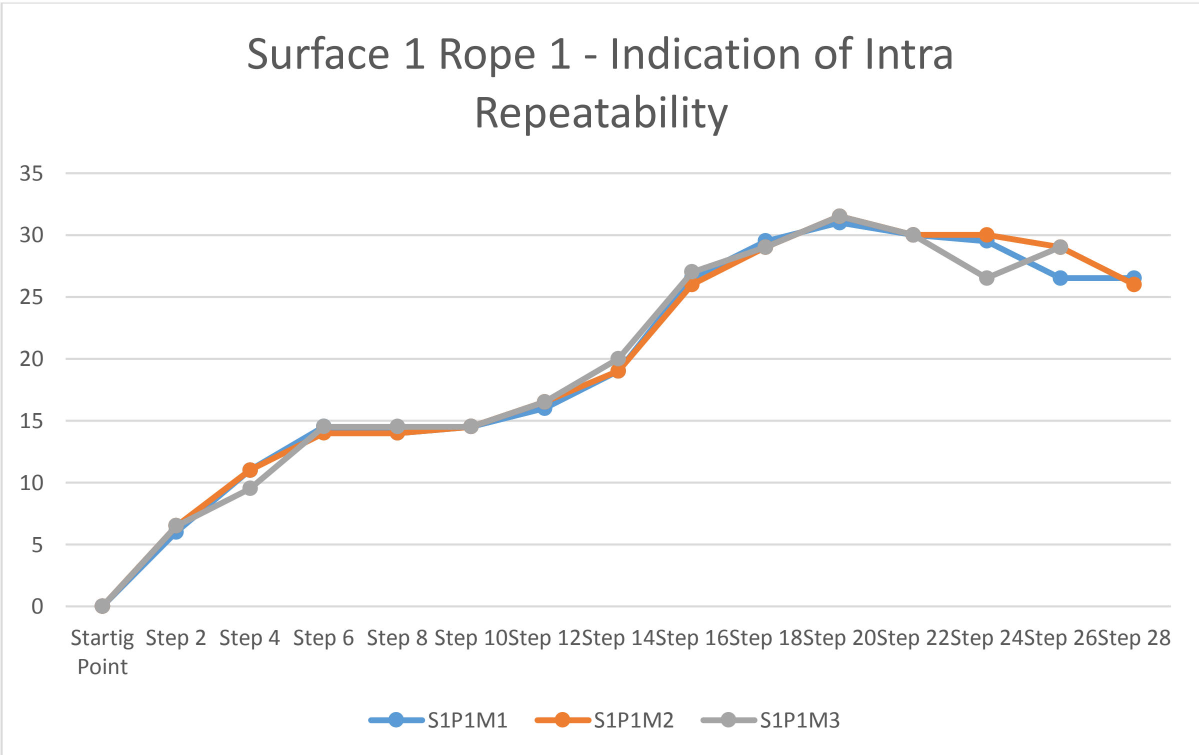

Grain Shape Impression - Indication of Intra Repeatbility
2,5
2
1,5
1
0,5
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4

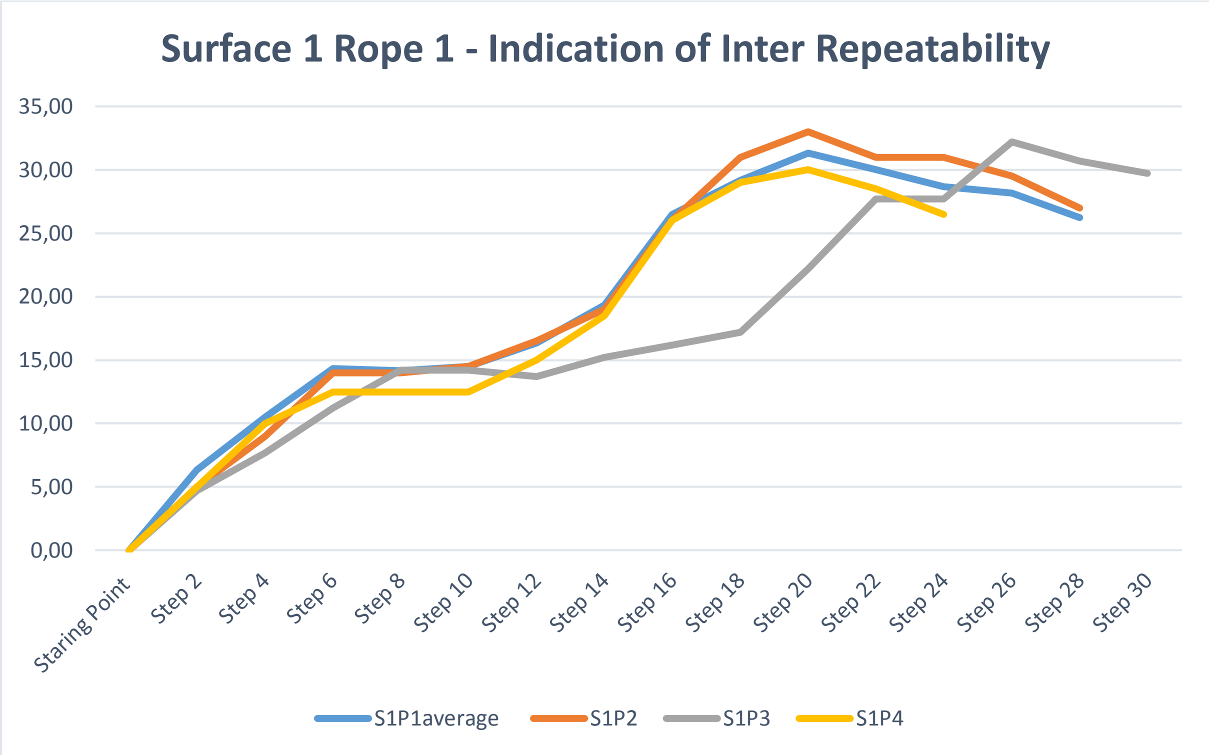

Grain Face Impression - Indication of Inter Repeatbility
2,5
2
1,5
1
0,5
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

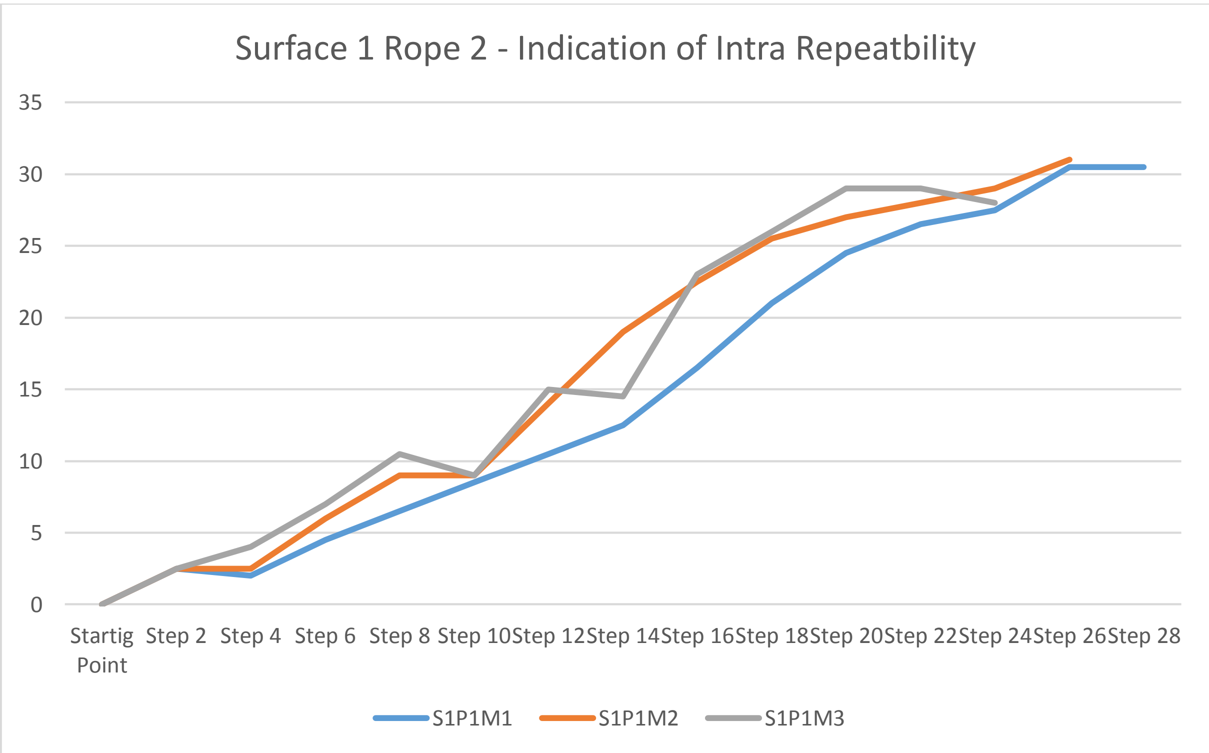

Grain Size - Indication of Intra Repeatbility
1,2
1
0,8
0,6
0,4
0,2
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4

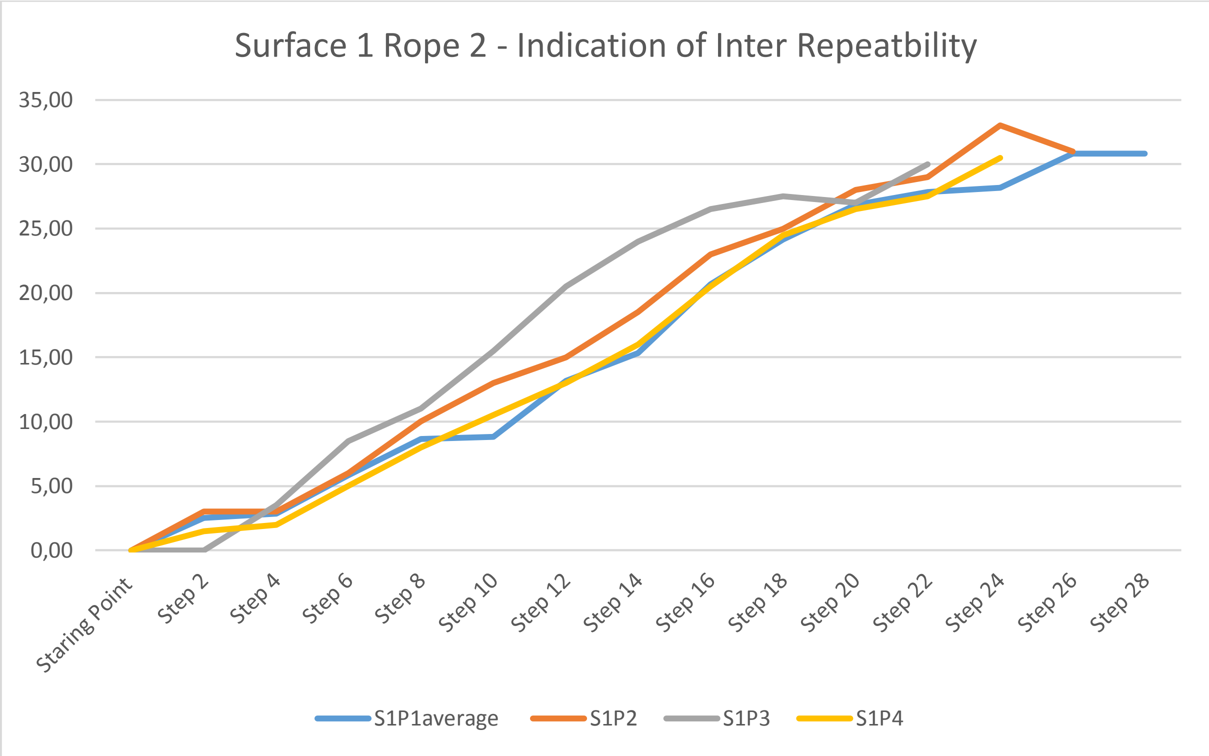


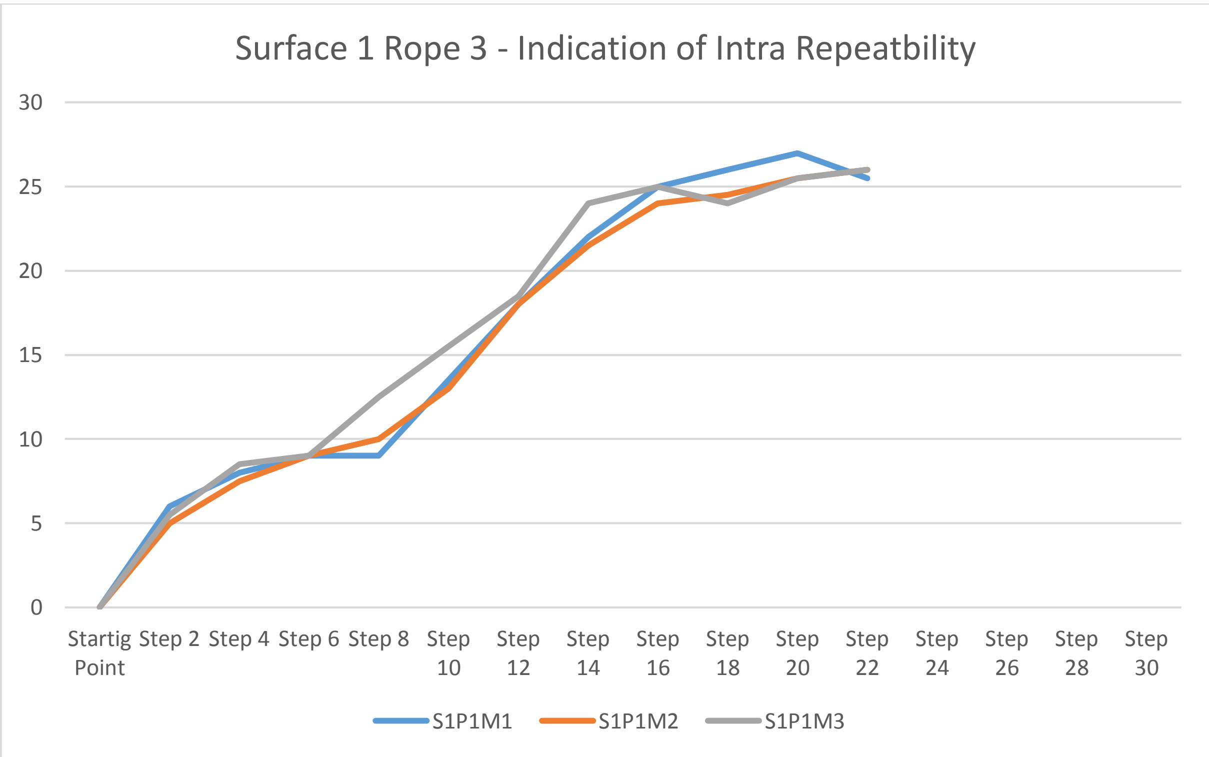
7.5.2 Height/Incline

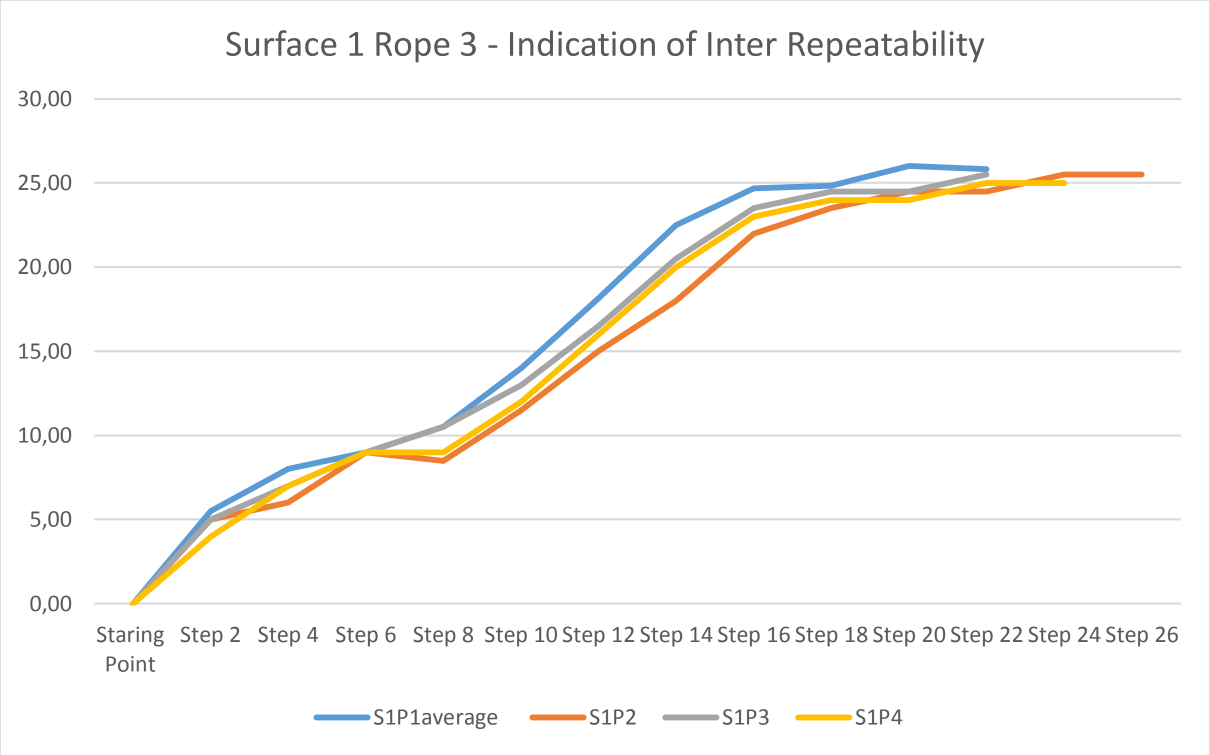


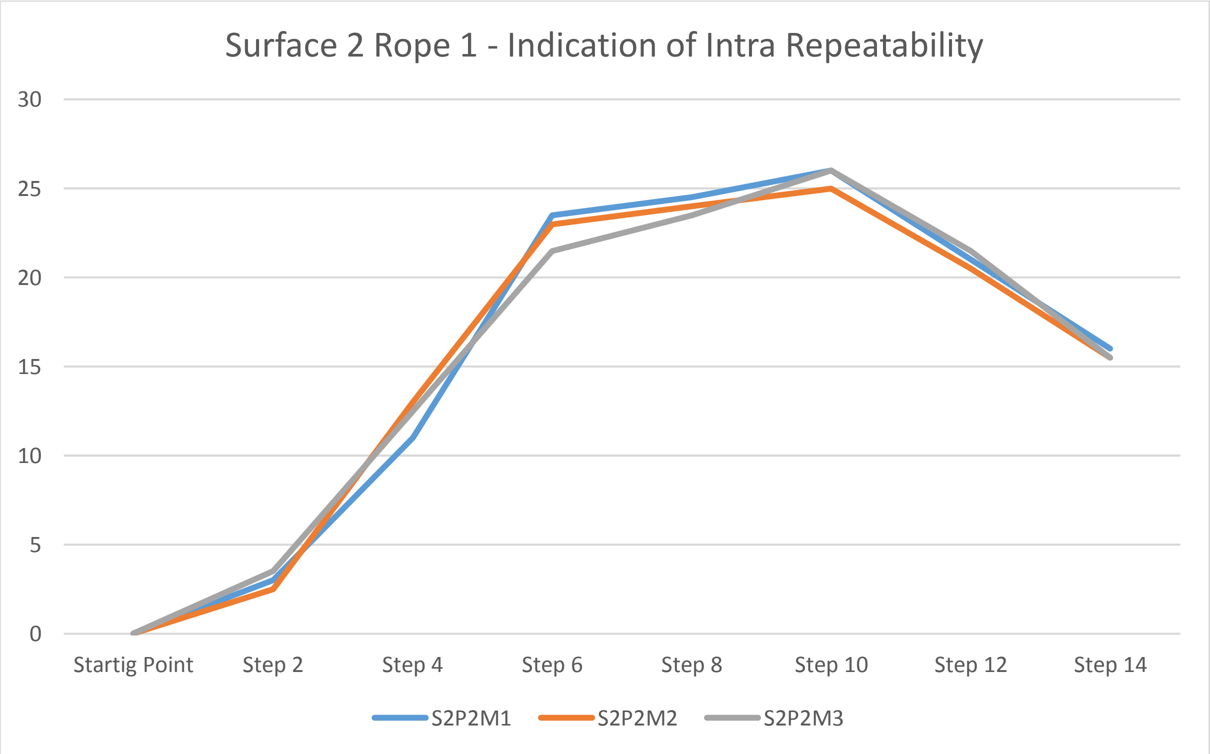

Surface 1 Rope 1 - Indication of Inter Repeatability
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
Staring Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
Step 20
Step 22
Step 24
Step 26
Step 28
Step 30
S1P1average
S1P2
S1P3
S1P4

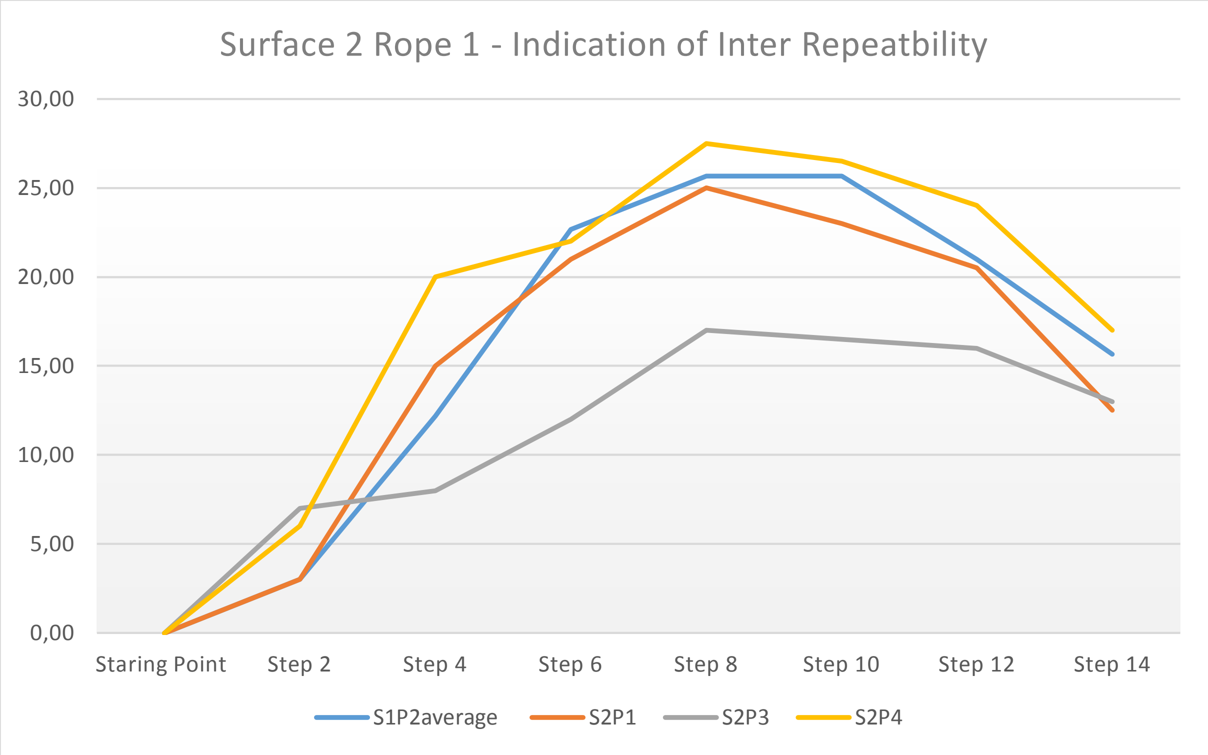

Surface 1 Rope 2 - Indication of Intra Repeatbility
35
30
25
20
15
10
5
0
Startig Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
Step 20
Step 22
Step 24
Step 26
Step 28
S1P1M1
S1P1M2
S1P1M3

