Movement and ground properties of training and competition arenas for horses - Biomechanical and epidemiological field studies and methodological development

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Background

Studies on Thoroughbred racehorses have demonstrated associations between surface properties, differences in training regimens and risk of orthopaedic injury (Parkin *et al* 2005; Verheyen *et al* 2006). Acute or repetitive high-impulsive and excessive loading have been proposed to be biomechanical risk factors for injury. Movement and loading of the lower limb are affected by factors such as limb conformation, shoeing material, type of shoe and ground surface character (Johnston *et al* 1995, Barrey *et al* 1991; Willemen *et al* 1999; Roepstorff *et al.* 1999). The complex movements of the distal limb have been elucidated in invasive and non-invasive models that demonstrate significant differences in the loading related to surfaces (Riemersma *et al* 1996; Kai *et al* 1999; Hood *et al* 2001). Accelerometers mounted in a splint boot and attached to the cannon bone can discriminate between surfaces of different indoor riding arenas (and sites within the arenas) (Roepstorff, unpublished data). Surface properties and maintenance may be important for performance and orthopaedic health of competition horses (Parkin *et al* 2004). Inertial navigation system (INS) technology provides the position, velocity, orientation, and angular velocity of a body by measuring the linear and angular accelerations They are light weight and applicable to real life measurements such as horse and rider and allows for technically difficult measurements of horses in natural training conditions, such as an outdoor dressage arena or during a series of jumps.

The following aims were constructed for this application

1. Describe the properties in commonly used riding surfaces.
2. Study the correlation between subjective and objective evaluation of surfaces in both training and competition arenas.

3a. Conduct a pilot study to document intensity and strategies for training/competition in competition horses at camps where the surface is being tested. 3b. Conduct a pilot study to document injury pattern in competition horses in these camps. 3a and 3b were performed in parallel. The longterm goal is to document any prevailing association between surfaces and its usage and the injury pattern.

4. Describe certain main biomechanical causes for orthopaedic injuries in relation to surfaces.
5. Develop instruments and methods for characterisation in the field of arenas and simple guidelines for usage of different surfaces.
6. Develop a wireless system for field registration of sensor signals on the horse during work and in freedom and document the movement patterns.
7. Characterize the gaits of the horse through signal patterns.

Materials and methods

A prospective longitudinal study was designed to follow show-jumping riders (mainly professional) and their horses, in Sweden, Switzerland, the UK and the Netherlands for 6 months during the competition season in 2009. It was aimed to document all aspects of training, including times trained in various ways as well as the surface usage when trained. Efforts were put into documenting surface use at competition arenas as well. To increase power the study was repeated with mainly the same riders in Sweden during 2010. Included in this presentation is 16 riders with 116 horses, on which descriptive statistics have been produced in the current report.

Criteria to assess the surfaces were developed through cooperation with the users (riders, arena constructors, maintainers, Figure 1). Arenas were typed according to the main components of their surface layers; sand, fibre, rubber, turf and other. The designation “other” was the non-constructed riding surfaces, e.g. ground used for hacking. Subjective evaluations were made by Swedish riders of their home arenas (figure 1). The investigator evaluated the arenas at yard visits and they were judged from the status of the day. Subjective agreement was documented for riders evaluating arenas at competition yards, including both warm-up and competition arenas. In conjunction with competing, 55 riders evaluated 140 Swedish competition arenas during 2009 using the criteria in Figure 1. Approximately 6 of the Swedish riders have also consistently evaluated the arenas during 2009 and 2010 (data not shown). Unfortunately for the sake of making reliable agreement statistics, few riders visited the same arena and formal between-rider agreement has therefore not been produced.

A light drophammer (LDH) was tested on training and competition tracks and the results were correlated to the subjective evaluation of the riders. The LDH, simulating the angled impact of the hoof was used on 25 different competitions (the day of a show jumping event) and training arenas of which ten were subjected to repeated measurements. Both turf and various sand based constructions were measured. At least 10 drops were performed at each arena when measured a given day. Fall time of the DH, maximal deceleration, impulse, and rise time in horizontal and vertical direction were calculated. Principal component analysis was used to show whether these variables could distinguish between arenas. In 10 of the arenas results were correlated to subjective evaluation using 6 different categories (surface hardness, plastic and elastic dampening, grip, evenness and uniformity) evaluated by an expert panel consisting of at least 15 riders. The ability of LDH to predict subjective assessment was tested using the PLS procedure in SAS.

