

Characteristics of Floors for Pig Pens: Friction, shock absorption, ammonia emission and heat conduction

Pedersen S. and Ravn, P.

Faculty of Agricultural Sciences, Department of Agricultural Engineering, Research
Centre Bygholm, Horsens, University of Aarhus, Denmark.

Soeren.pedersen@agrsci.dk

ABSTRACT

In respect to improving animal welfare and to minimize the ammonia emission from animal facilities, it is important to have appropriate information on the impact of the flooring system in pig pens. Twelve different floors, six commercially available and six experimental floors for pig pens, were investigated in respect to four different characteristics: friction coefficients, shock absorption, ammonia emission and heat conduction. The friction coefficients were measured as dynamic friction for dry floors and floors wetted with water and rapeseed oil and as static friction for dry floors. The floor elasticity was measured as shock absorption when letting a weight fall on the test floors. The ammonia emission was measured in a wind tunnel with ammonia water wetted test floors. Heat conduction was measured by a heated body placed on the test floors. The results showed that the friction coefficient for slatted floors of plastic and cast iron was lower than for concrete and also lower than recommended in literature in respect to animal welfare. The ability to absorb shocks was better for slatted floors of plastic and cast iron than for concrete slatted floors. The ammonia emission was higher from slatted floors of concrete than from slatted floors of plastic and cast iron. Finally, the heat conduction for concrete slatted floors was higher compared to slatted floors of plastic and cast iron. In conclusion, concrete slats were ideal for the animals in respect to the risk of slipping, but less than ideal in respect to elasticity and ammonia emission, furthermore they were cold for the animals. Plastic and cast iron slats were too slippery, but better for the environment in respect to ammonia emission, moreover they were warmer for the pigs to lie on.

Keywords: Pig, floor, friction, shock absorption, ammonia emission, heat conduction, Denmark

1. INTRODUCTION

Pigs are normally kept in pens their whole life, thus the pen must provide appropriate conditions for the pigs. Therefore, it is important to get more information about different types of flooring used in pig pens. This study examines the characteristics of different flooring systems, where it is important that the floors are not too slippery (Nilsson, 1988, Richter, 2002), on the other hand they must wear the claws to a certain level, but not be so rough that the pigs wear down their claws. It is also preferable that the floor is not too rigid, with respect to leg health. The floor surface must be made in such a way that as much as possible of the urine deposited on the floor will run off quickly to the slurry system with a minimum of ammonia emission to the environment (Aarnink et al., 1997). Another factor is the heat transmission of the floor, which depends on the heat transmission coefficient and the heat capacity of the floor. If the heat transmission coefficient is high combined with a high heat capacity, the floor will be cold, which can be a disadvantage under cold climate

conditions and an advantage during warm conditions. The objective of the work is to make a characterization of floors based on laboratory measurements, which can be used to select floor types.

2. MATERIALS AND METHODS

2.1 Floors

The twelve tested floors were selected and constructed to examine and compare different alternatives of slatted floors and one solid floor. The floors are described in Table 1. Table 2 shows the slat dimensions and number of repetitions of the different tests.

Table 1. Description of the tested floors

Number	Material	Type	Comments
1	Polyethylene	Slatted	Commercially available
2	“	“	As floor 1, with sand incorporated in the surface
3	“	“	As floor 1, with rubber strips in the surface
4	Concrete	Solid	Flag with a slightly profiled surface
5	“	Slatted	Commercial short element
6	“	“	Commercial long element
7	“	“	As floor 6, with brushed surface
8	“	“	With 50 % concrete replaced by plastic granules
9	“	“	Studded plastic cover
10	Cast iron	“	Commercial
11	“	“	As floor 10, with polished surface
12	“	“	As floor 10, mechanically treated with grooves

Table 2. Dimensions of floors, and number of repetitions of tests

	Slat width, mm	Slat depth, mm	Slot width, mm	Number of repetitions			
				Friction **)	Shock absorption	Ammonia emission	Heat conduction
1 Plastic	10	17*)	10	33	10	3	1
2 “	10	17*)	10	33	10	3	1
3 “	10	17*)	10	33	10	3	1
4 Concrete	Flag	65	-	33	10	3	1
5 “	81	90	19	33	10	3	1
6 “	81	90	19	33	10	3	1
7 “	81	90	19	33	10	3	1
8 “	181	90	19	33	10	3	1
9 “	81	90	19	33	10	3	1
10 Cast iron	11	7	10	33	10	3	1
11 “	11	7	10	33	10	3	1
12 “	11	7	10	33	10	3	1

*) T-shaped slats

**) Five dynamic measurements parallel and five perpendicular to slats for dry, wetted with water or rapeseed oil, and three static measurements for dry floors.