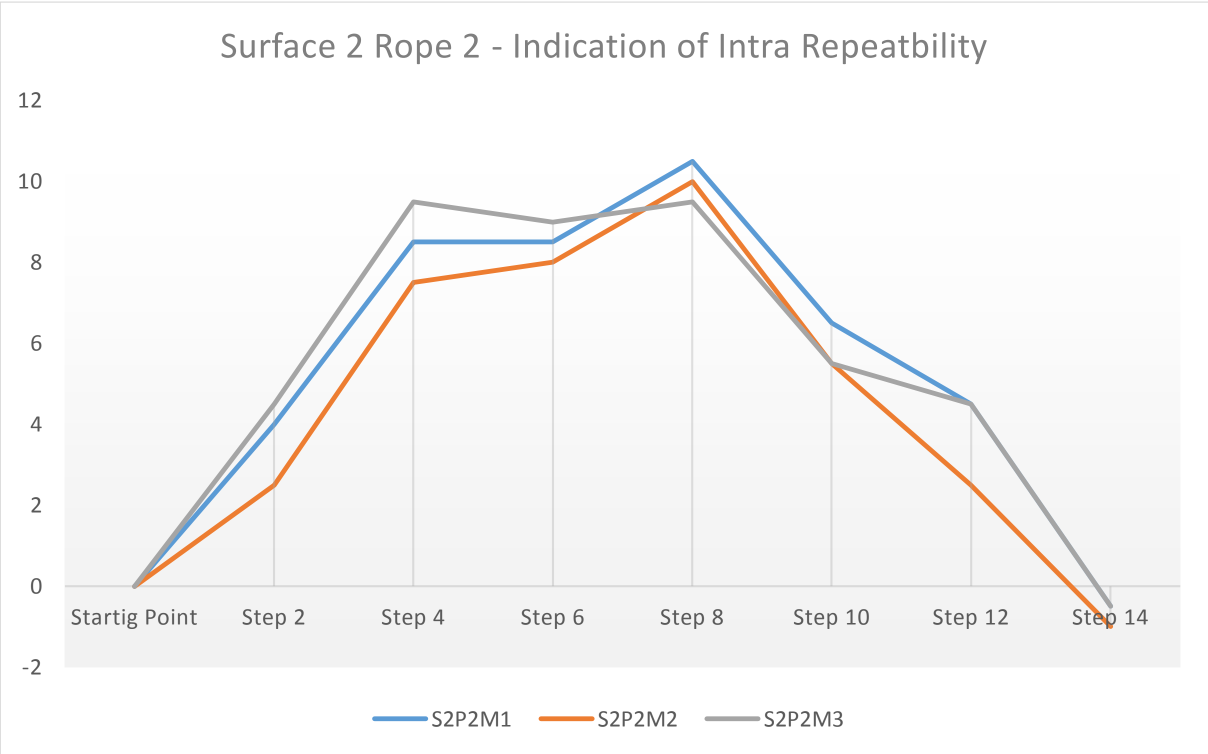

Surface 1 Rope 2 - Indication of Inter Repeatbility
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
Staring Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
Step 20
Step 22
Step 24
Step 26
Step 28
S1P1average
S1P2
S1P3
S1P4

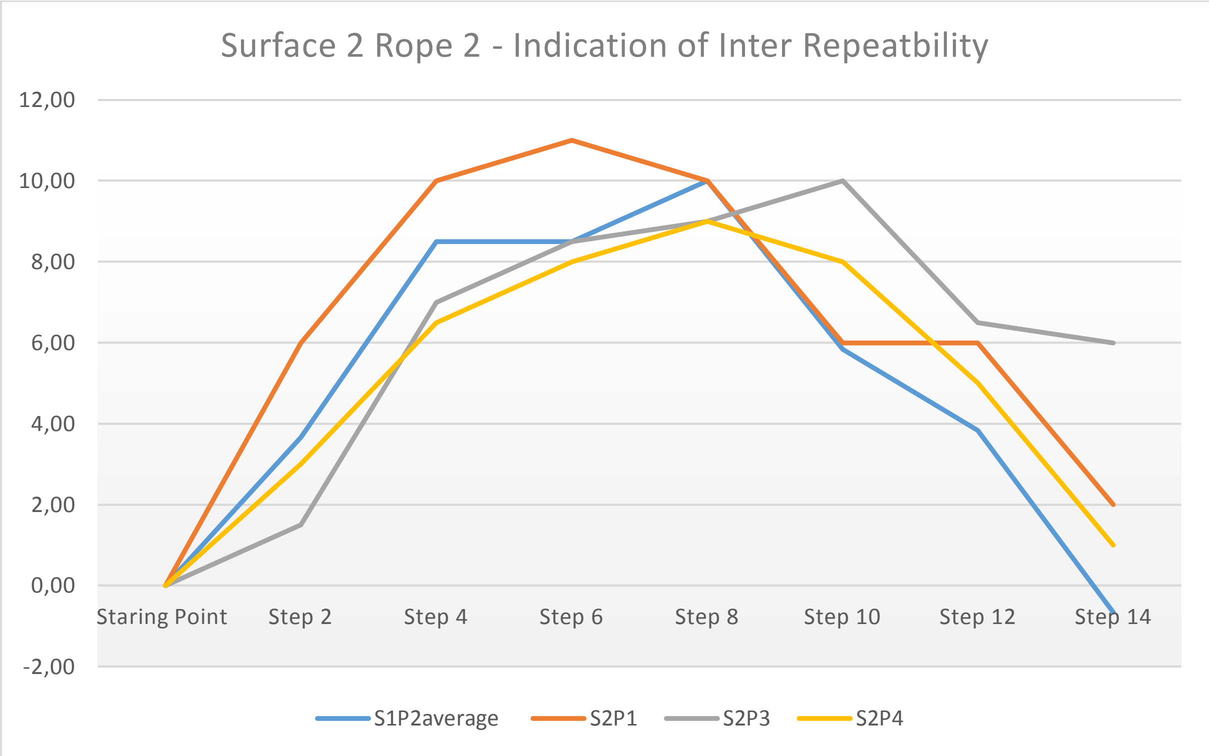

Surface 1 Rope 3 - Indication of Intra Repeatbility
30
25
20
15
10
5
0
Startig Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
Step 20
Step 22
Step 24
Step 26
Step 28
Step 30
S1P1M1
S1P1M2
S1P1M3

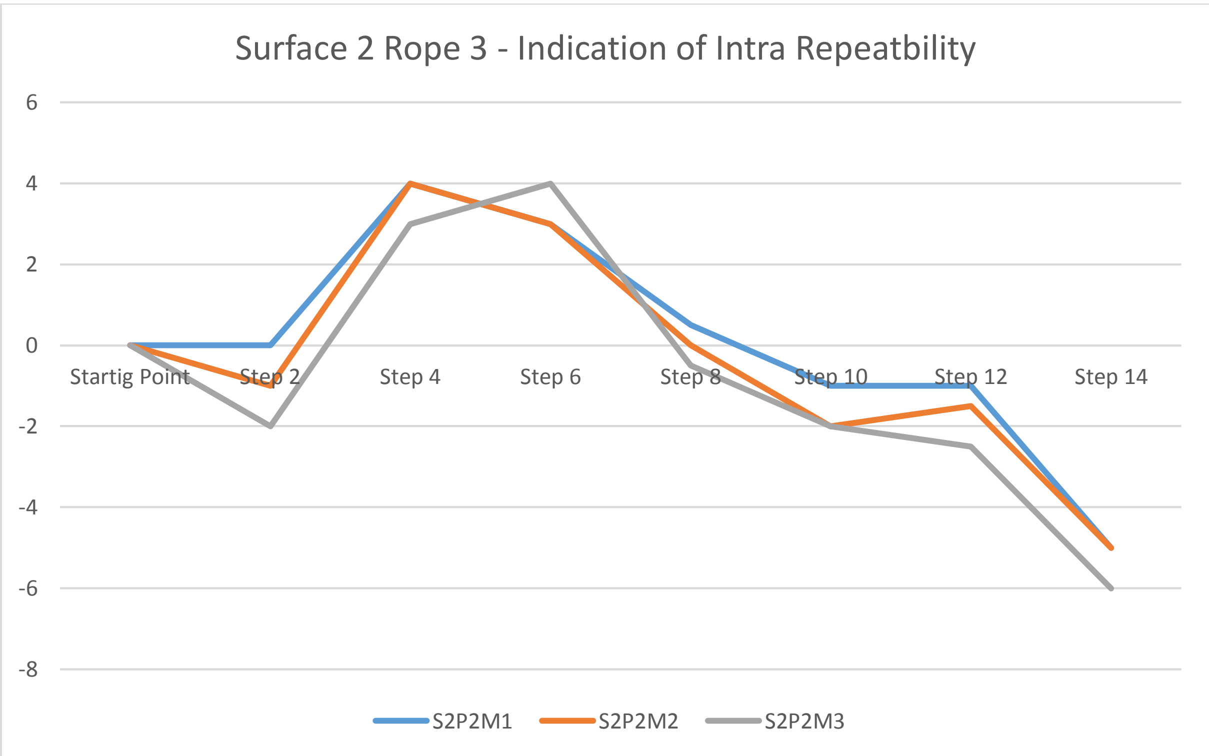

Surface 1 Rope 3 - Indication of Inter Repeatability
30,00
25,00
20,00
15,00
10,00
5,00
0,00
Staring Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
Step 20
Step 22
Step 24
Step 26
S1P1average
S1P2
S1P3
S1P4

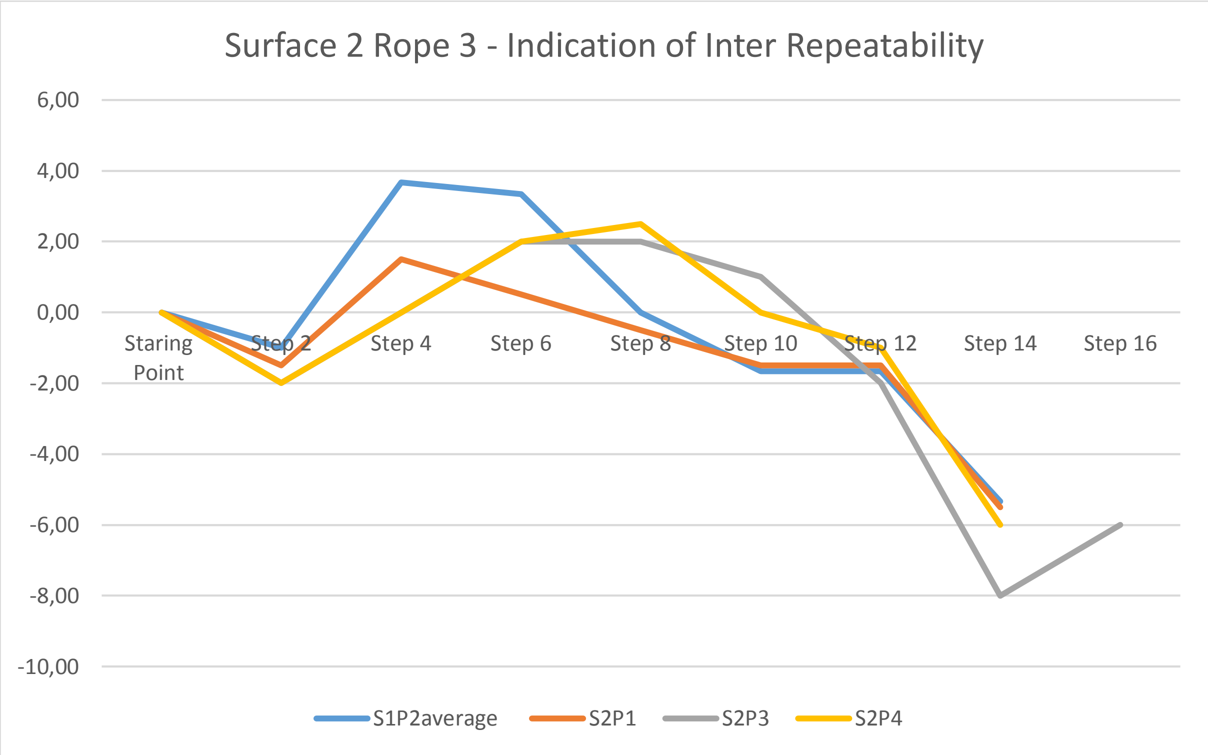

Surface 2 Rope 1 - Indication of Intra Repeatability
30
25
20
15
10
5
0
Startig Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
S2P2M1
S2P2M2
S2P2M3

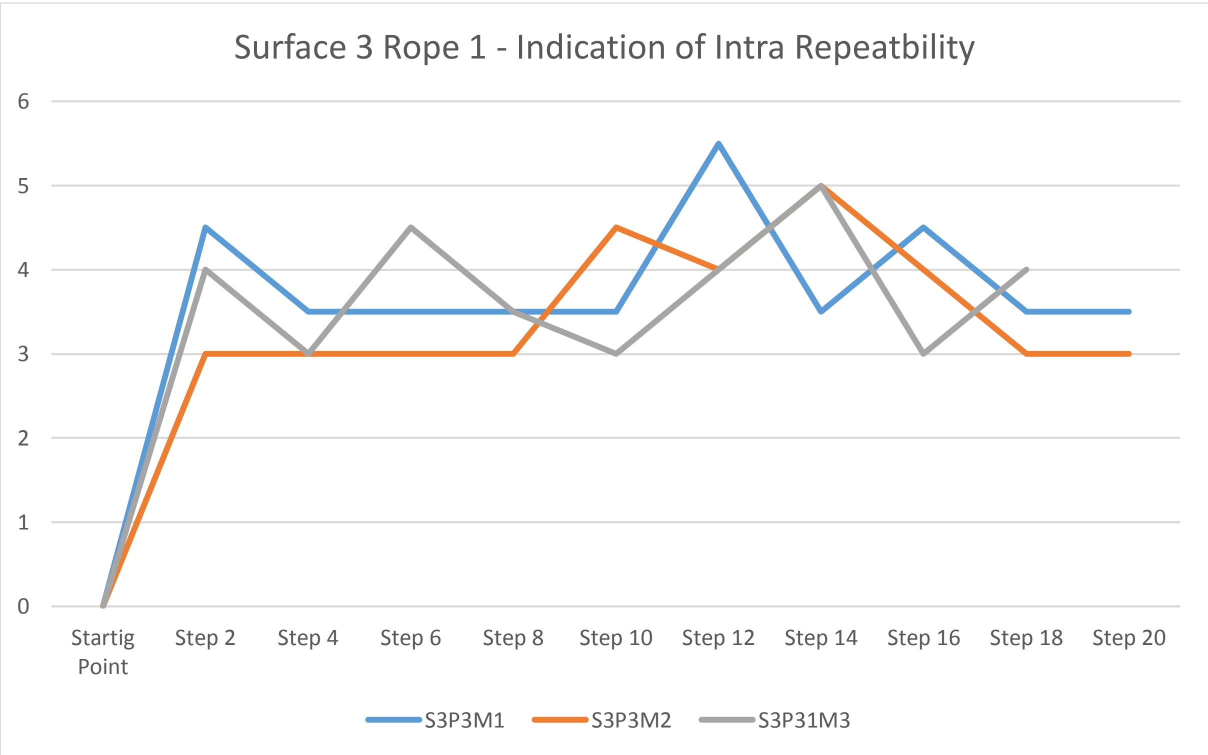

Surface 2 Rope 1 - Indication of Inter Repeatbility
30,00
25,00
20,00
15,00
10,00
5,00
0,00
Staring Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
S1P2average
S2P1
S2P3
S2P4

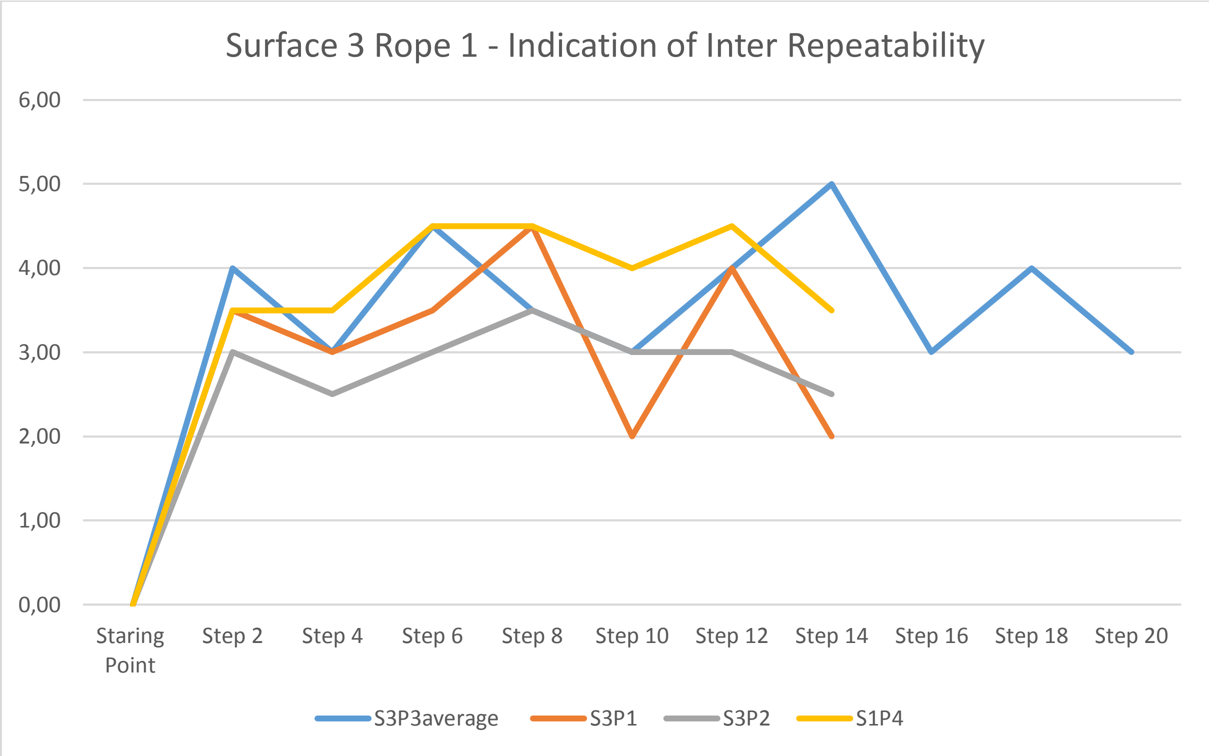

Surface 2 Rope 2 - Indication of Intra Repeatbility
12
10
8
6
4
2
0
-2
Startig Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
S2P2M1
S2P2M2
S2P2M3

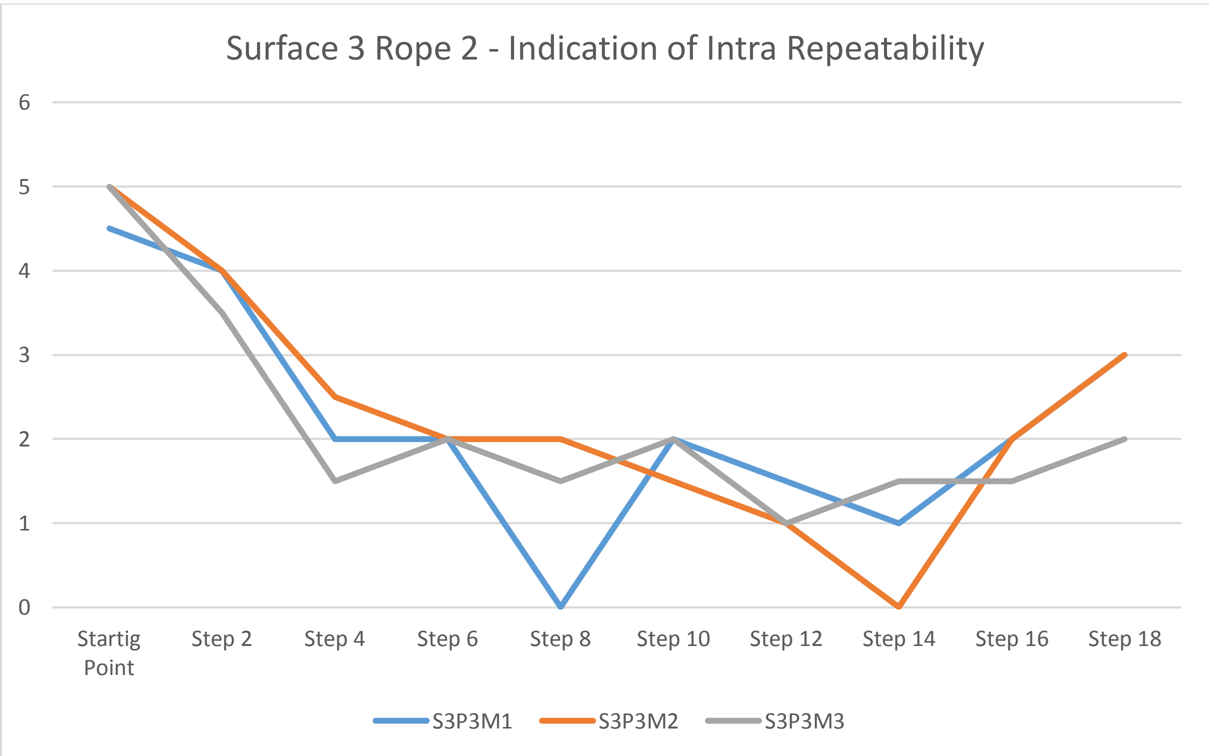

Surface 2 Rope 2 - Indication of Inter Repeatbility
12,00
10,00
8,00
6,00
4,00
2,00
0,00
-2,00
Staring Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
S1P2average
S2P1
S2P3
S2P4