The heavy drop hammer has been developed. From the original version (Peterson 2008) we have a new system for dampening, a suitable mechanical spring and a 3-D load cell. The most updated version has in total been used on total 2500 tests, in 40 training camps, 6 countries, of which 1200 drops were made on the yards in the epidemiological study. The following variables were evaluated from each drop : +/- peak vertical acceleration , +/-filtered peak vert acc, +/-peak horizontal acceleration, +/-filtered peak horizontal acc, peak load, filtered peak load, peak load rate, impulse, loading modulus, unloading modulus, hysteresis, rebound impulse, time to rebound, time from peak to peak load, time from peak to peak acceleration and shear angle.

A single, fixed high speed camera (1,000 frames/s) was aimed at landing spots after different fences during two competitions. A total of 64 hoof landings were recorded on one sand and one turf surface (using studs on the turf). Hoof movements were tracked from calibrated video sequences. Landing velocities, landing angles, maximal vertical and horizontal deceleration and timing of maximal deceleration peaks were calculated and compared between leading/trailing fore/hindlimbs. All outcomes were analysed for limb, using Generalised Linear Models and controlling for effects of surface and obstacle.

Accelerometers were used to measure, on 3 horses in walk, trot and canter, the movement in three different spaces; horizontal, lateral and vertical. The collected data have been analyzed by comparing the typical amplitudes (signal strengths) for the different gaits and by studying other qualities in their signal patterns.

Results

1.Properties of commonly used riding surfaces.

The composition

In general arenas consisted of sand, or sand added by synthetic material; wax, fibre and textile or rubber, or turf. It was sometimes difficult to get accurate data on the foundation of arenas. In Sweden some arenas have a special type of foundation with a deep layer consisting of rubber pieces supposed to give a elastic compliancy in response the the load of the horse. There is also lacking information on drainage. Some newer arenas in Europe have the ebb and flood system, where the humidity of the arena is well controlled by a sub soil watering and drainage system. The type of arenas in the epidemiological had 7 *composite categories* identified: sand, sand/rubber, sand/fibre, sand/fibre/rubber, sand/wood chip, wood chip/fibre and turf. (All riders also had at least one surface for hacking, denoted non-arena.)

The heavy drop-hammer

The presentation is made on 44 arenas and 374 drops. The arenas evaluated were of; sand (n=7), sand/fibre (n=12), waxed sand (n=4), sand/rubber (n=11), waxed sand/rubber (n=4), turf (n=4), wood chip (n=1) and gravel (n=1) (here the gravel surface is a race track for trotters). Some variables from the heavy drop hammer data can be seen in figures 2-6 on hoof collision, horse – limb – surface collision, elasticity/'going' and shear respectively for categorised surfaces according to the table above. Vertical deceleration of the drop hammer's metal hoof represents the initial impact between the horse's hoof and the surface. The characteristic can be described as surface firmness. Maximal vertical deceleration is presented in figure 2. The trotter race track (gravel) has a high surface firmness and the turf track in this case the softest top. The drop hammer also simulates the part of the step when the hoof is in contact with the ground and the horse puts its weight on the limb. It is ofted referred to as the second impact at the horse ground interaction (Thomason 2008). This is measured by a load cell. Data from the load cell is shown in figure 3 as maximal load and maximal load rate. The compliancy, dampening, stiffness of the surface are described with the load and load rate parameters. The surface can absorbe energy from the second impact between the horse and the surface. This is what creates the dampening of the collision. Energy can be stored and "given back" to the horse if the surface is elastic. The energy can also be transferred to the ground and result in plastic deformation of the ground material and heat which would be the case if the surface is compliant but not elastic ("deep and dead"). In figure 4 the energy dissipation, hysteresis (Nm) of the surface is shown. The impulse (Ns) in the same figure shows the accumulated load over the time of the "second collision". If we look at the wood surface we can se that the impulse is fairly high and the hysteresis low. This means that a relatively small amount of energy is lost. The wood surface gives the energy back to the the mechanical hoof i.e. is elastic, which is seen in the next figure (5) where the rebound area is high. The rebound area (rebound impulse) depends on the amount of energy that remains in the drop hammer system when it bounces and hits the surface a second time. The shear strength of the surface is measured as a quotient between the vertical and horizontal acceleration (figure 6).