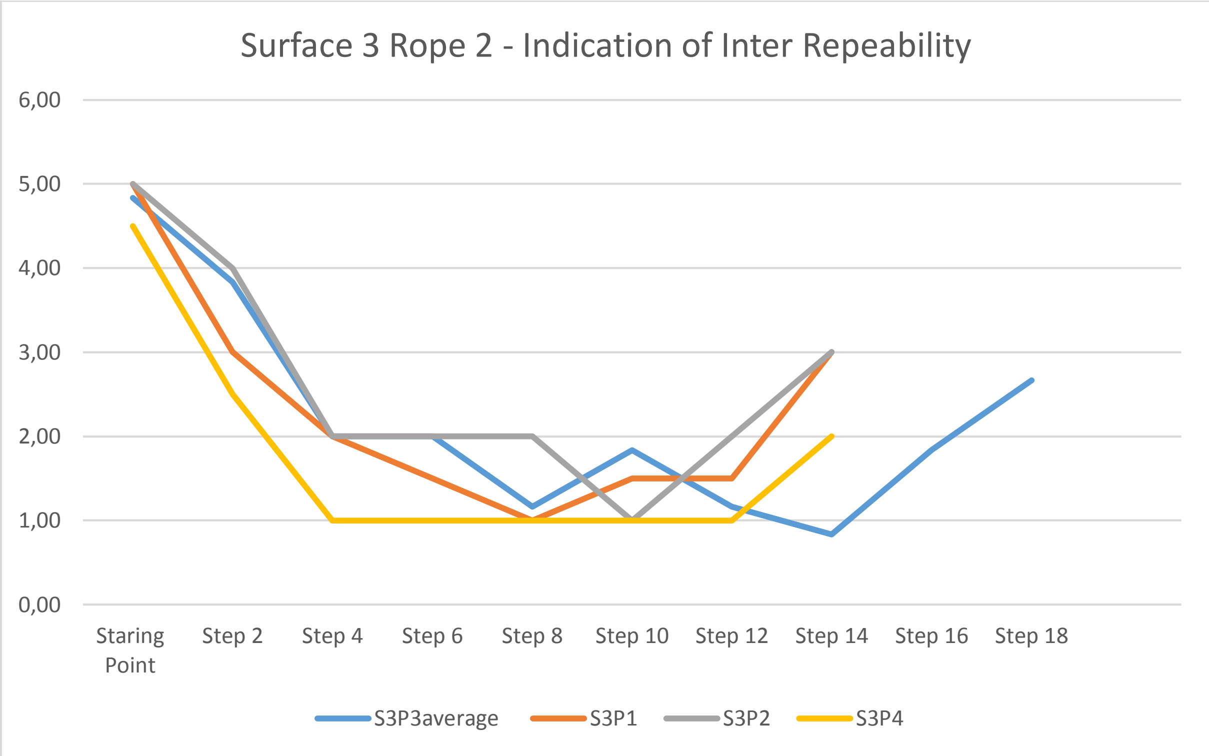

Surface 2 Rope 3 - Indication of Intra Repeatbility
6
4
2
0
-2
-4
-6
-8
Startig Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
S2P2M1
S2P2M2
S2P2M3

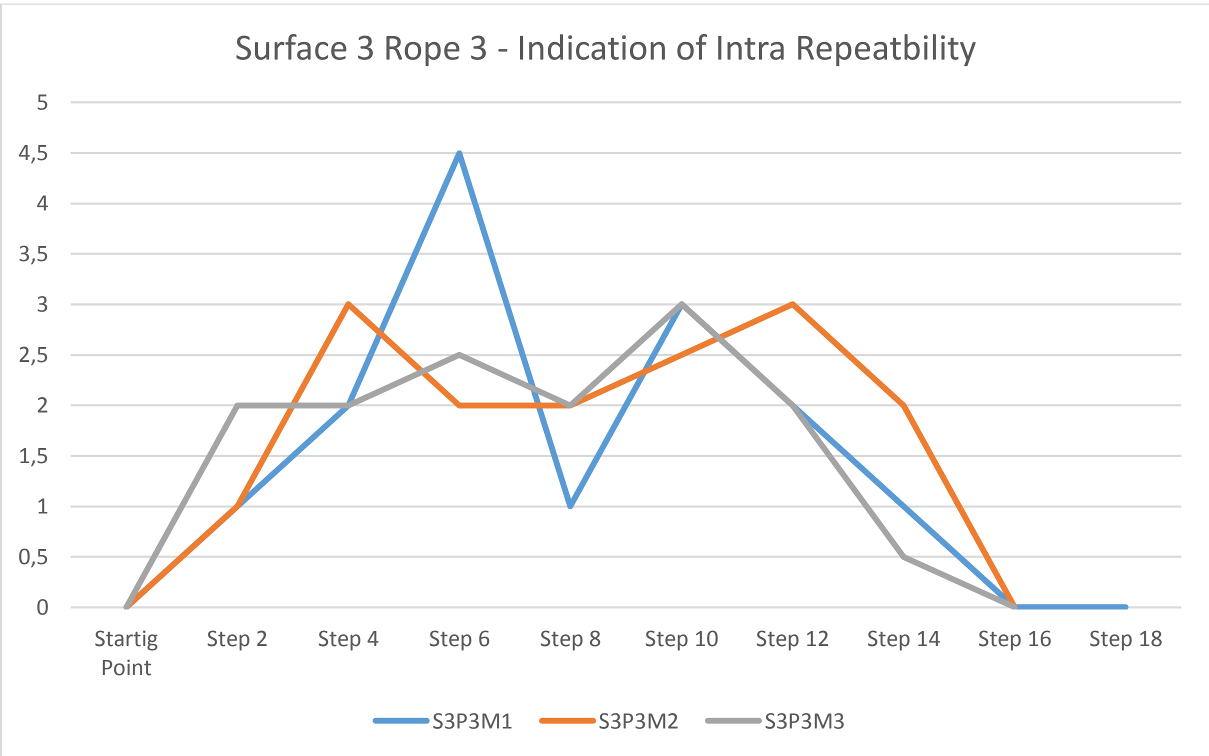

Surface 2 Rope 3 - Indication of Inter Repeatability
6,00
4,00
2,00
0,00
-2,00
-4,00
-6,00
-8,00
-10,00
Staring Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
S1P2average
S2P1
S2P3
S2P4

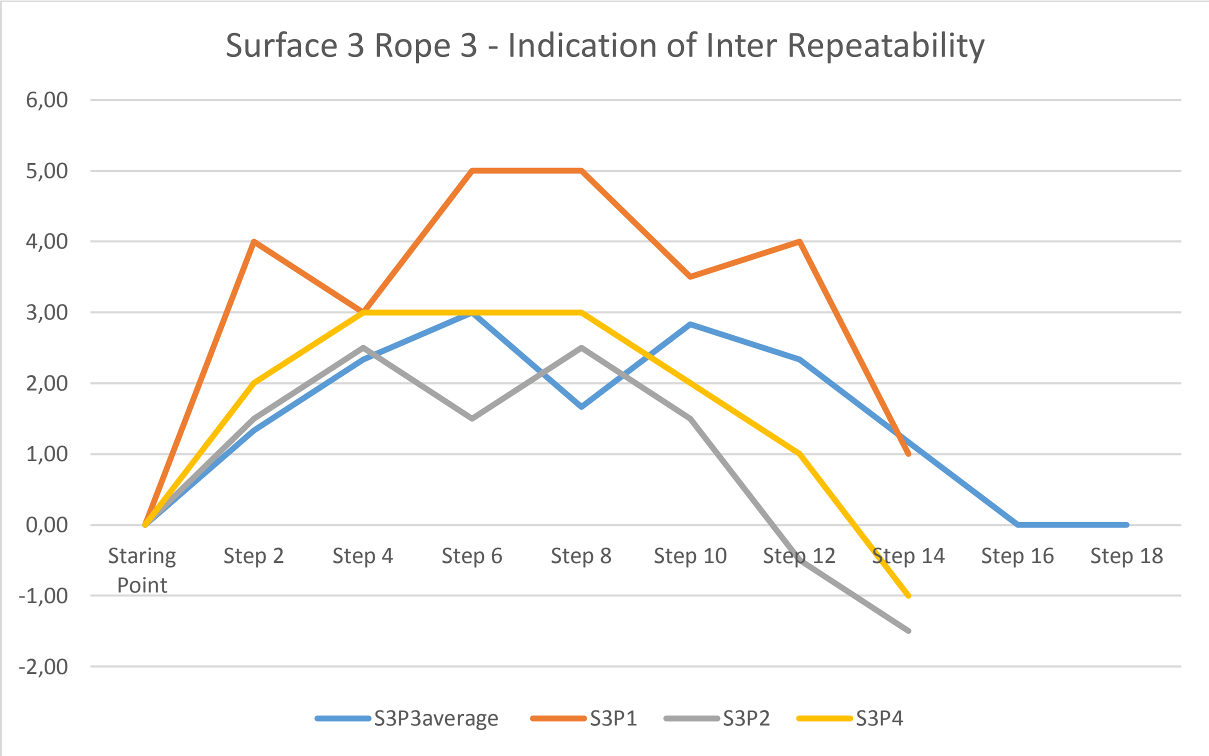

Surface 3 Rope 1 - Indication of Intra Repeatbility
6
5
4
3
2
1
0
Startig Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
Step 20
S3P3M1
S3P3M2
S3P31M3

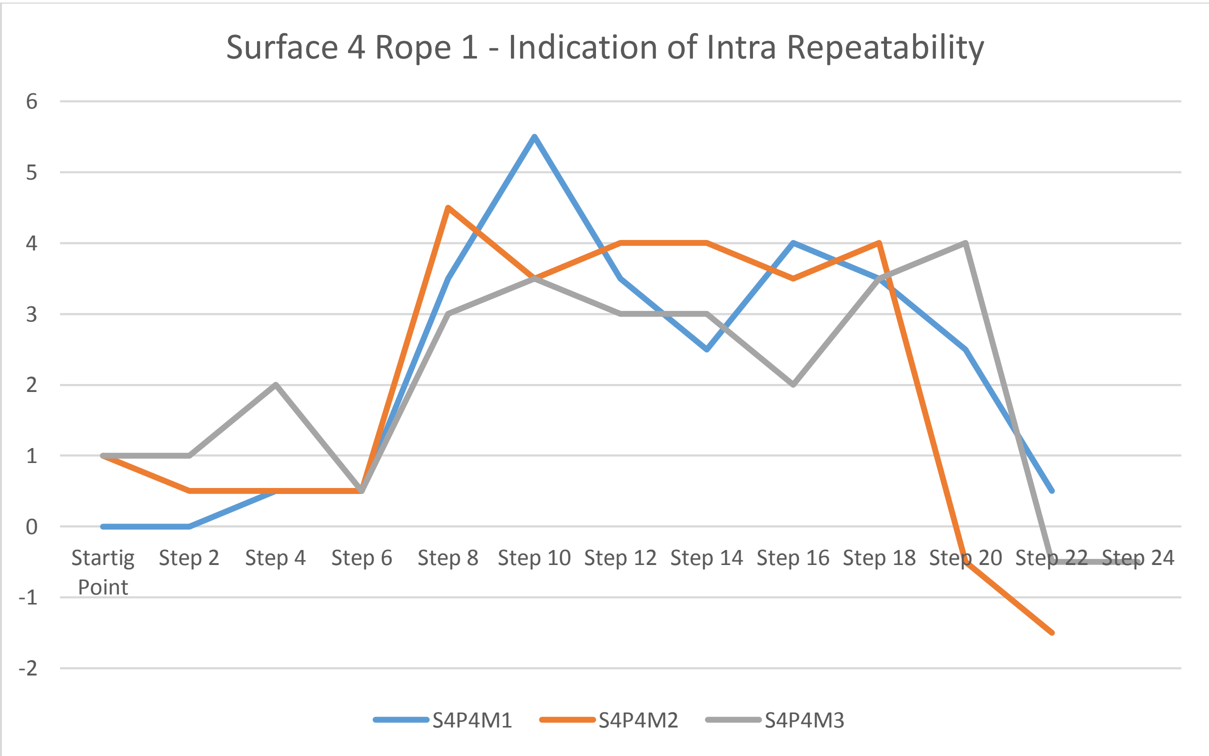

Surface 3 Rope 1 - Indication of Inter Repeatability
6,00
5,00
4,00
3,00
2,00
1,00
0,00
Staring Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
Step 20
S3P3average
S3P1
S3P2
S1P4


Surface 3 Rope 2 - Indication of Intra Repeatability
6
5
4
3
2
1
0
Startig Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
S3P3M1
S3P3M2
S3P3M3

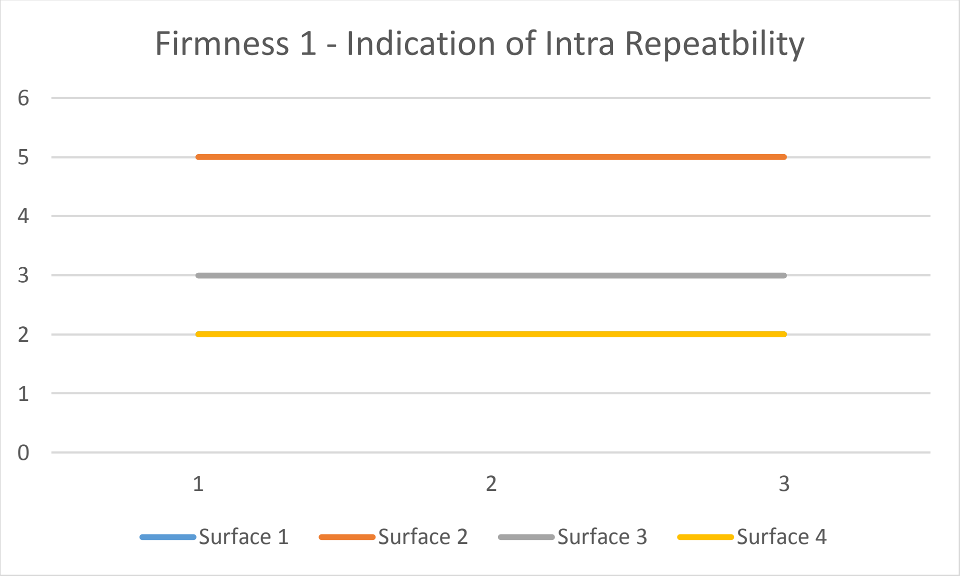

Surface 3 Rope 2 - Indication of Inter Repeability
6,00
5,00
4,00
3,00
2,00
1,00
0,00
Staring Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
S3P3average
S3P1
S3P2
S3P4

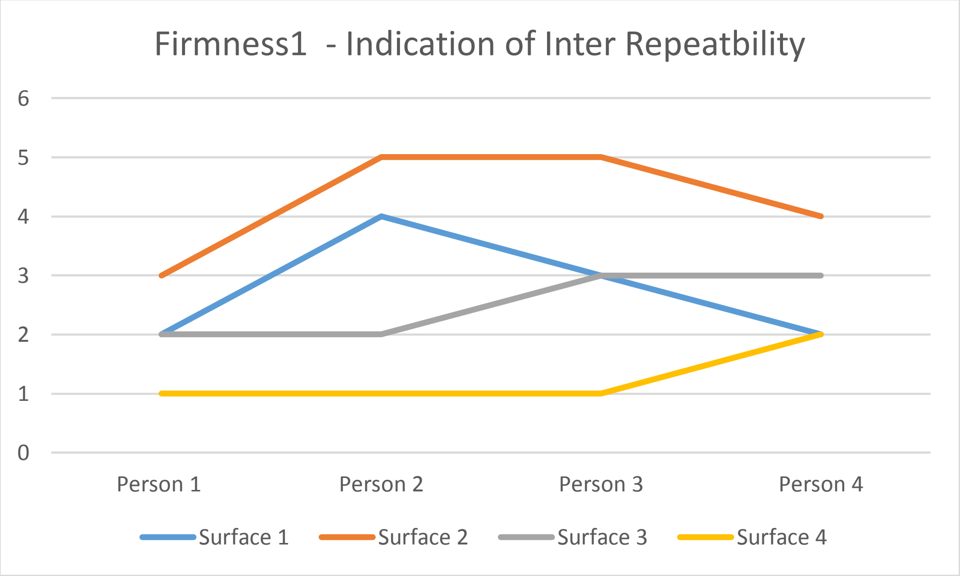

Surface 3 Rope 3 - Indication of Intra Repeatbility
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
Startig Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
S3P3M1
S3P3M2
S3P3M3

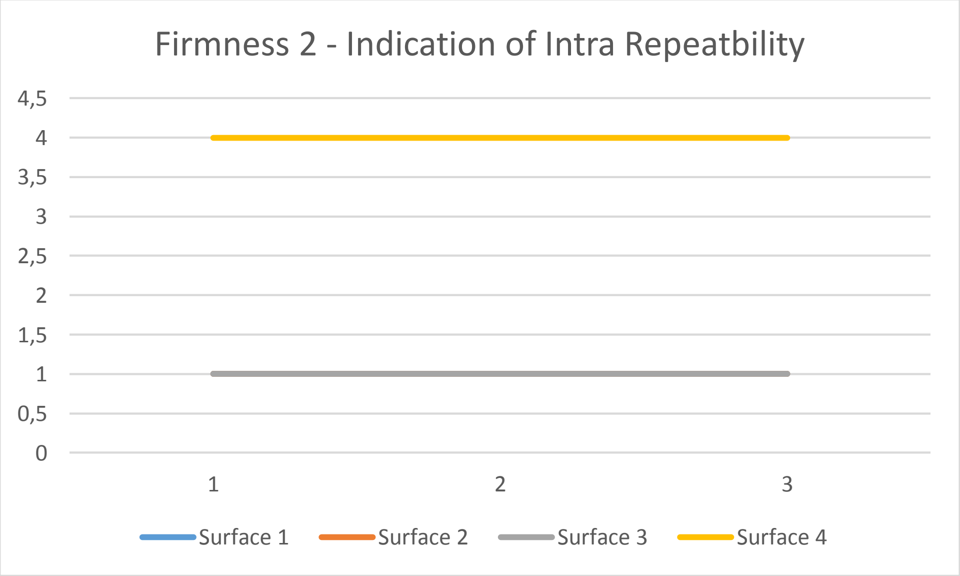

Surface 3 Rope 3 - Indication of Inter Repeatability
6,00
5,00
4,00
3,00
2,00
1,00
0,00
-1,00
-2,00
Staring Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
S3P3average
S3P1
S3P2
S3P4

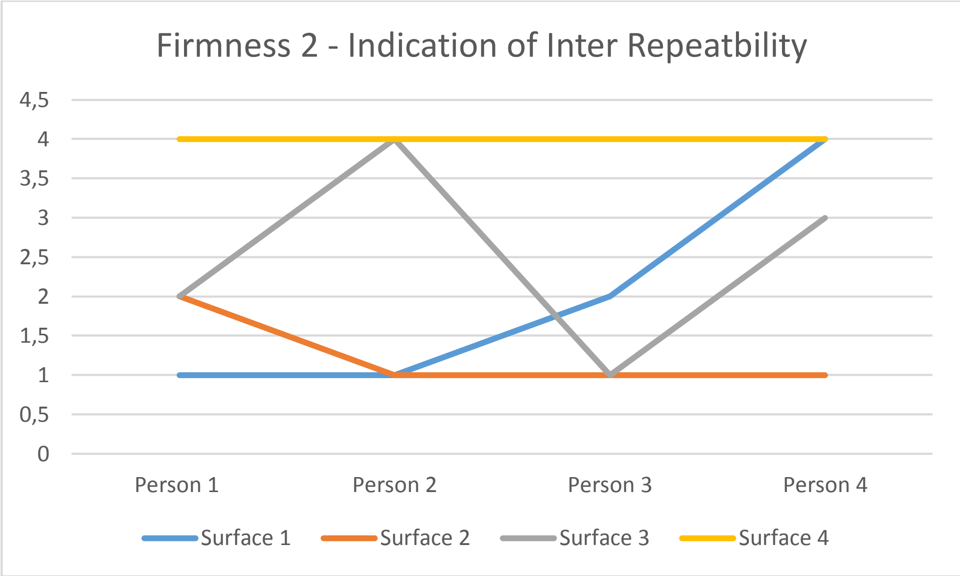

Surface 4 Rope 1 - Indication of Intra Repeatability
6
5
4
3
2
1
0
-1
-2
Startig Point
Step 2
Step 4
Step 6
Step 8
Step 10
Step 12
Step 14
Step 16
Step 18
Step 20
Step 22
Step 24
S4P4M1
S4P4M2
S4P4M3

7.5.3 Firmness

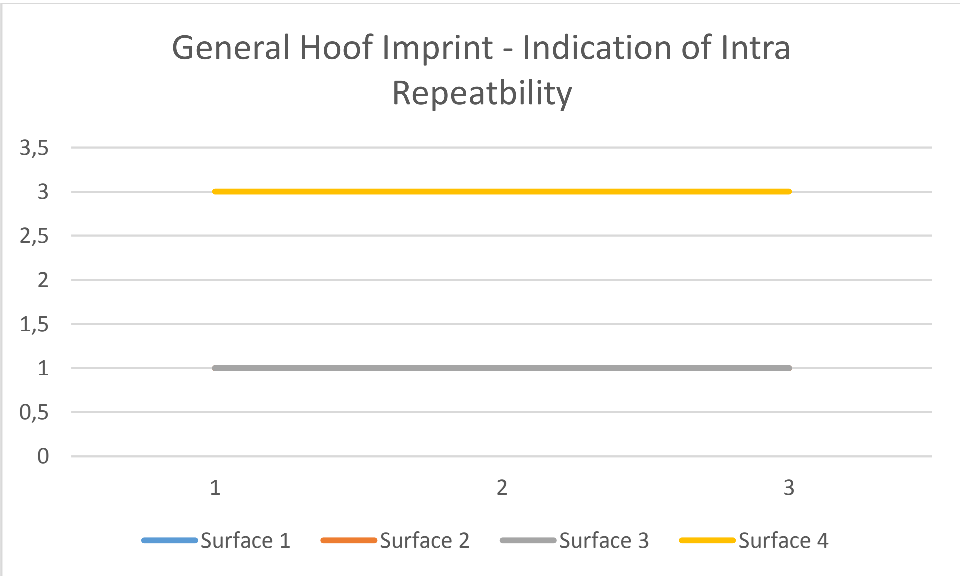


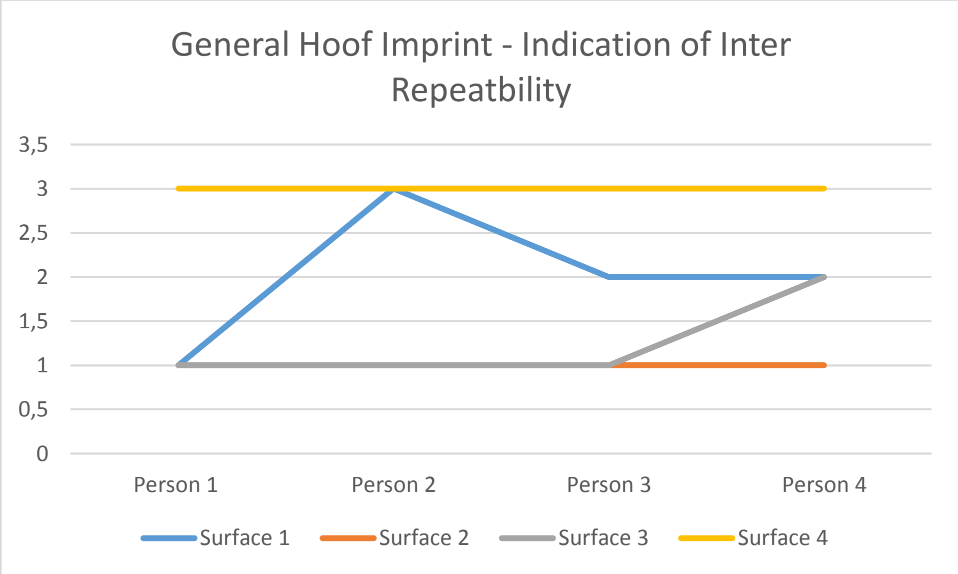


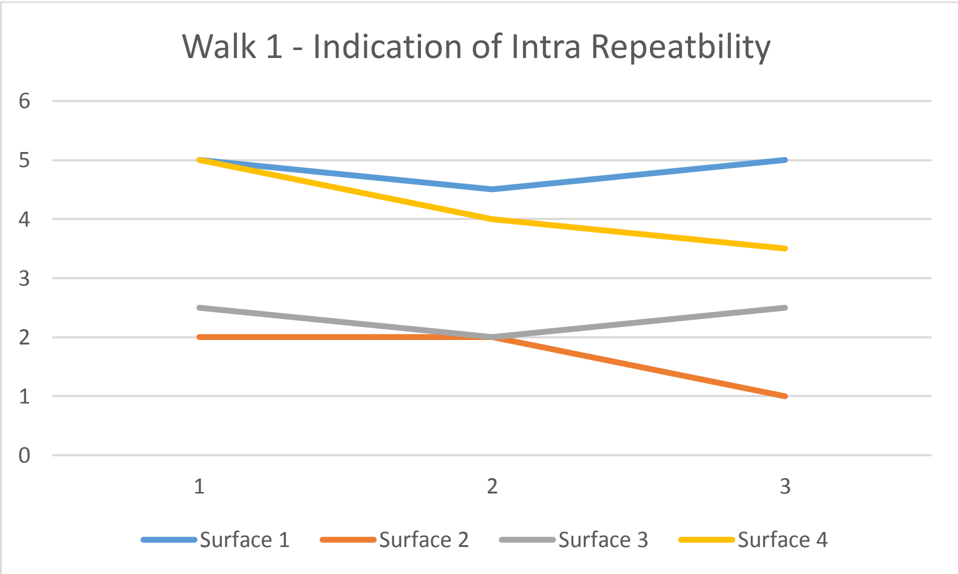


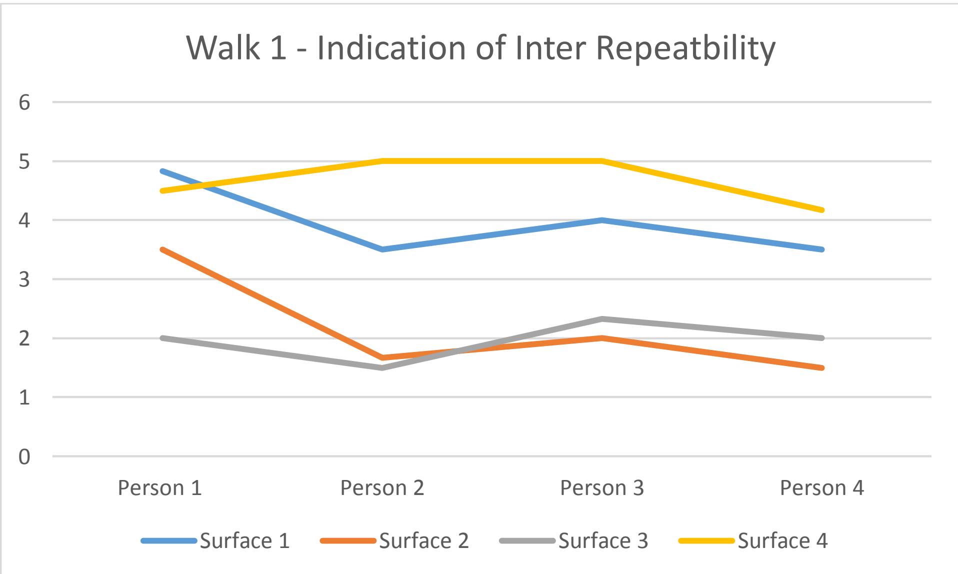


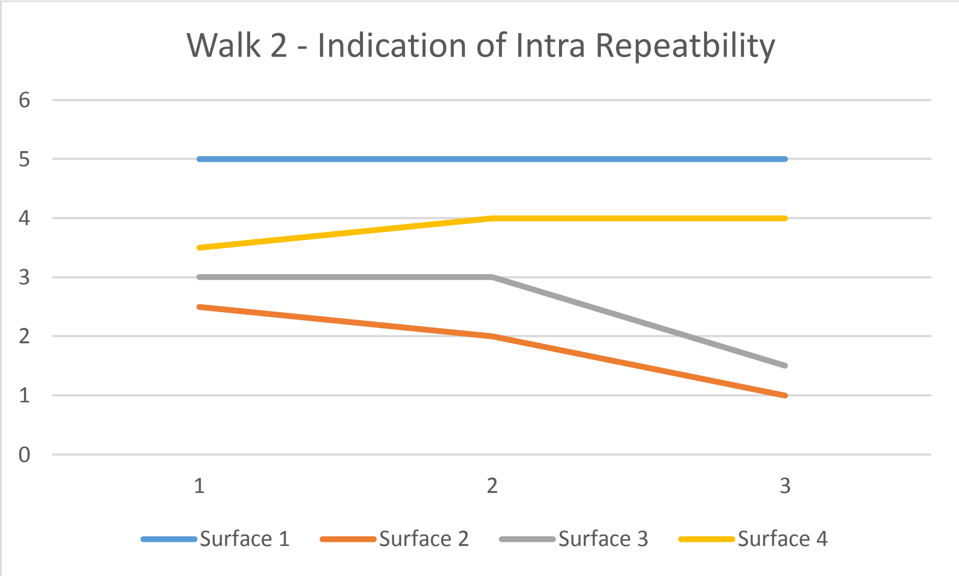
7.5.4 Penetration Depth/Hoof Imprint

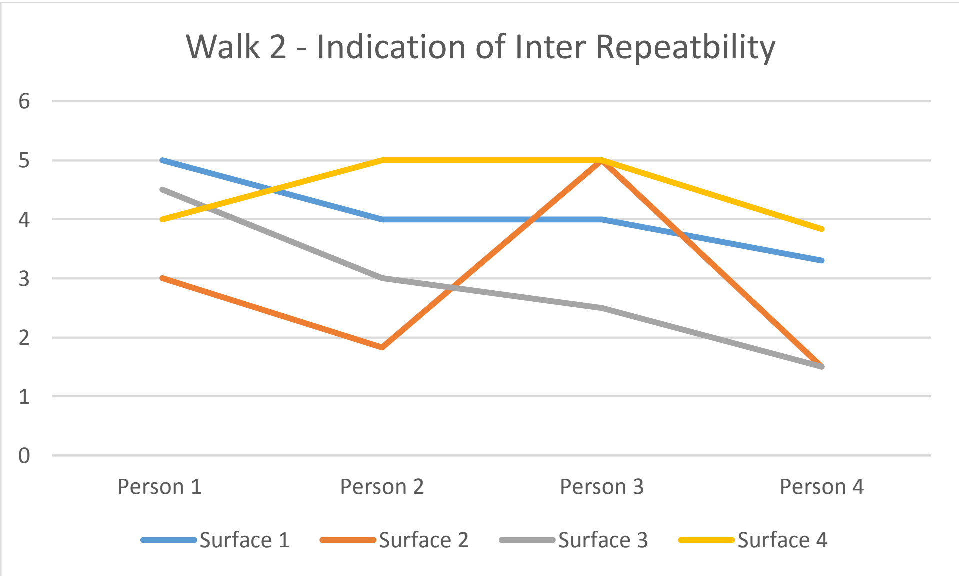


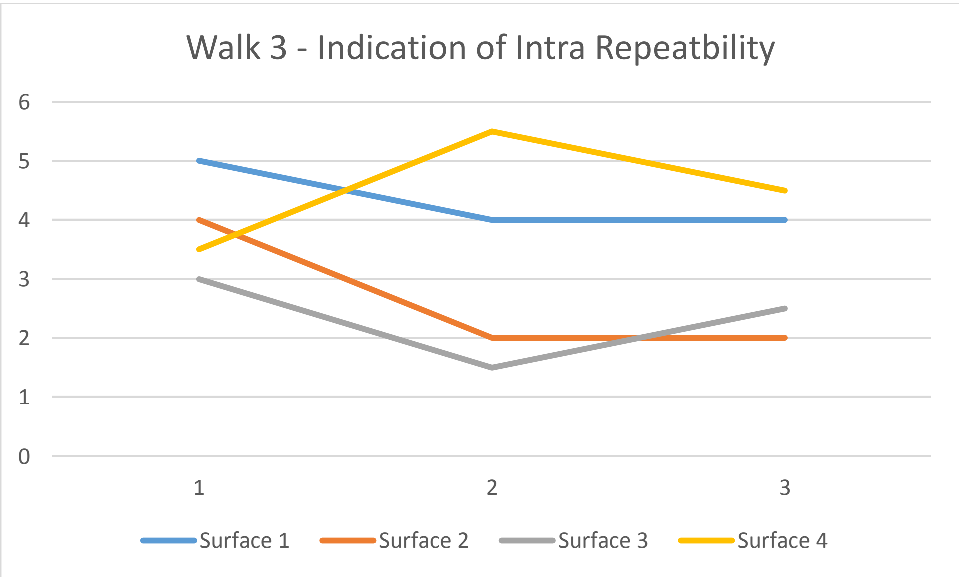

General Hoof Imprint - Indication of Inter Repeatbility
3,5
3
2,5
2
1,5
1
0,5
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

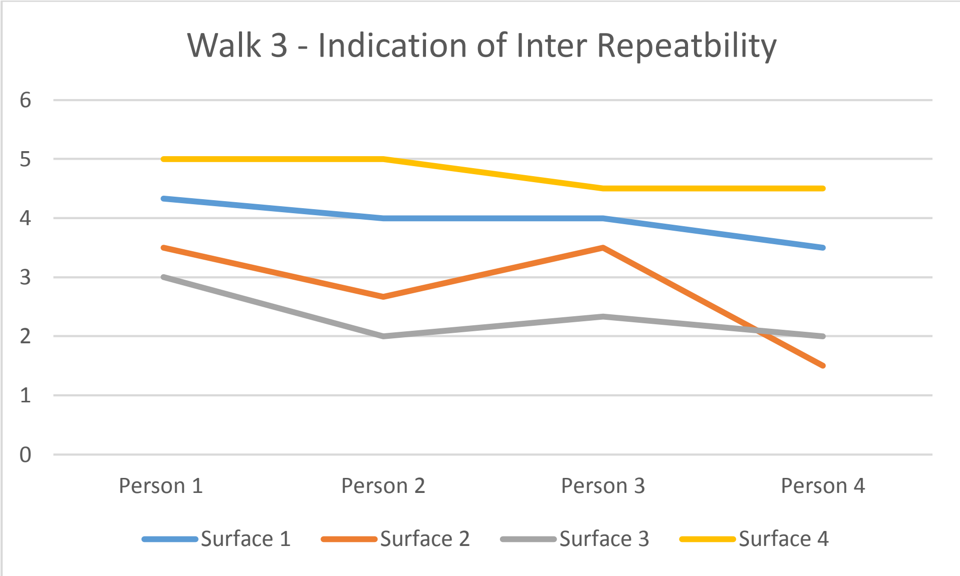

Walk 1 - Indication of Intra Repeatbility
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4


Walk 1 - Indication of Inter Repeatbility
6
5
4
3
2
1
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

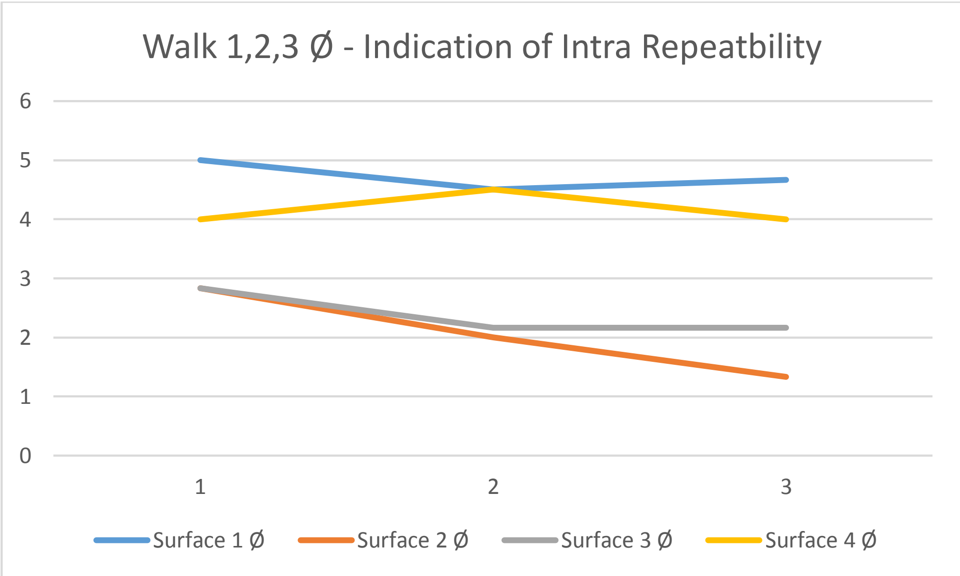

Walk 2 - Indication of Intra Repeatbility
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4


Walk 2 - Indication of Inter Repeatbility
6
5
4
3
2
1
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

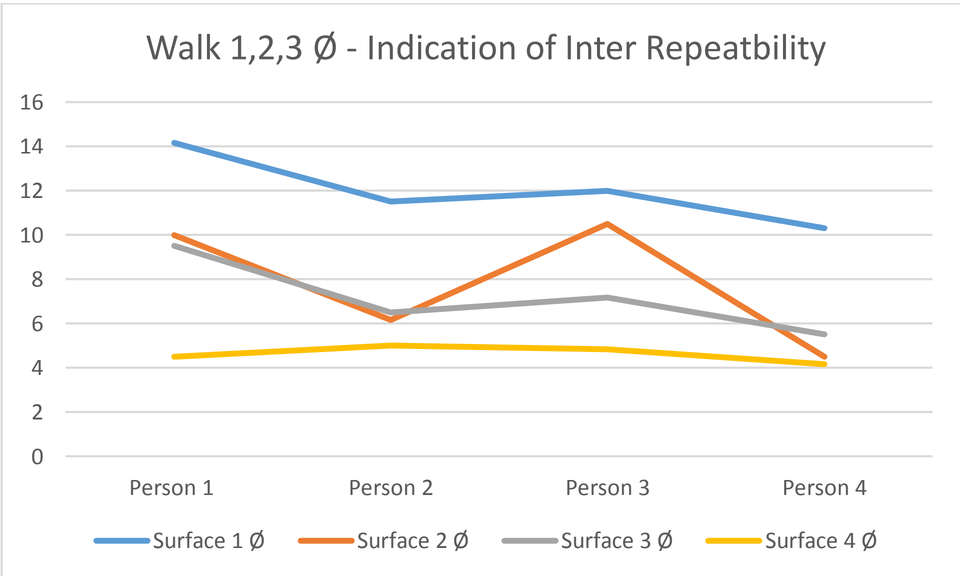

Walk 3 - Indication of Intra Repeatbility
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4



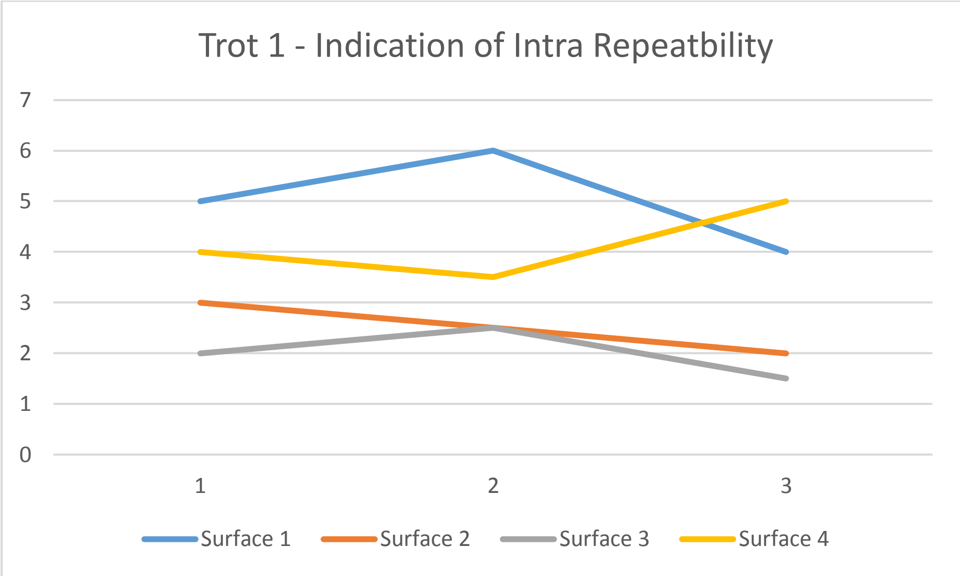
Walk 3 - Indication of Inter Repeatbility
6
5
4
3
2
1
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

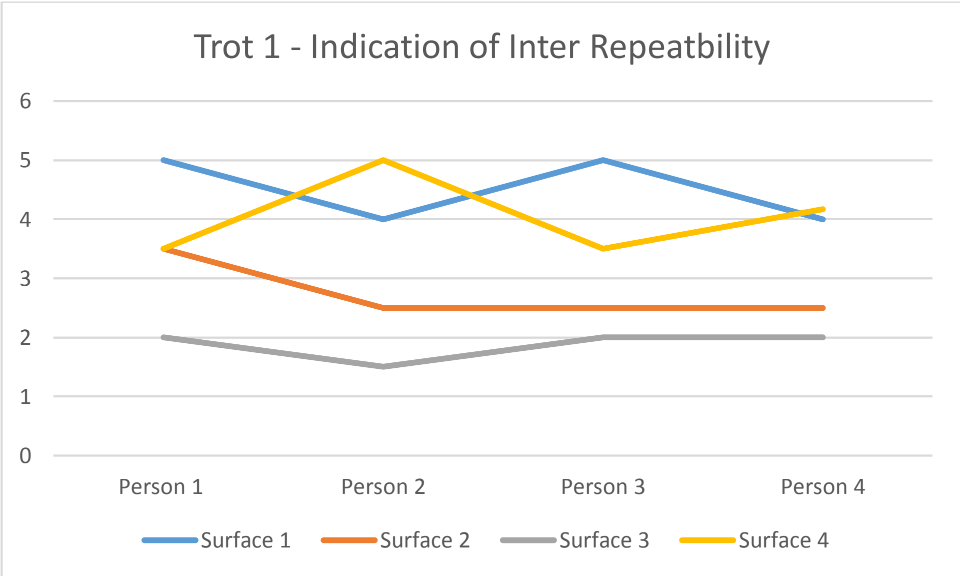


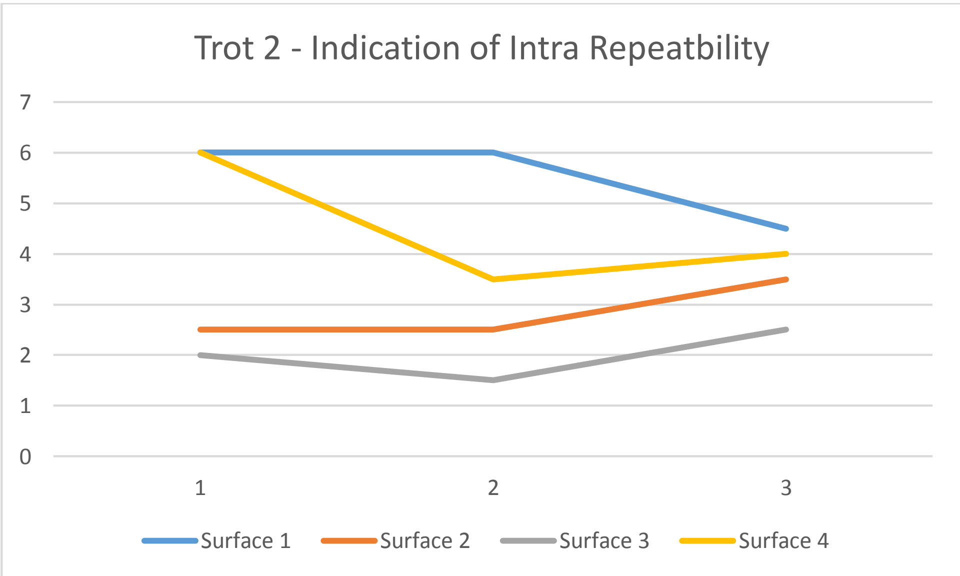
Walk 1,2,3 Ø - Indication of Intra Repeatbility
6
5
4
3
2
1
0
1
2
3
Surface 1 Ø
Surface 2 Ø
Surface 3 Ø
Surface 4 Ø