2. Study the correlation between subjective and objective evaluation of surfaces in both training and competition arenas.

Subjective evaluation by the riders and the interviewers

The investigator and rider gave the sand/fibre arenas the highest score in total evaluation and that these arenas have the highest scores for elasticity, evenness and uniformity (data not further shown).

Subjective evaluation by the riders within and outside the study of competition arenas
E.g. the riders could pick out the "loose and deep" arena as having low surface firmness, high dampening and low elasticity. The judgment of surface firmness was in agreement with mechanical measurements done with a light drop hammer. The large spread indicates differences between rider evaluations of the same arena. The LDH measurements differentiated between main types of arenas and was able to predict surface hardness with good correlation to subjective evaluation while the other parameters were poorer predicted.

3a. Pilot study to document intensity and strategies for training/competition and injury patterns in competition horses at camps where the surface is being tested.
Preliminary results from Sweden 2009 demonstrates large differences in how the riders train, in the number of days lost and also in their surface usage (tables 2-3) . The total time with registration is seen from table 3 (days at risk). The training volume differences (controlling for time at risk) are highly statistically significant, while the days-lost associations are somewhat harder to analyse and results not yet concluded (few horses at each rider and when horses have days days-lost they may have many). Results from the pilotstudy were published in a student thesis (Pedersen, 2010).

4. Biomechanical events at the hoof-surface collision landing after competition obstacles on 2 surfaces (aim specified relative to application).
Landing speed differed among limbs ($p<0.02$ for all speeds and models). The leading hoof approached the ground more acutely angled to the horizontal plane than the trailing comparing fore ($p<0.001$) and hindlimbs ($0.05\geq p>0.01$) respectively. Differences in landing and braking kinematics were found also between surfaces and between obstacles, however these effects were hard to separate because of the non-experimental design.

5.Develop instruments and methods for characterisation in the field of arenas and simple guidelines for usage of different surfaces.
The heavy drop-hammer is the main tool for this purpose and may when results have been analysed more thoroughly, and more validated to the horse, be used routinely for this purpose. Compare alsowith aim 1.

7.Characterize the gaits of the horse through signal patterns

The stride frequency, corrected values of maximum and minimum and the way that forces in different planes varied, show clear differences between walk, trot and canter and should be good starting-points to proceed the work with automatic detection of gaits in horses, using accelerometerdata.

Discussion

A large number of surfaces has been evaluated. Sand/fibre and sand/rubber dominated the sample. The arenas investigated are such that top-level show-jumping riders use and should represent arenas perceived as 'better' by these riders. Although more common surfaces, i.e. sand or wood chip were also represented. These new arena types seem to enhance performance, but we still don't know how they affect the short- and longterm health of the horses. In the data there is no evidence that a specific type of arena spares the horse from locomotor problems. There are indications that riders that vary surfaces and don't train the horses too little may have less physical health problems with their horses. However for this conclusion to be reached further analysis is necessary and SHS (2010) has granted means in order for this data to be fully analysed.

The heavy drop-hammer made it possible to evaluate characteristics of the arenas and it simulates the impact and the loading of the hoof. For example, in figure 4; Energy dissipation. The total impulse is low, when hysteresis is large, and vice versa. The gravel surface (a harder trotting surface) is in this aspect opposite to the riding wood chip surface. On gravel the impulse is low (total energy) and hysteresis (losing much energy) is large.