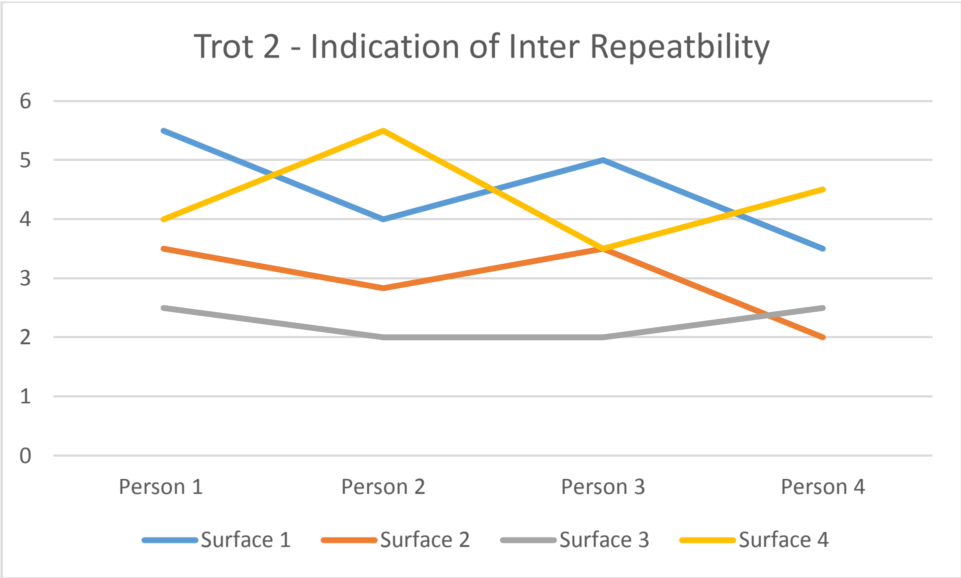


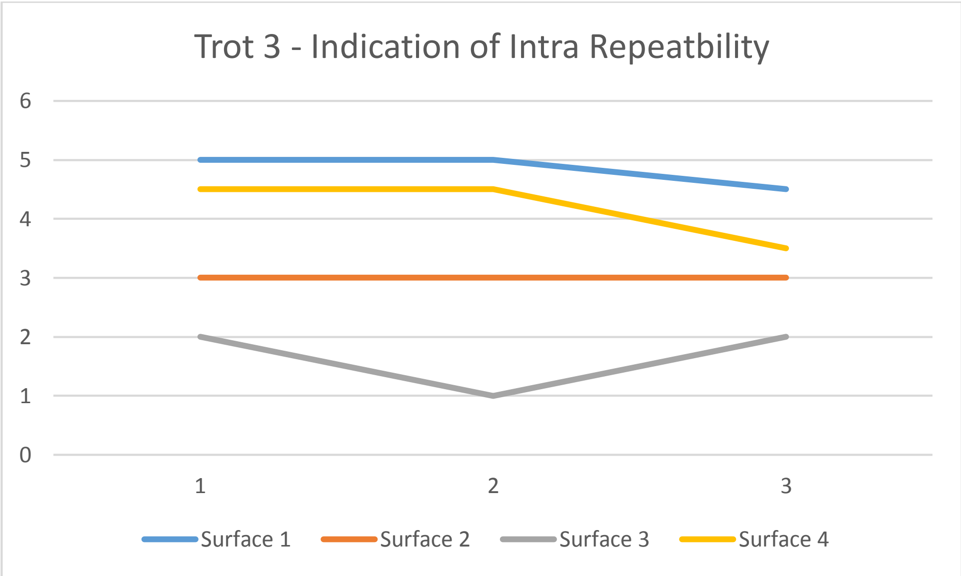
Walk 1,2,3 Ø - Indication of Inter Repeatbility
16
14
12
10
8
6
4
2
0
Person 1
Person 2
Person 3
Person 4
Surface 1 Ø
Surface 2 Ø
Surface 3 Ø
Surface 4 Ø

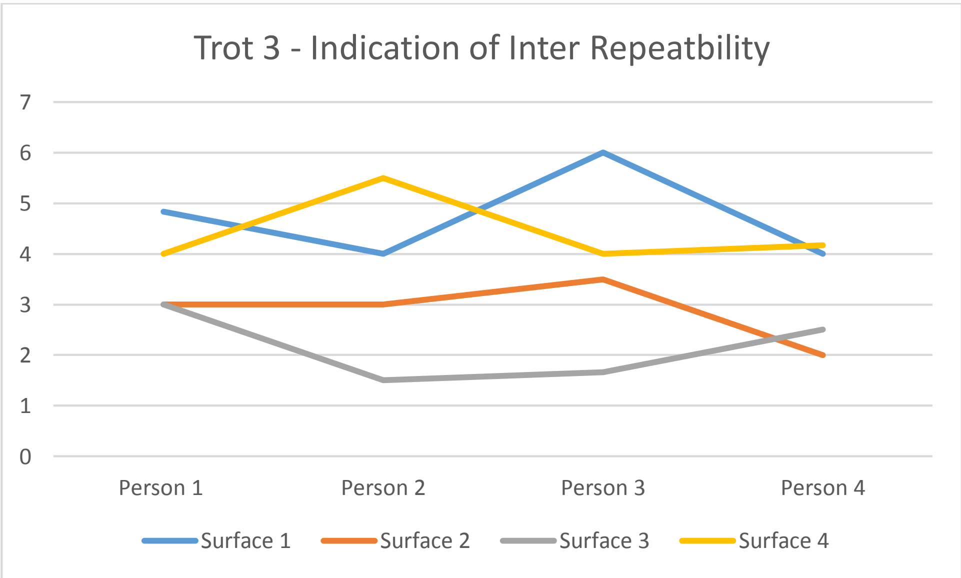

Trot 1 - Indication of Intra Repeatbility
7
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4

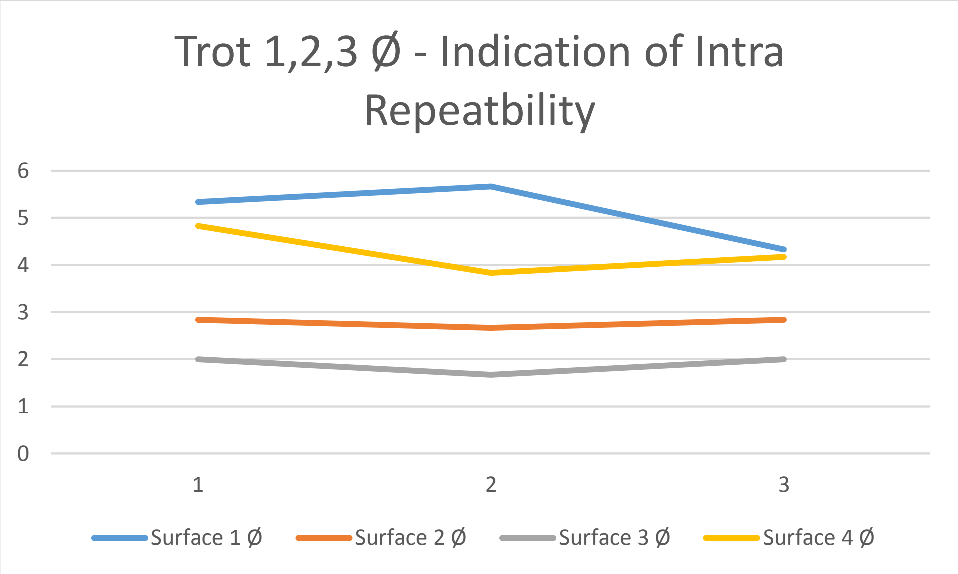

Trot 1 - Indication of Inter Repeatbility
6
5
4
3
2
1
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

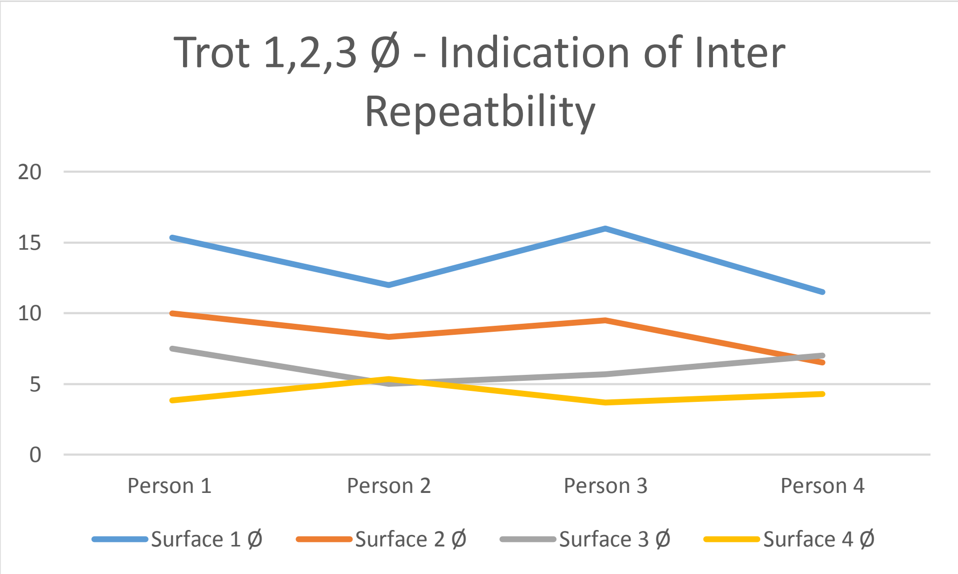

Trot 2 - Indication of Intra Repeatbility
7
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4

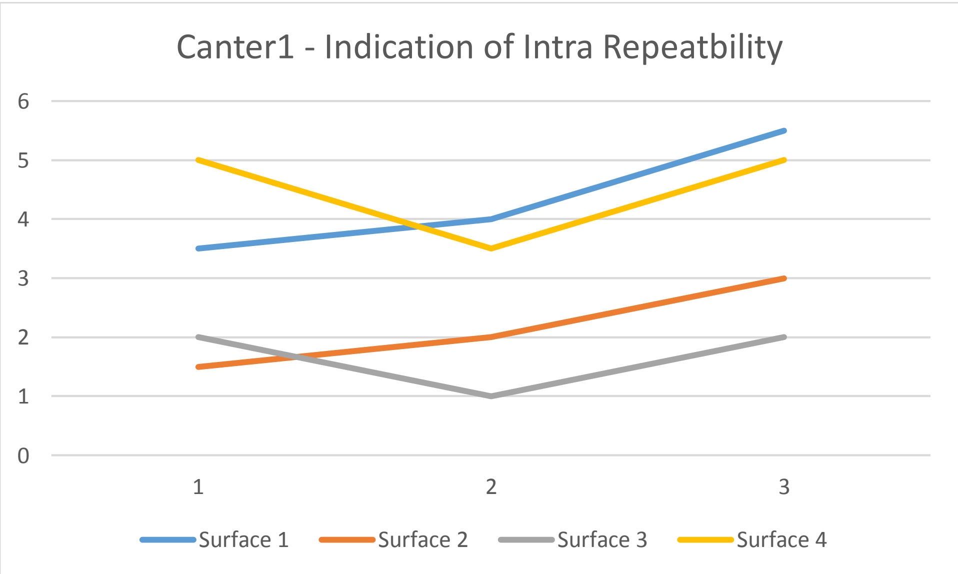

Trot 2 - Indication of Inter Repeatbility
6
5
4
3
2
1
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

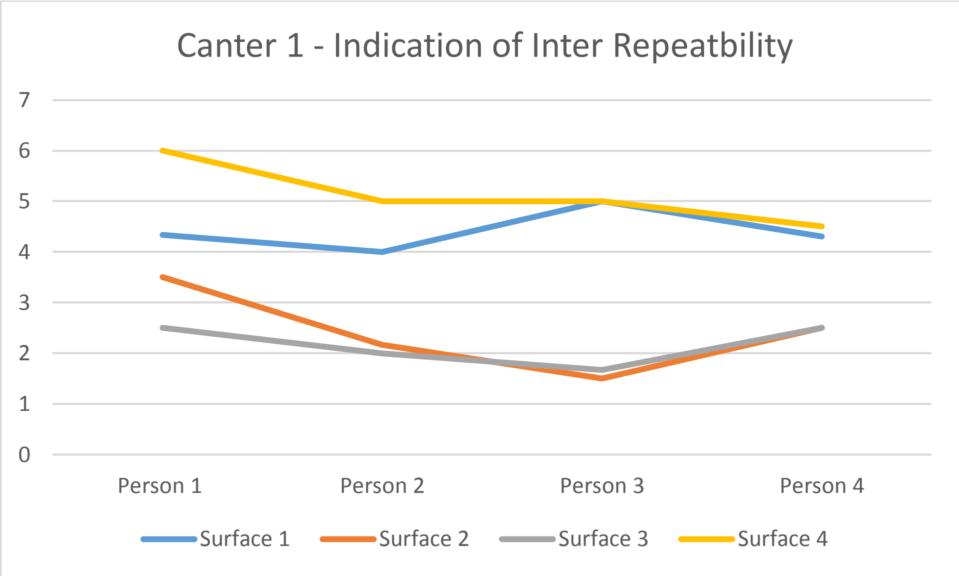

Trot 3 - Indication of Intra Repeatbility
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4

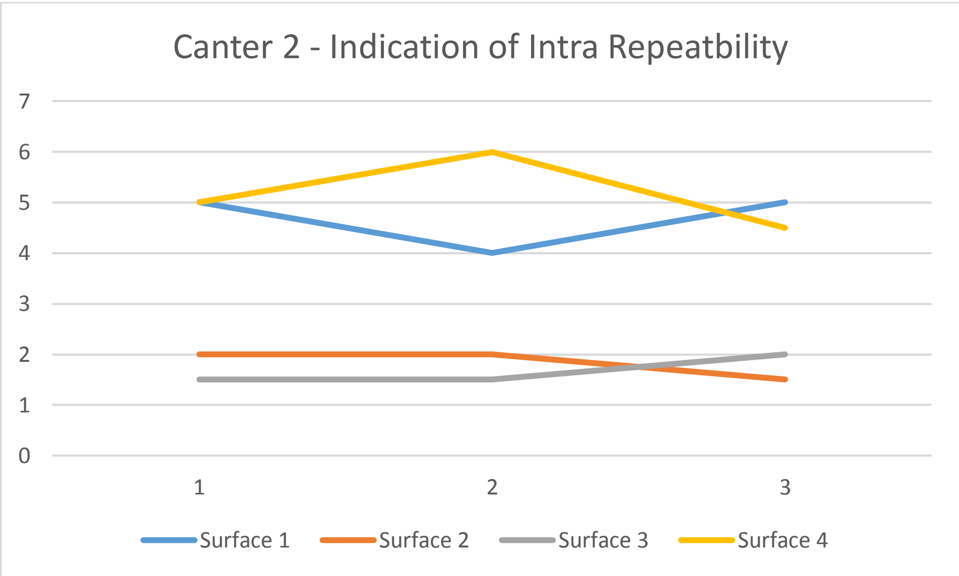

Trot 3 - Indication of Inter Repeatbility
7
6
5
4
3
2
1
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

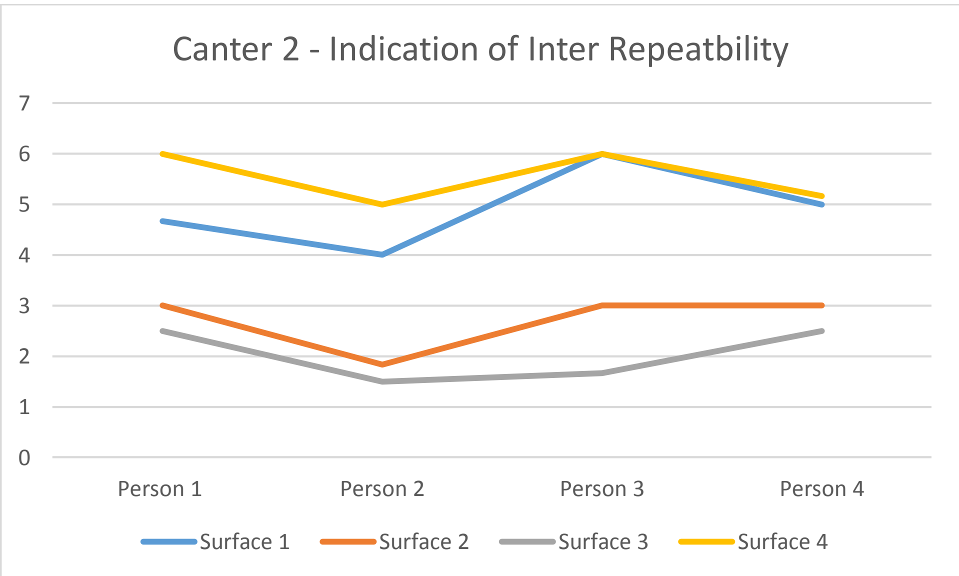

Trot 1,2,3 Ø - Indication of Intra Repeatbility
6
5
4
3
2
1
0
1
2
3
Surface 1 Ø
Surface 2 Ø
Surface 3 Ø
Surface 4 Ø

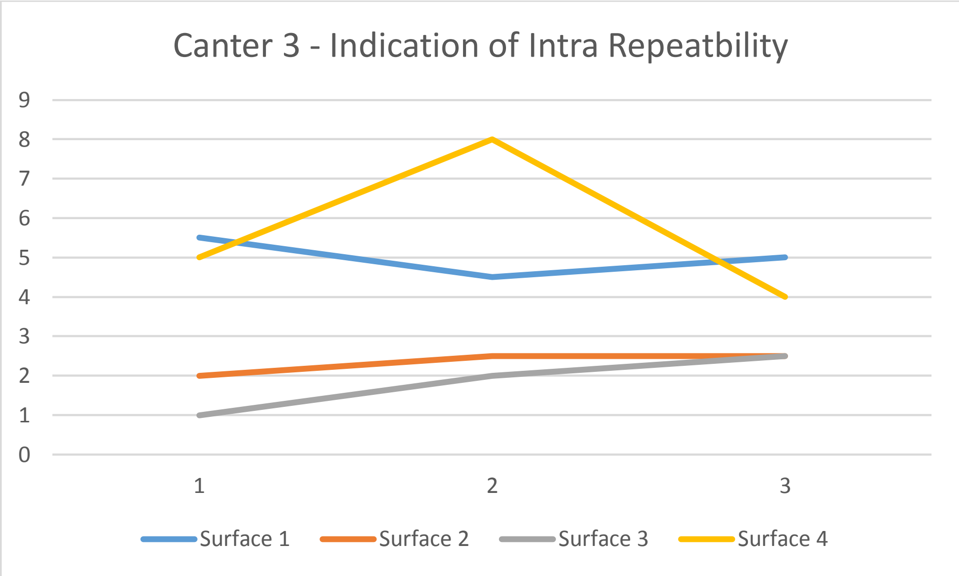

Trot 1,2,3 Ø - Indication of Inter Repeatbility
20
15
10
5
0
Person 1
Person 2
Person 3
Person 4
Surface 1 Ø
Surface 2 Ø
Surface 3 Ø
Surface 4 Ø

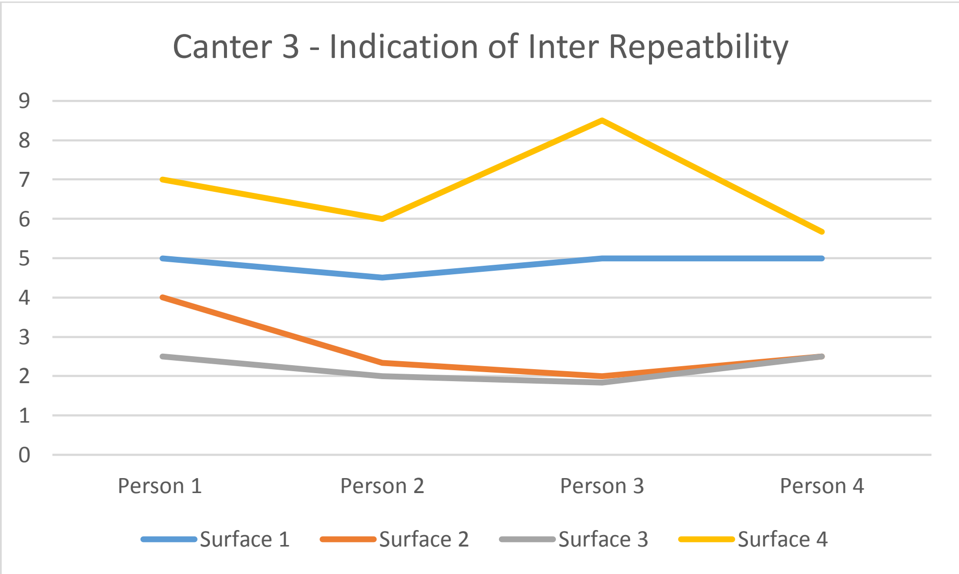

Canter1 - Indication of Intra Repeatbility
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4

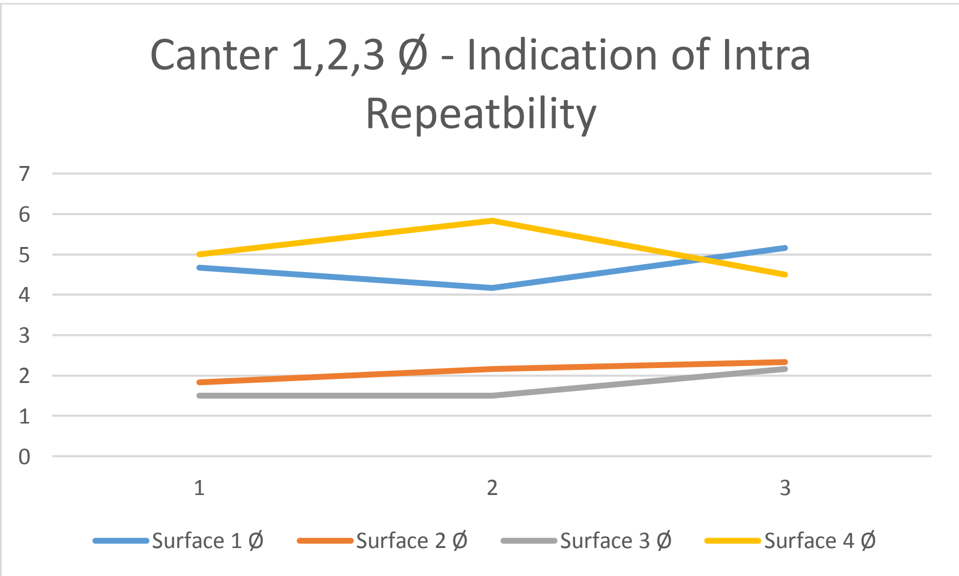

Canter 1 - Indication of Inter Repeatbility
7
6
5
4
3
2
1
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

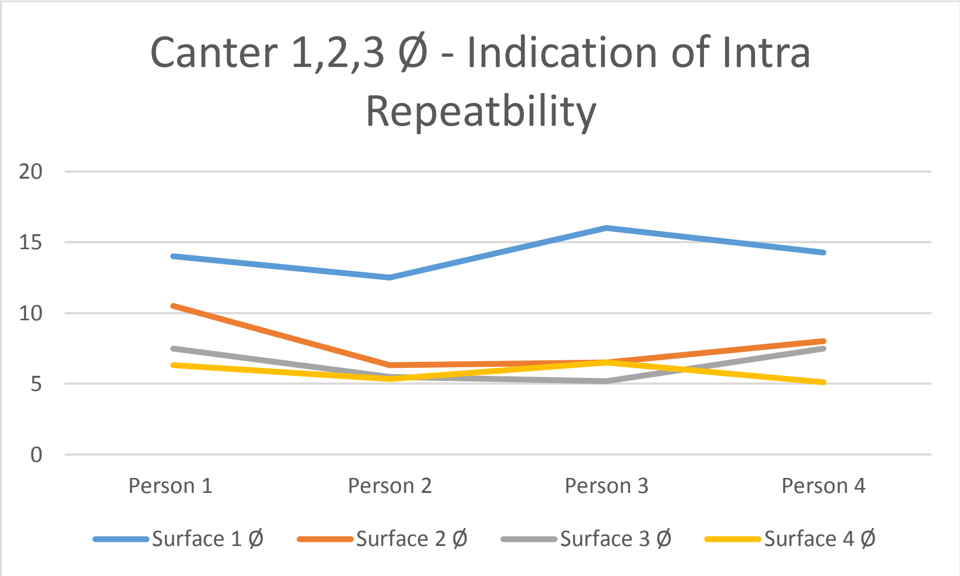

Canter 2 - Indication of Intra Repeatbility
7
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4

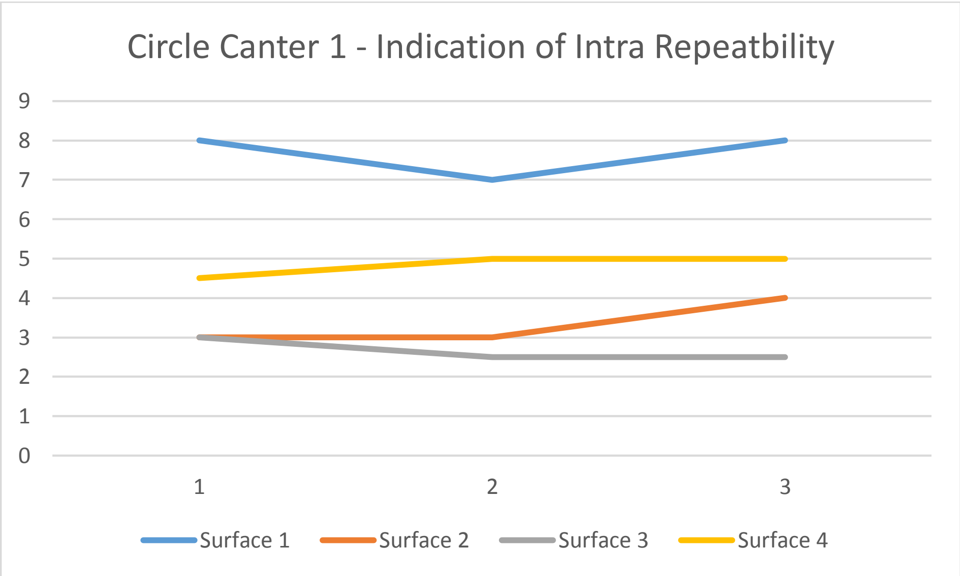

Canter 2 - Indication of Inter Repeatbility
7
6
5
4
3
2
1
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

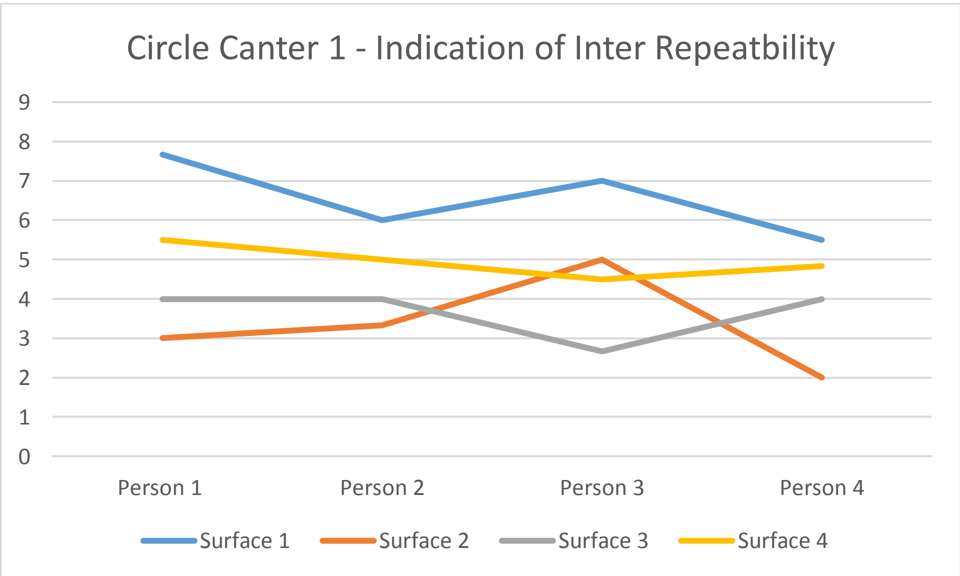

Canter 3 - Indication of Intra Repeatbility
9
8
7
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4

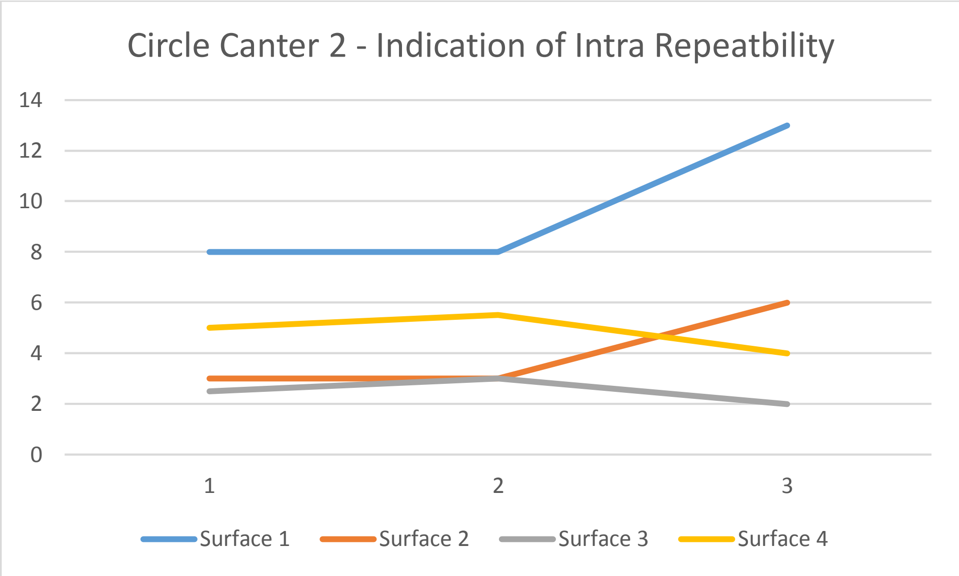

Canter 3 - Indication of Inter Repeatbility
9
8
7
6
5
4
3
2
1
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

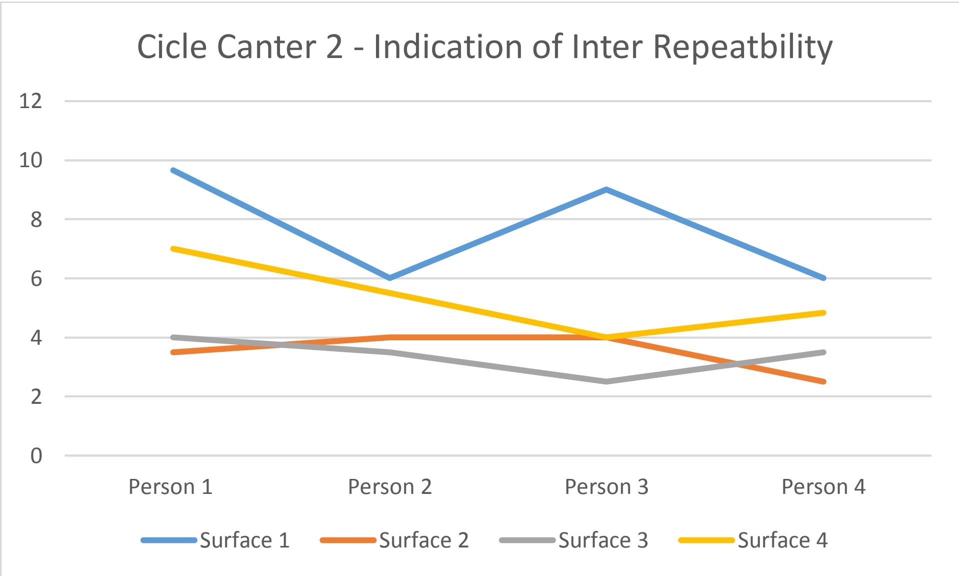

Canter 1,2,3 Ø - Indication of Intra Repeatbility
7
6
5
4
3
2
1
0
1
2
3
Surface 1 Ø
Surface 2 Ø
Surface 3 Ø
Surface 4 Ø

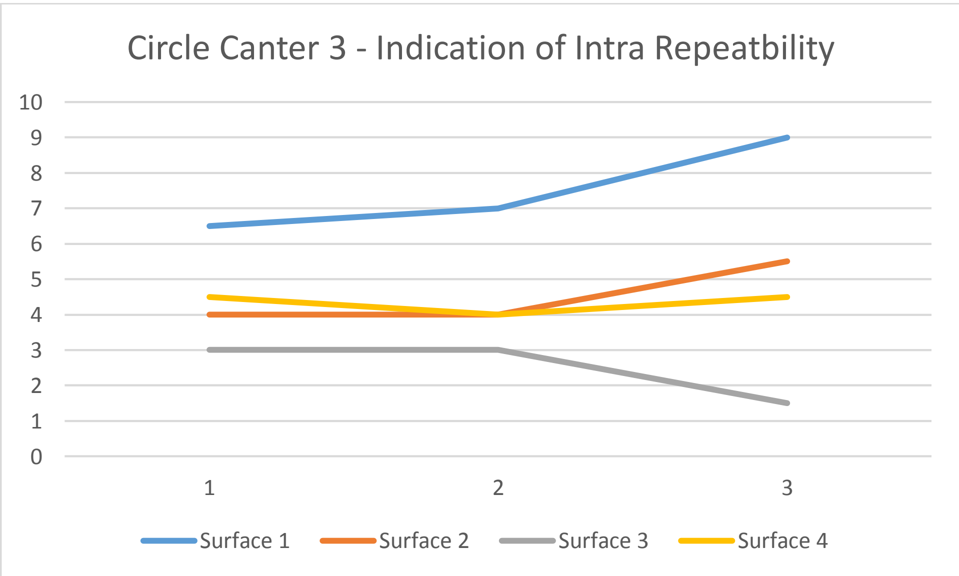

Canter 1,2,3 Ø - Indication of Intra Repeatbility
20
15
10
5
0
Person 1
Person 2
Person 3
Person 4
Surface 1 Ø
Surface 2 Ø
Surface 3 Ø
Surface 4 Ø

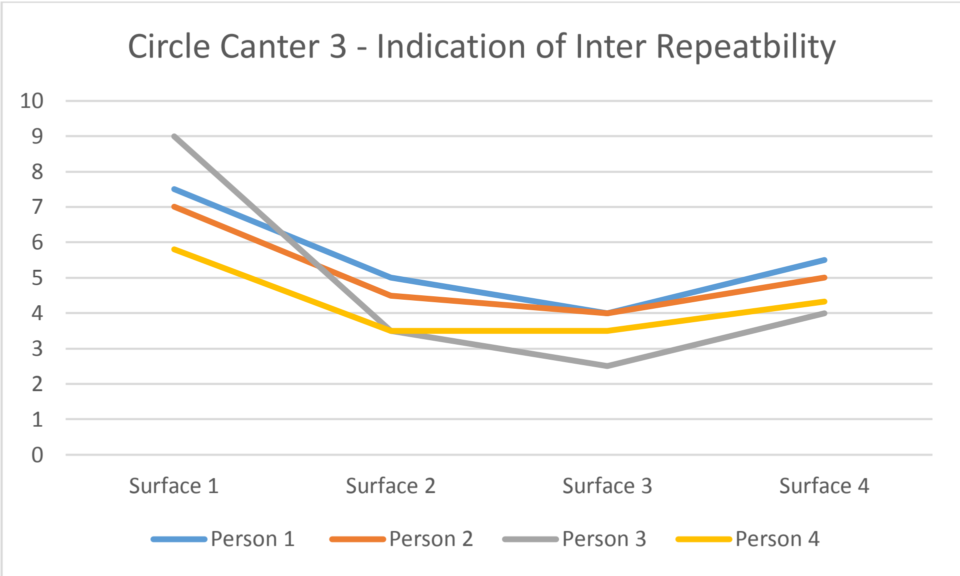

Circle Canter 1 - Indication of Intra Repeatbility
9
8
7
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4


Circle Canter 1 - Indication of Inter Repeatbility
9
8
7
6
5
4
3
2
1
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

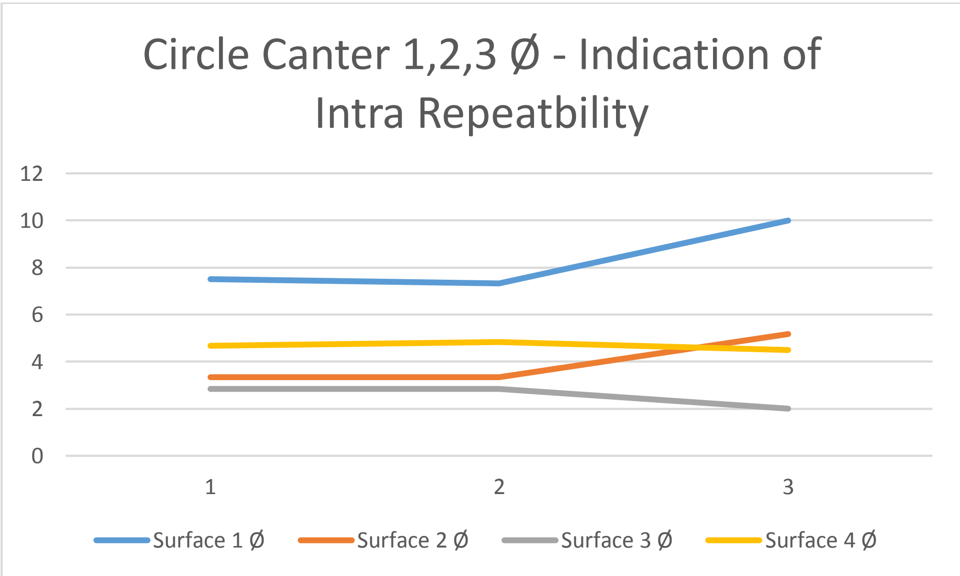

Circle Canter 2 - Indication of Intra Repeatbility
14
12
10
8
6
4
2
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4


Cicle Canter 2 - Indication of Inter Repeatbility
12
10
8
6
4
2
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

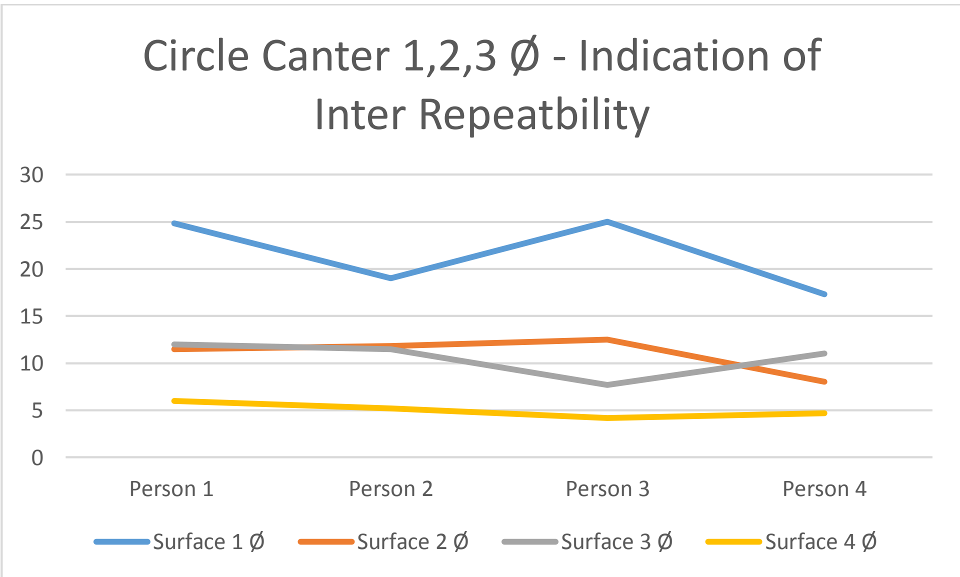

Circle Canter 3 - Indication of Intra Repeatbility
10
9
8
7
6
5
4
3
2
1
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4



Circle Canter 3 - Indication of Inter Repeatbility
10
9
8
7
6
5
4
3
2
1
0
Surface 1
Surface 2
Surface 3
Surface 4
Person 1
Person 2
Person 3
Person 4

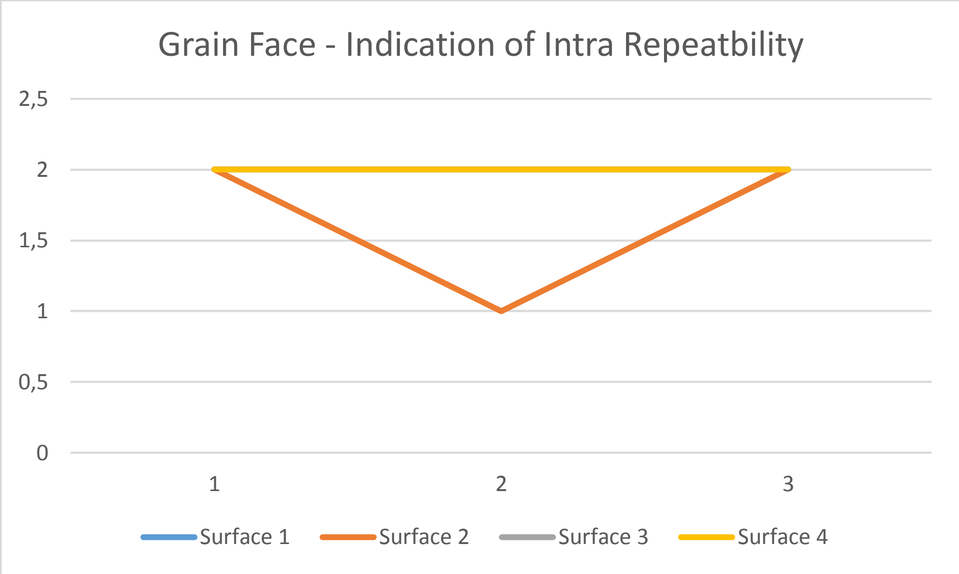


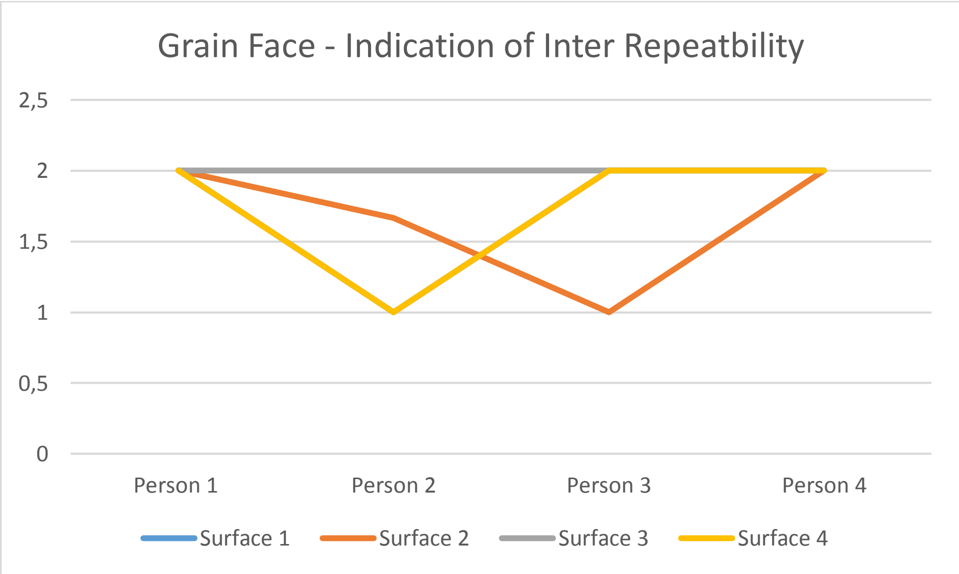
Circle Canter 1,2,3 Ø - Indication of Intra Repeatbility
12
10
8
6
4
2
0
1
2
3
Surface 1 Ø
Surface 2 Ø
Surface 3 Ø
Surface 4 Ø