Arenas were subjectively evaluated. Few riders visited the same competition arena and formal between-rider agreement could therefore not be produced. The riders graded the characteristics of arenas quite differently and that some had problems to fully understand the concepts of compliancy and rebound of surfaces (elastic versus plastic deformation). The riders had the least difficulties with grading the surface firmness (based on similarity in judging and the LDH see below). This is natural since this is actually easy to evaluate when walking on the surface yourself. Through time some riders tended to change the scales towards 1= bad 5 = good, instead of the more factual criteria although written instructions (figure 1) were available in the recording sheet. The judgment of surface firmness was in agreement with mechanical measurements done with a LDH. LDH measurements could be used to distinguish between equestrian arena surfaces and to assess a limited number of characteristics relevant to riders. We note that the LDH primarily aims at simulating impact, accordingly other methods, ie. the heavy drop hammer, would be necessary to assess other properties. Future studies may show their relevance to orthopaedic risk of injury.

There is large variation for a number of training factors in the epidemiological part. Firstly riders train horses of various ages and numbers of horses they train. There are further large differences in the training volume between the riders, as well as the type of training they perform. They also vary in proportion of rest days, the proportion of days lost and their competition strategies (for some competition is a more major part of the physical training). These findings are all very interesting and the variation mimics the variation found among thoroughbreds (Dyson et al., 2008). However the results must be analysed properly including methods that can take account of clustering at several levels in the data.

With regard to the biomechanical events occurring when landing after a competition obstacle, the landing and braking characteristics of the hooves varied substantially between hind, fore, trailing and leading limbs. Developing mechanical testing devices for arena surfaces, this fairly wide range of biomechanical events must be considered, in order to simulate the horse-surface interaction. Scrutinisation of the films makes clear that horse hooves must be able to accommodate to huge variations in landing angles, forces (vertical, horizontal, lateral) and movements of the hooves at landing. The heavy drophammer will let us define the surfaces with respect to a number of characteristics. Taken together, the results from that part and the hoof landing characterics shed some light on the hoof landing interaction variation and give ideas on pathogenesis for injuries that must be explored and validated in further work. Bear in mind the multifactorial reasons for injuries.

The heavy drop-hammer is the main instrument for characterisation in the field of arenas and contructing guidelines for usage of different surfaces and may when results have been analysed more thoroughly, and more validated to the horse, be used routinely for this purpose. We hope this work will be achieved within one and half year.

The 6th aim was to develop a wireless system for field registation of sensorsignals on the horse during work and in freedom and document the movement patterns. Considerable developmental work was put into developing the electronics of this system but the efforts failed and it was decided that the heavy drop-hammer was a more useful way to assess the surfaces.

It was also shown that using an accelerometer walk, trot and canter can be differentiated. We have further used a combined GPS and heart rate meter to characterize the activity and intensity of the horses. (However there were severe technical difficulties with purchased Polar heart rate meters and we could not use this widely on the riders- the aims was to characterize the intensity). However we use accelerometers fastened to the hoof in current experiments to exactly determine the timing, and characteristics, of take-off and landing of obstacles in a study to further validate the heavy drop hammer against horse conditions.

The means from this project was used to initiate a larger project with two PhD-students, financed by World Horse Welfare, the FEI and subsequently Stiftelsen Hästforskning again. Because of that it has swelled out, but in other areas the strategy has been altered to achieve the intended result (e.g. technical development was changed).

Publications and student work

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Pedersen, A. 2010. Träningsupplägg i fem hoppstall- en pilot studiehttp://www.essays.se/essay/1f0f9f1b65/

Other dissemination of results to stakeholders

Preliminary epidemiological results have been presented on several conferences; ISES 2010, ICEP 2010, CESMAS 2010

A large number of presentations to stakeholders have been made in connection to international equestrian events like Amsterdam intenational show jumping, Gothenburg horse show, World Equestrian Games in Leipzig and other general forums for the equestrian community. Presentations have been made specifically for FEI judges and coursebuilders, for the Equine pathway organization in UK and on behalf of the Swedish Equestrian federation.

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Table 1. The proportion of the days when ridden categories used (relative to sound days), the times used per activity in minutes for hacking, fitness, flatwork and jumping and in hours for total.