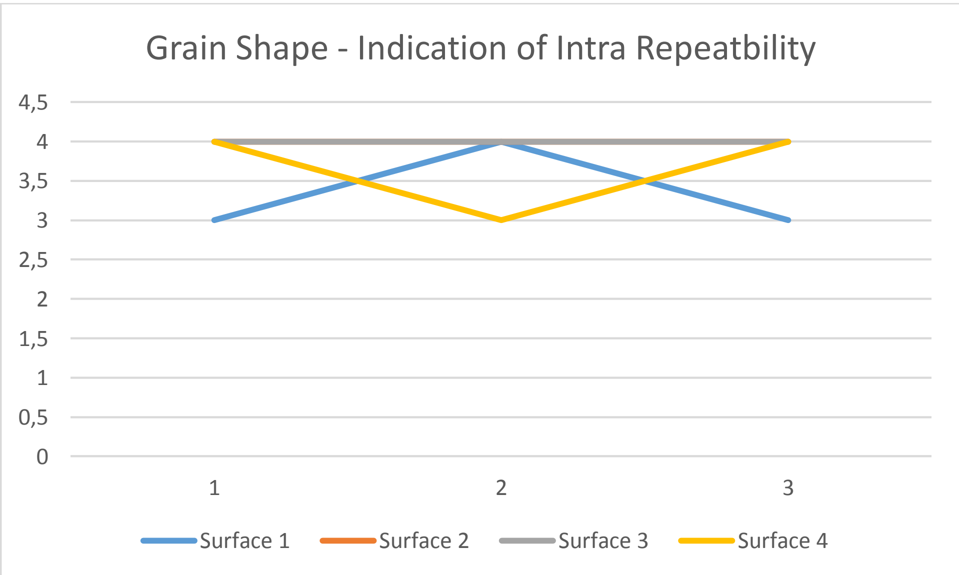


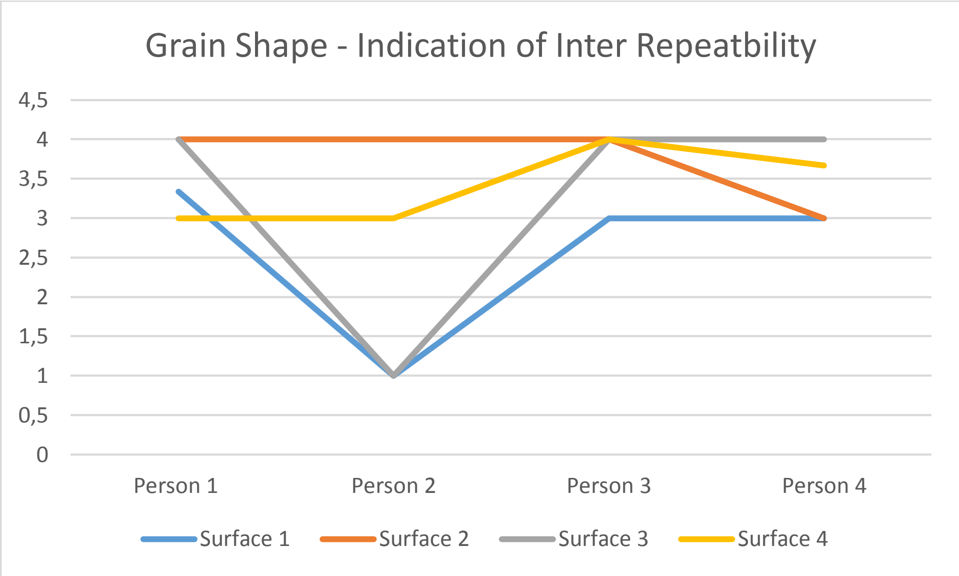
Circle Canter 1,2,3 Ø - Indication of Inter Repeatbility
30
25
20
15
10
5
0
Person 1
Person 2
Person 3
Person 4
Surface 1 Ø
Surface 2 Ø
Surface 3 Ø
Surface 4 Ø

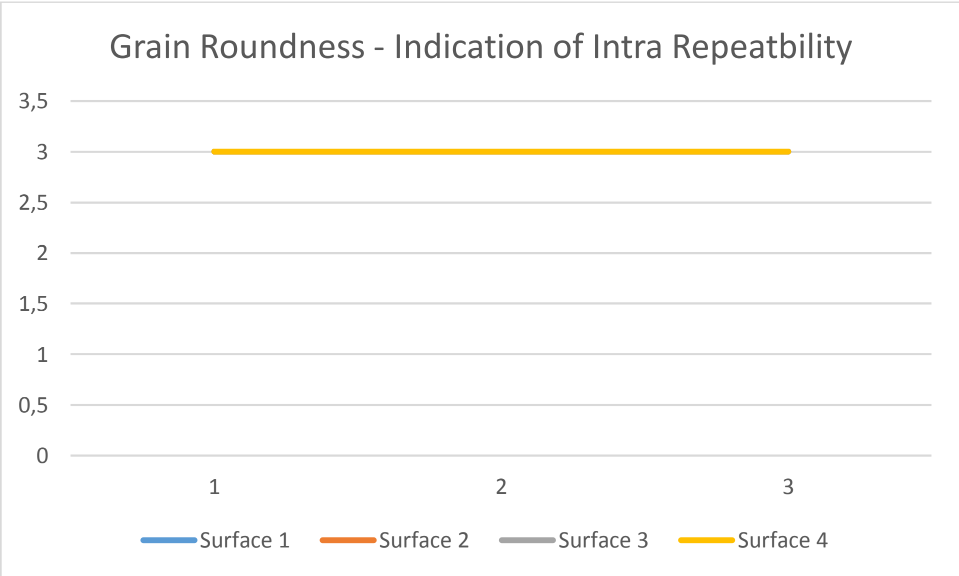
7.5.5 Grain Face and Appearance

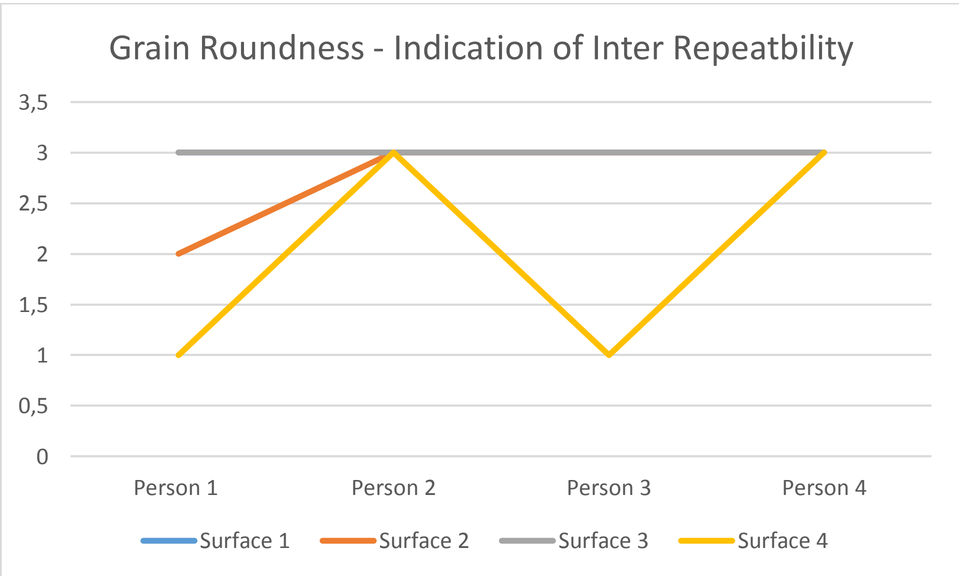




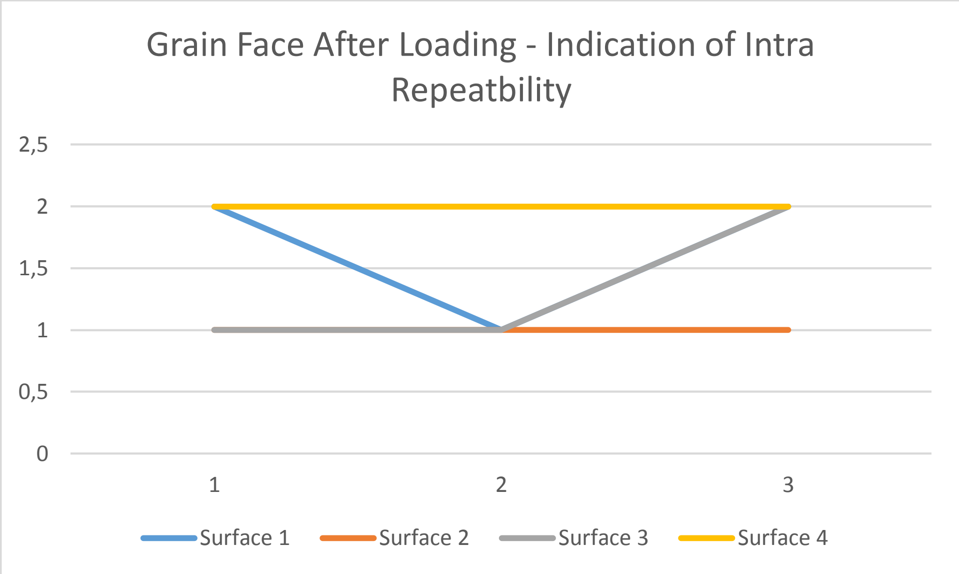


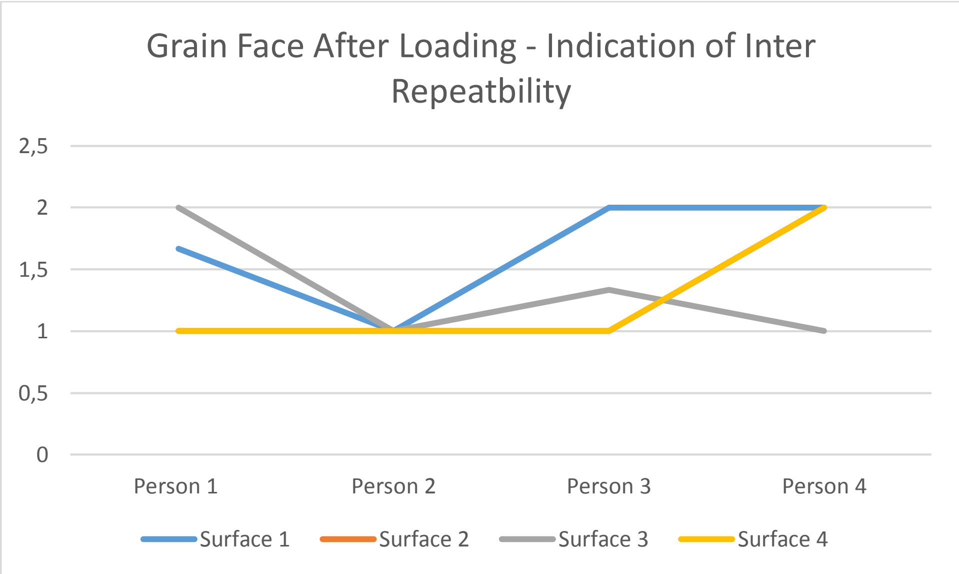

Grain Shape - Indication of Inter Repeatbility
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

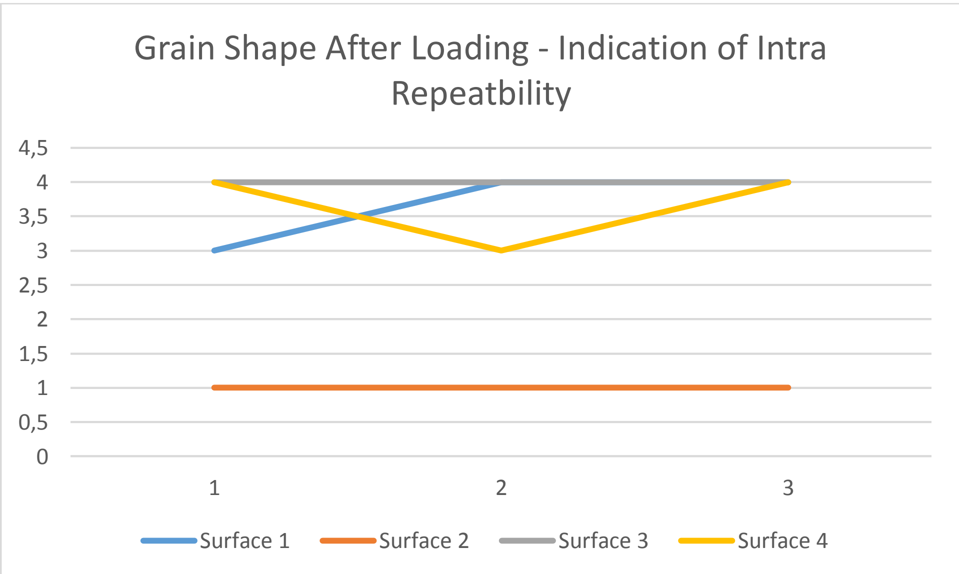

Grain Roundness - Indication of Intra Repeatbility
3,5
3
2,5
2
1,5
1
0,5
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4

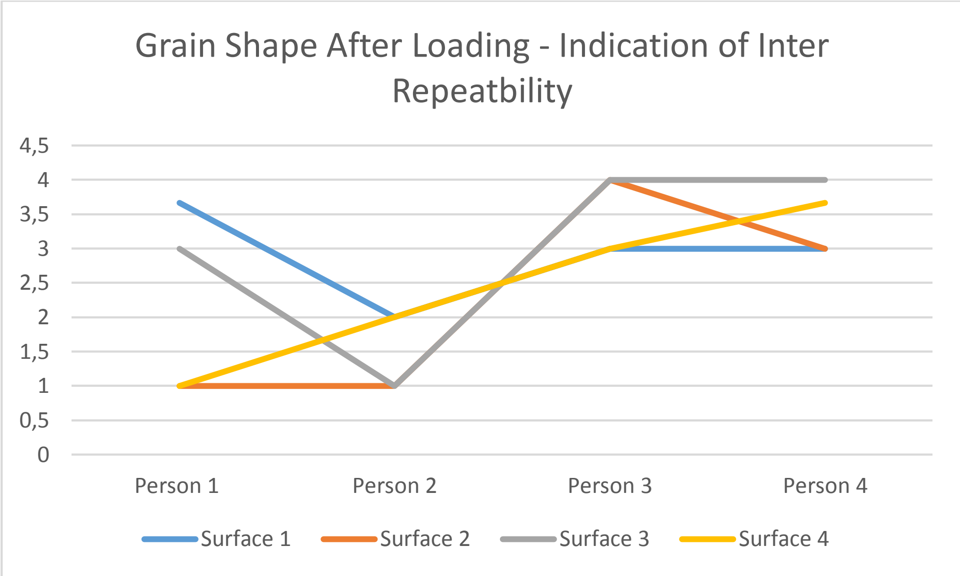

Grain Roundness - Indication of Inter Repeatbility
3,5
3
2,5
2
1,5
1
0,5
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

7.5.6 Material Alteration – Stress/Load

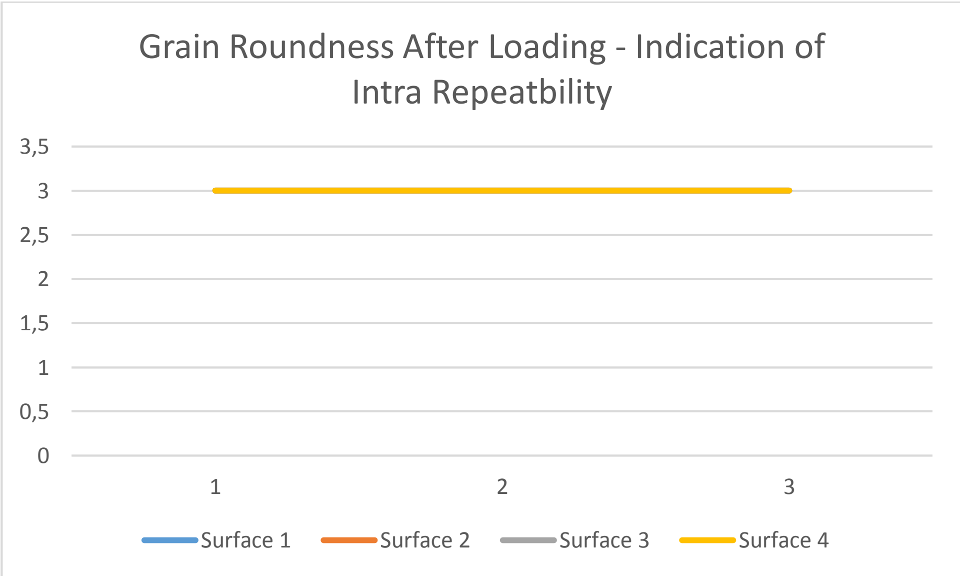




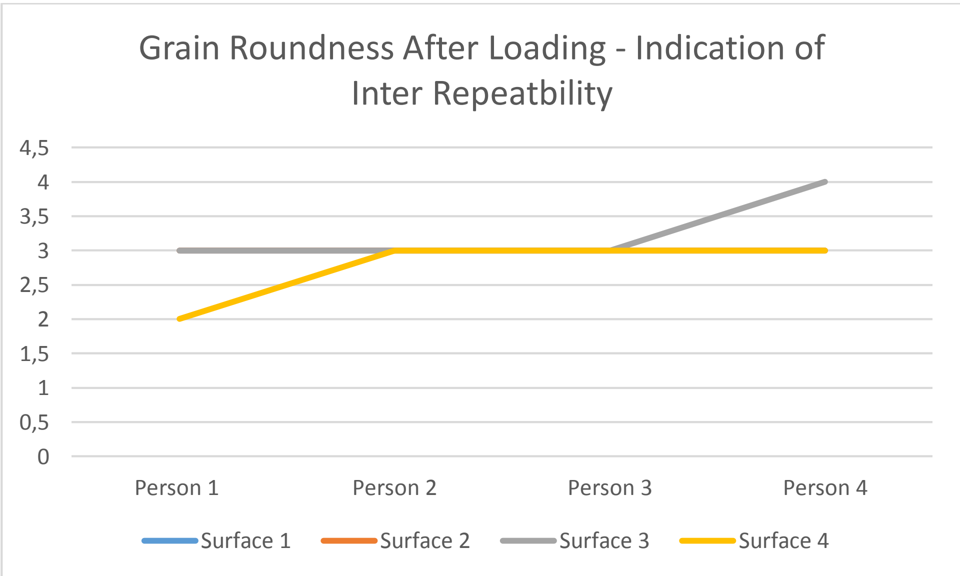




Grain Shape After Loading - Indication of Inter Repeatbility
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

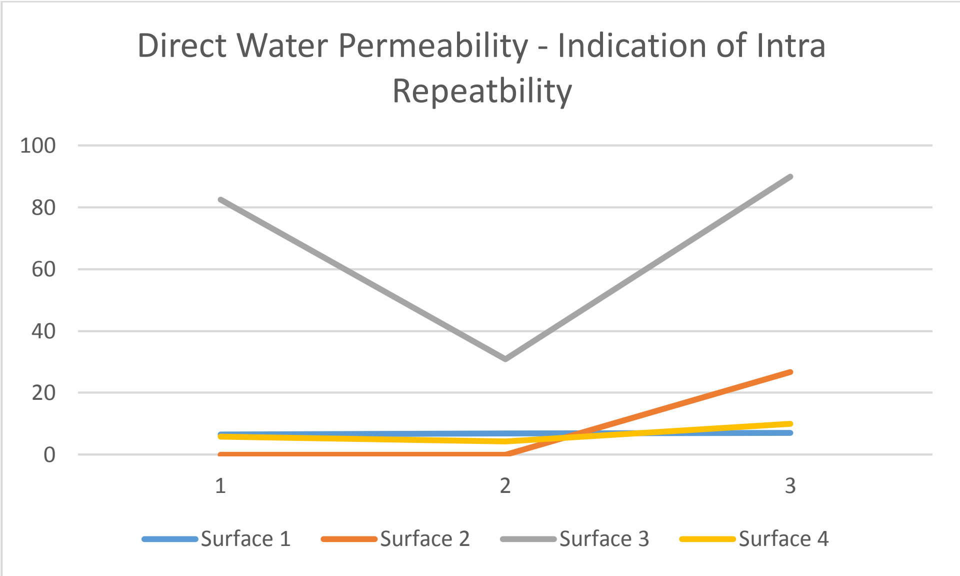


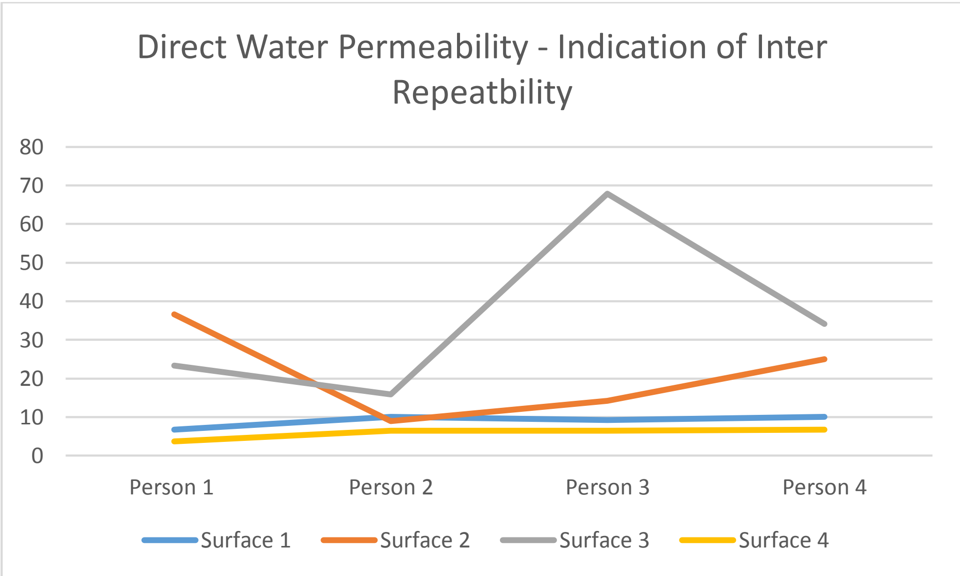
Grain Roundness After Loading - Indication of Intra Repeatbility
3,5
3
2,5
2
1,5
1
0,5
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4