	Hacking			Fitness			Flatwork			Jumping		
	Proportion	Minutes when used		Proportion	Minutes when used		Proportion	Minutes when used		Proportion	Minutes when used	
Rider	%	Mean	Std	%	Mean	Std	%	Mean	Std	%	Mean	Std
A	77	37	13	3	49	16	63	30	7	19	45	13
B	16	43	12	7	33	7	53	29	8	23	32	13
C	31	41	16	5	34	13	53	54	15	17	56	14
D	24	39	5	6	48	9	61	35	6	19	43	10
E	3	31	11	7	34	5	65	37	7	32	44	9
F	26	44	7	5	47	6	58	45	7	21	56	12
G	4	44	9	3	34	14	57	46	9	26	49	8
H	21	41	7	1	33	6	59	36	8	38	43	7
I	20	38	5	1	40	0	55	31	5	24	41	10
J	24	37	9	12	42	12	46	35	8	19	47	12

K	20	51	7	12	40	4	50	38	7	21	44	6
L	6	32	5	0	45	,	78	36	7	31	43	9
M	3	35	5	10	35	5	65	37	6	29	45	10
N	22	35	9	9	31	3	44	34	8	27	41	11
O	19	43	4	13	42	6	53	38	9	34	46	7
P	10	39	9	16	42	6	36	34	5	33	41	8
	18	40	11	7	40	9	52	37	10	25	44	11

Table 2. Days at risk, health status as judged by owner, planned rest, overall lost, levels/classes and competition days. Note that owners and veterinary records did not always agree och health status and in these cases horses were considered having days lost even if riders considered them healthy.

Rider		Total	Optimally fit		Not opt. fit		Not fit		Planned rest		Lost		*Competition*	*Per day without*
	Horses	days	days	%	days	%	days	%	days	%	Horses	Days	*Levels*	*days lost*
A	4	727	595	96	9	1	15	2	103	17	3	9	73	14,4
B	11	764	432	89	42	9	8	2	97	20	4	11	23	6,1
C	4	620	608	98	12	2	0	0	90	15	3	11	50	9,6
D	7	756	670	98	14	2	0	0	221	32	2	17	72	16,1
E	5	845	771	92	18	2	49	6	217	26	1	49	149	26
F	9	1404	1197	96	35	3	10	1	364	29	6	77	84	10,4
G	5	705	622	93	49	7	0	0	220	33	4	32	55	13,1
H	7	420	404	96	16	4	0	0	144	34	2	15	68	26,1
I	8	624	549	93	25	4	0	0	68	12	2	28	89	18
J	8	1112	1051	100	3	0	0	0	325	31	1	3	105	14,6
K	7	1302	1143	99	10	1	0	0	169	15	3	12	124	12,7
L	9	1683	1549	93	77	5	37	2	725	44	4	90	144	17
M	8	1147	1014	98	17	2	0	0	298	29	2	10	197	27,2
N	10	1150	932	91	52	5	12	1	198	19	3	90	120	16,2
O	3	555	526	95	19	3	7	1	104	19	2	29	82	19,6
P	11	2024	1635	99	12	1	9	1	554	33	3	21	133	12,3
	116	15838	13698	96	410	3	147	1	3897	27	45	504	1568	15,8

Table 3. The surfaces used in Sweden 2009. The categories are not ordered. extern is mainly warm-up and competition.

		Type of surface used (%)					
Rider	Part (of all healthy time)	Sand	Turf	Other	Sand /fiber	Sand /wood	*Extern)*
A	3.1%		2.0	52.8	16.4	18.0	10.9
B	1.1%	21.7		19.5	50.0		8.8
C	3.5%		2.8	21.3	25.9	43.0	7.1
D	2.3%	36.9	13.1	30.9		2.8	16.3
E	2.4%	35.9	7.9	16.7		11.7	27.8
F	2.9%		15.4	23.3	44.1		17.2
G	2.4%	23.4		55.4		8.1	13.0

H	2.7%	58.9	13.3	1.2			26.7
I	2.0%	43.4	12.1	25.8		0.8	17.9
J	2.2%	34.9	27.4	21.4		3.8	12.5
K	2.4%	40.1		25.3		19.4	15.2
L	2.5%	41.7	11.0	3.8		26.5	17.0
M	2.1%	32.0	10.2	17.9		9.9	29.9
N	1.9%	10.1		23.9	45.3		20.7
O	3.2%	35.6	10.1	23.4		7.6	23.3
P	1.7%	38.8		31.2	14.7		15.2
All	2.3%	26.3	7.7	24.9	13.2	10.8	17.1

Figure 1

Subjective assessment of arenas was done according to the following criteria and gradings:

*How **firm/loose** is the top layer? How much can the hoof rotate in the surface?*

1 = The surface is very loose. The hoof rotates easily in the surface. The hoof leaves a "crater" in the surface with no contour. E.g. the top layer is for example dry sea-sand.
2 = The hoof leaves imprints where it is possible to detect a vague hoof shape. E.g. wet turf.
3 = The hoof leaves a well defined imprint in the surface. The sole and the frog can be distinguished in the imprint. (When the horse pushes off a "heel" is built up in the surface behind the imprint.)
4 = The hoof leaves an imprint mainly from the shoe. You can clearly hear the sound of hoof beats.
5 = The surface is very firm. No imprints or only the rim of the shoe is seen. E.g. firm gravel/dirt road or tarmac road.

*How much of the maximal loading is dampened? The **amount** of **dampening** is evaluated as described below. (The type of dampening is described in the following question.)*

1 = The footing is very stiff. E.g. concrete.
2 = The footing is moderately stiff. E.g. could be a turf track with a high degree of clay content and which is rather dry.
3 = The footing has a limited degree of dampening. E.g. Sand based arena with a certain amount of "giving in" of the top layer but no deep pliancy.
4 = A footing that has a moderate/ obvious dampening. The dampening of the maximal loading (at least) partly derives from pliancy in deeper layers. E.g. this could either be an optimal turf track or an artificial (geo textile / wax-coated) surface. It could also be a relatively deep sand based arena.
5 = The ground is very dampening (deep/loose or elastic). E.g. either like a deep, dry sand dune or like an extremely elastic footing, e.g. rubber material with very good elasticity also in deeper layers.

*How much of the dampening is achieved by **elasticity** of the ground?*

In the previous question you described the amount of dampening in the footing. Now you are asked to describe how much of the dampening that "swings back", gives energy back to the horse i.e. is elastic.

1 = Totally non-elastic dampening. No energy is given back to the horse. (Dead ground.)
E.g. very loose and deep sand, like dry washed sand with no binding material.
2 = About 25% of the dampening is elastic.
3 = Approximately 50% of the dampening is elastic
4 = Mainly, ~75% elastic dampening.
5 = Very elastic most of the energy is returned to the horse (a "tuned" elasticity). E.g. arena with fibre-sand that is very elastic in the top layer. Another example is arenas constructed with rubber layer deeper in the construction.

*How good is the **grip**?*

1 = The footing is very slippery. You would not ride on it without studs.
2 = The horse would slip if you turn in high-speed or make relatively sharp turns. It will also slip at push off now and then. (You would probably not choose to make the horse jump on the footing without studs.)
3 = The hoof slides slightly in the landing. The hoof doesn't slip at push-off during trotting and cantering in moderate speeds and turns. (The footing permits jumping but you would maybe not do a jump off on it without studs.)
4 = The horse only rarely slips at hard breaking, sharp turns or at push-off.
5 = Extremely good grip, the horse "never" slips whatever the way you ride.

*How **even** is the surface? Is the hoof able to land flat on the ground? Grade the evenness from one to five where:*

1 = Very uneven, at every step the hoof meets the surface at different angles. E.g. frozen surface with plenty of hoof imprints.
2 -4 = In between 1 and 5
5 = Very even, a completely smooth, even surface.

*How **uniform/**consistent is the footing, including all previous properties over the entire arena? Grade from one to five where:*

1 = Large variation between different parts of the arena, i.e. very deep or slippery in certain parts of the arena.
2 -4 = In between 1 and 5

5 = Very uniform, all properties are the same all over the arena.