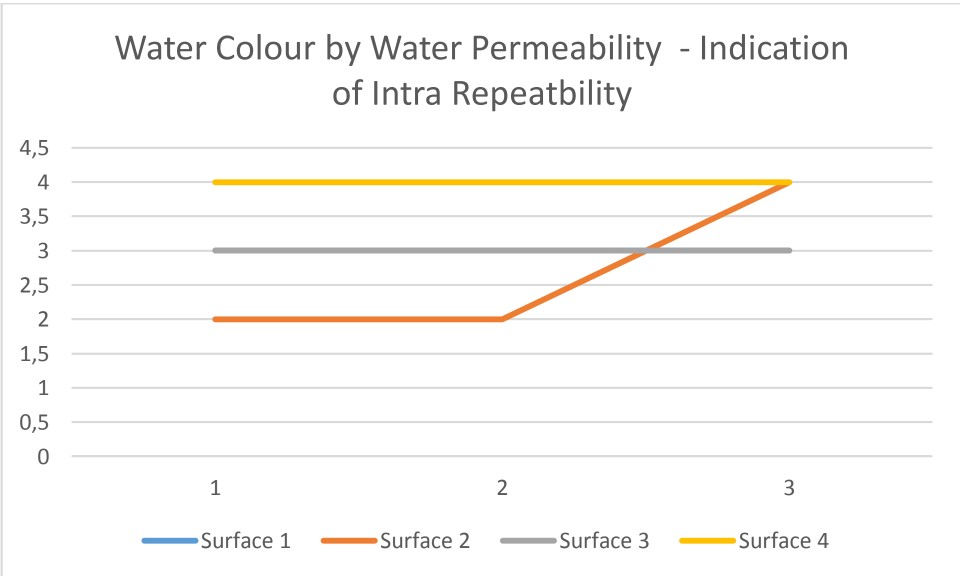


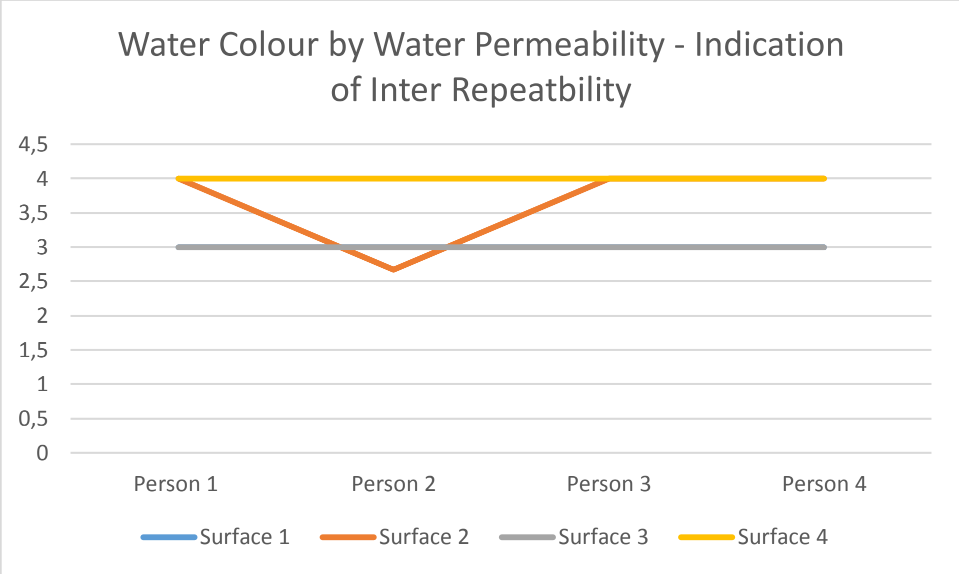
Grain Roundness After Loading - Indication of Inter Repeatbility
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

7.5.7 Water Permeability

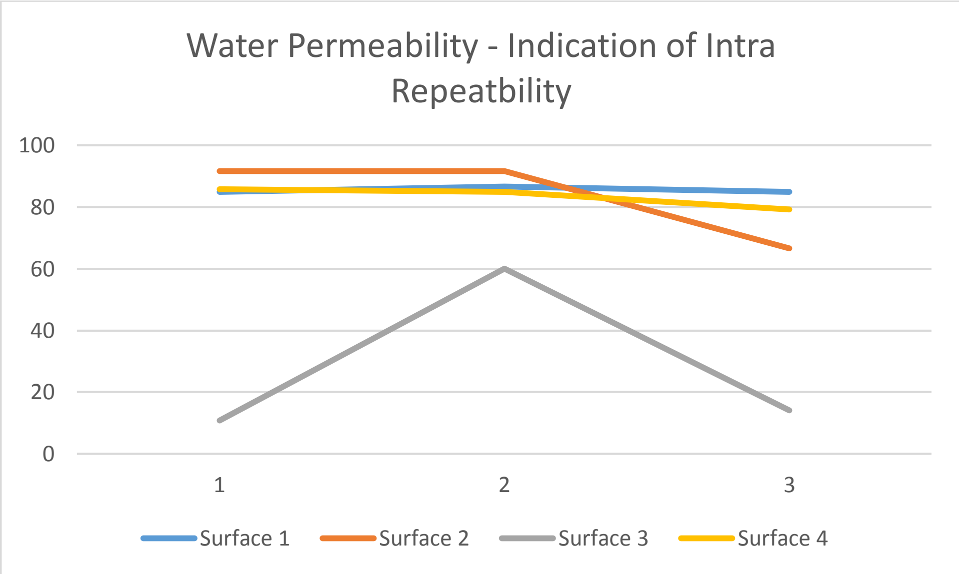




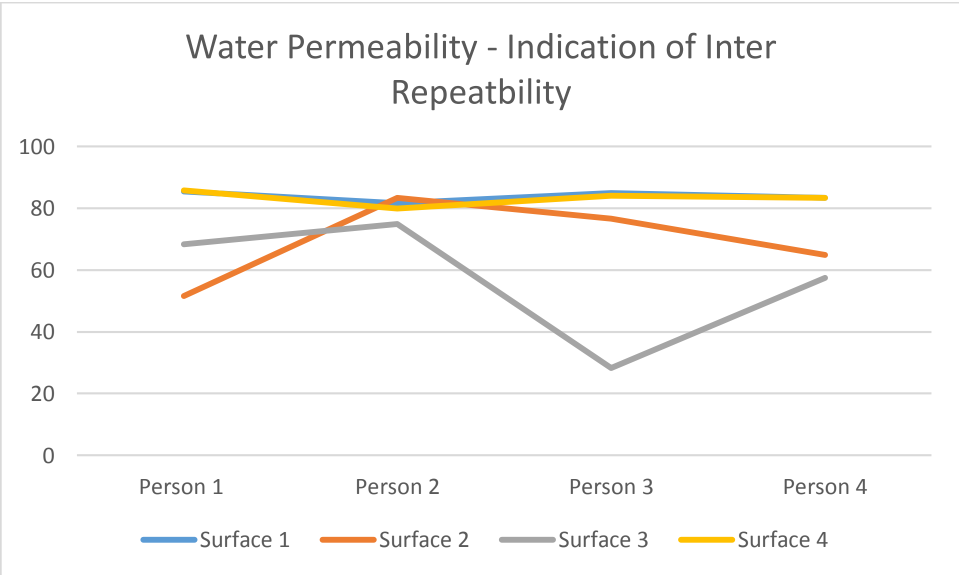




Water Colour by Water Permeability - Indication of Inter Repeatbility
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

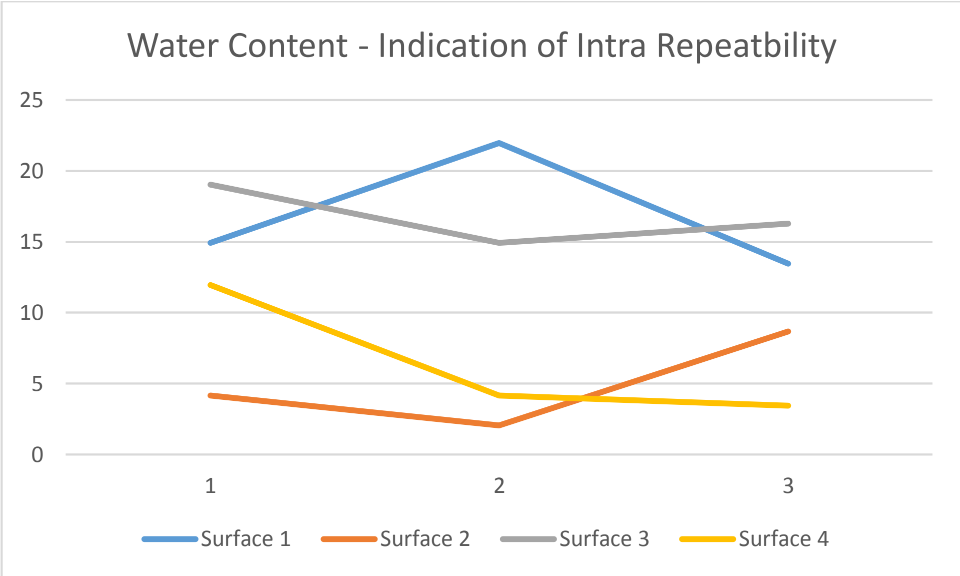


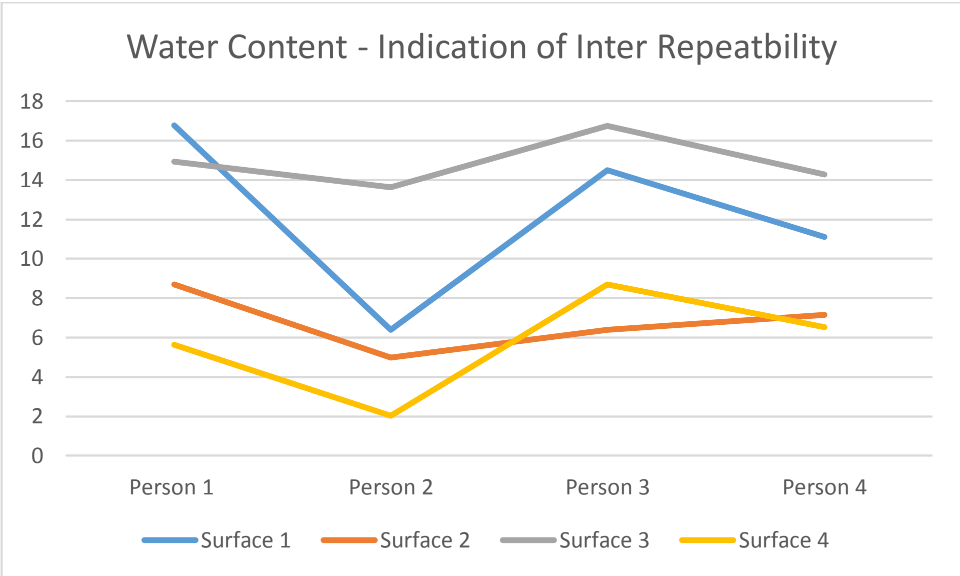
Water Permeability - Indication of Intra Repeatbility
100
80
60
40
20
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4



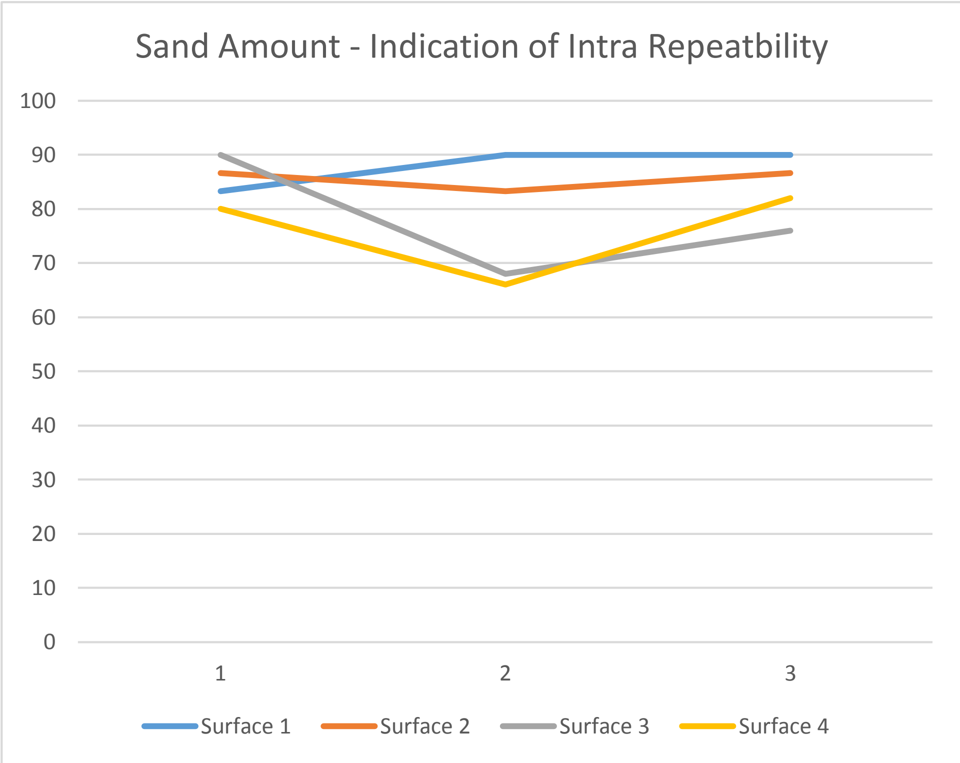
Water Permeability - Indication of Inter Repeatbility
100
80
60
40
20
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4

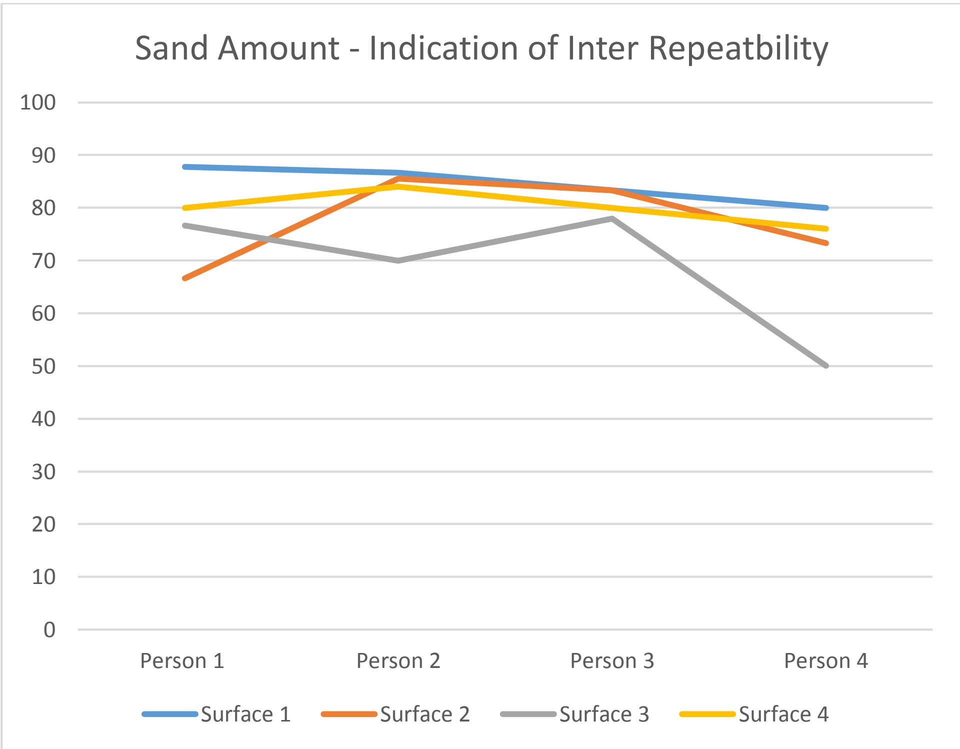
7.5.8 Water Content

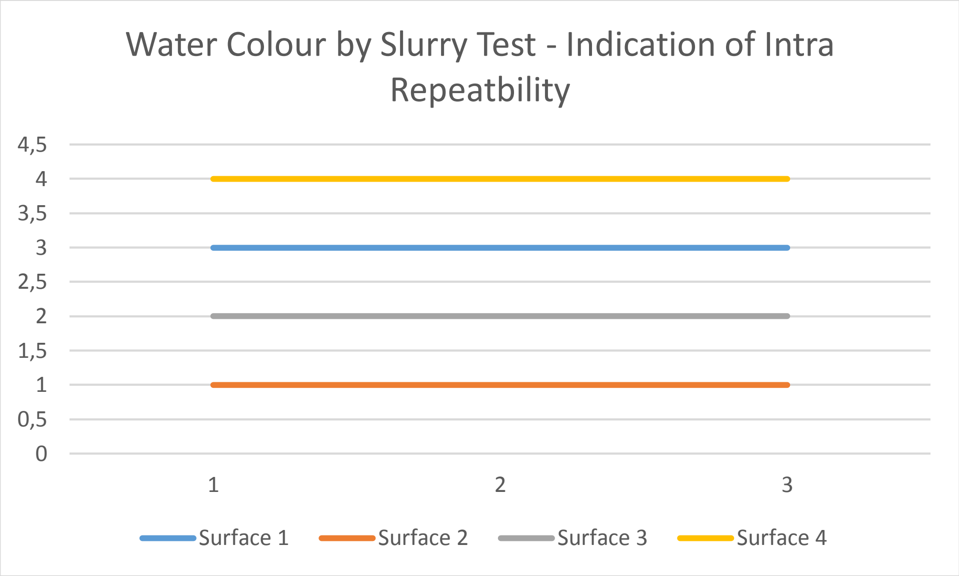


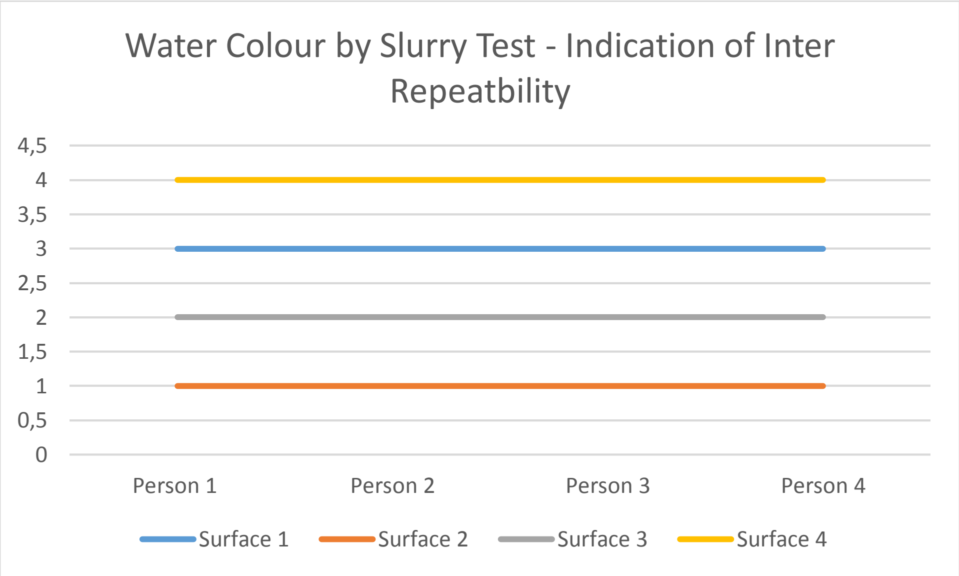


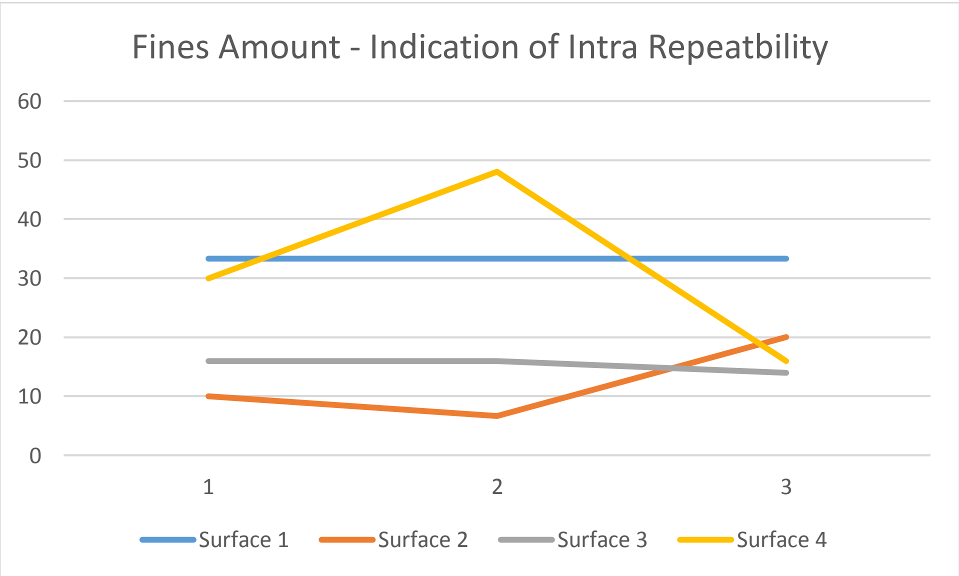
7.5.9 Slurry Test

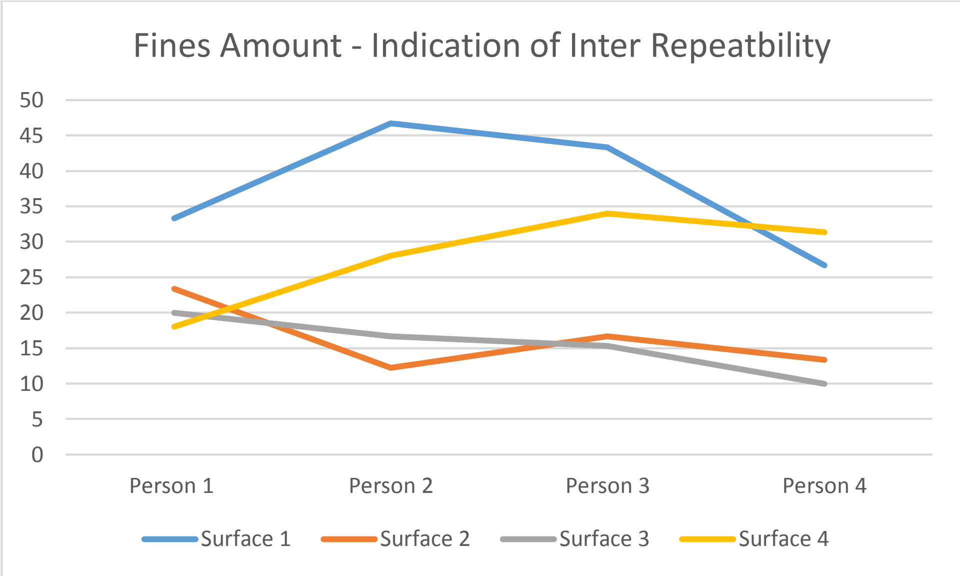

Sand Amount - Indication of Intra Repeatbility
100
90
80
70
60
50
40
30
20
10
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4


Sand Amount - Indication of Inter Repeatbility
100
90
80
70
60
50
40
30
20
10
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4


Water Colour by Slurry Test - Indication of Intra Repeatbility
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4


Water Colour by Slurry Test - Indication of Inter Repeatbility
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4


Fines Amount - Indication of Intra Repeatbility
60
50
40
30
20
10
0
1
2
3
Surface 1
Surface 2
Surface 3
Surface 4



Fines Amount - Indication of Inter Repeatbility
50
45
40
35
30
25
20
15
10
5
0
Person 1
Person 2
Person 3
Person 4
Surface 1
Surface 2
Surface 3
Surface 4