Figure 2-6 demonstrated the characteristics of 44 arenas according to the following

Figure 2. Surface firmness

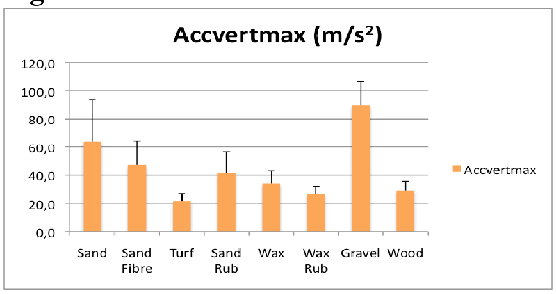

Figure 3. Dampening

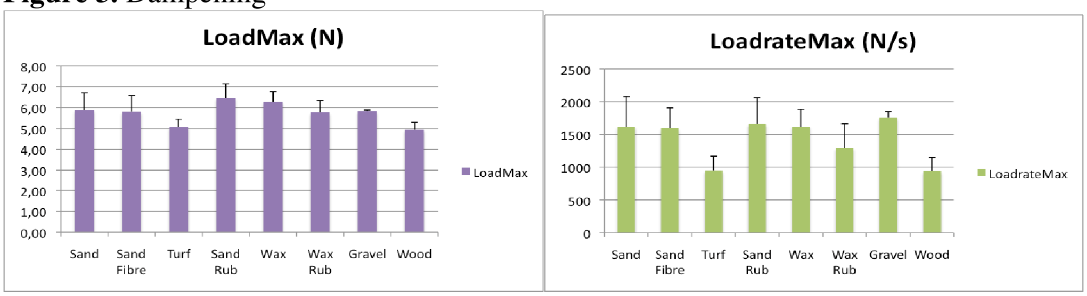

Figure 4. Energy dissipation

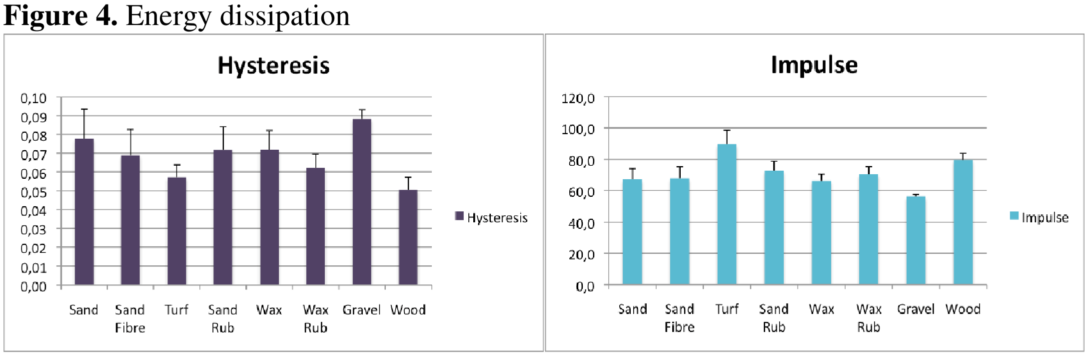

Figure 5 .Elasticity / ”going”

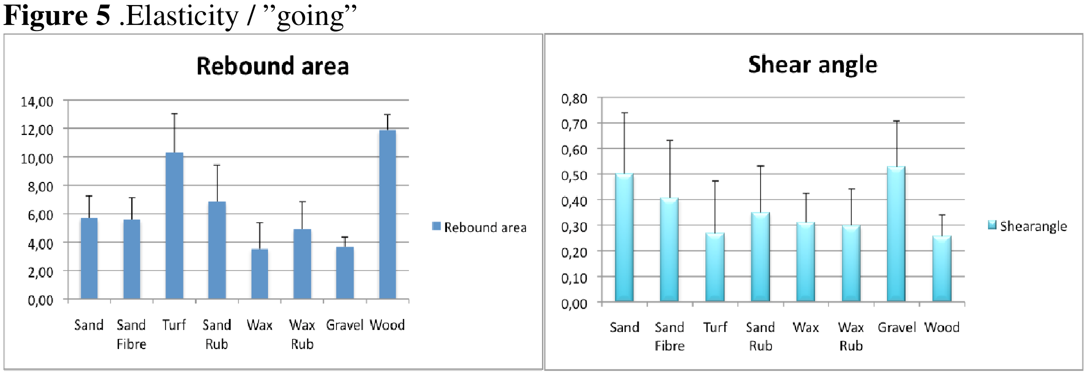

Figure 6. Shear