Figure 1 shows the slatted floors made of plastic (polyethylene) with different surfaces. Figure 2 represents the concrete floors with different surfaces, and Figure 3 represents the slatted floors of cast iron with different surfaces.

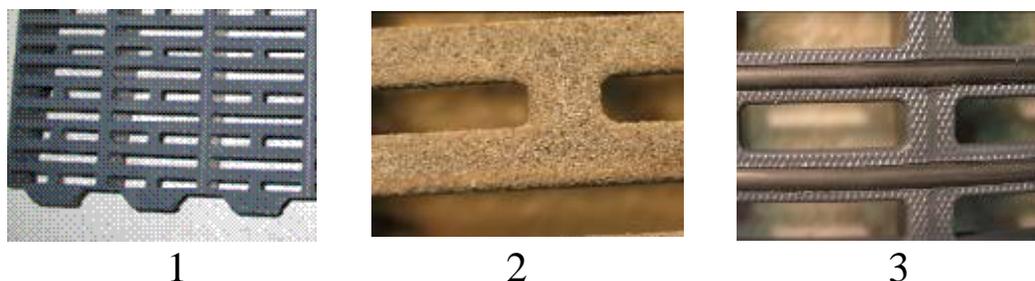


Figure 1. Plastic: floor 1, standard slat, 2, close-up view of slat with sand incorporated in the surface and 3, close-up view of slat with rubber strips.

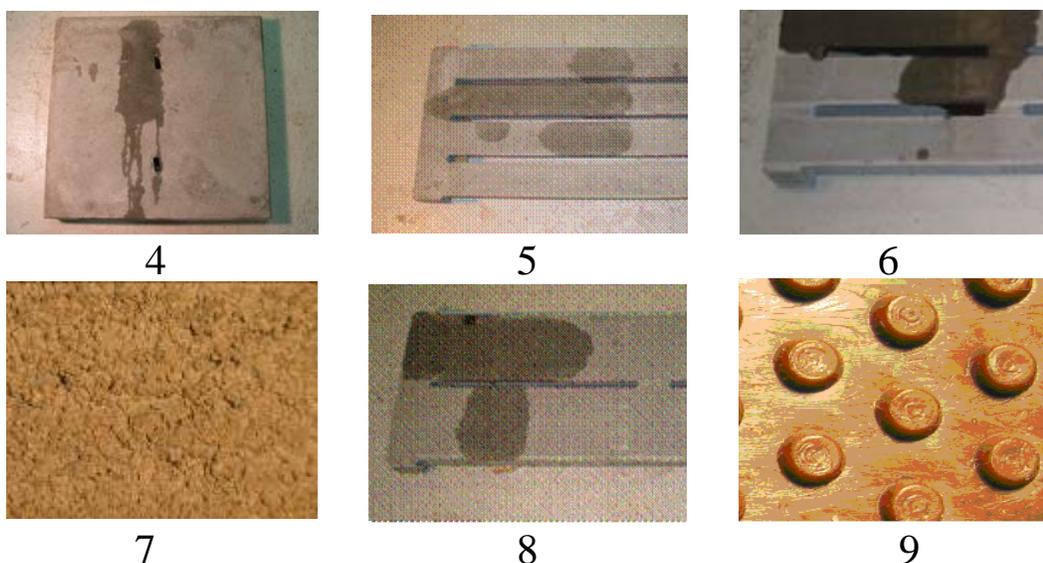


Figure 2. Concrete: floor 4, solid concrete, 5, concrete slatted floors, short element, floor 6, concrete slats, long element, 7, close-up view of concrete slats floor with brushed surface, 8 slats where fifty percent of the concrete is replaced by plastic granules and 9, close-up view of concrete slats with a plastic studded cover.



Figure 3. Cast iron: floor 10, grid of cast iron, 11 close-up view of cast iron grid grinded in the surface and 12, close-up view of cast iron grid mechanically treated with grooves.

2.2 Friction

Dynamic friction is traditionally defined as the average friction over a certain distance however the dynamic friction can vary very much, especially when moving perpendicularly to slats. Another important factor is the surface condition, because surfaces with a layer of manure can be very slippery. The measurements of friction were carried out with the test facilities shown in Figure 4. A circular block of polyurethane (“claw”) Philan®44-A85 with a diameter of 30 mm, representative for growing pigs, was moved along the test floor. Initially, the influence of the weight on the friction coefficients for all the 12 tested floors, was measured for loads of 8, 31 and 126 kNm⁻². No influence was recorded on the friction coefficient by different weights, which can be explained by the rigidity of all the 12 tested floors, therefore a force of 50 N corresponding to 70.7 kNm⁻², was selected for the tests. The friction was measured over a distance of 191 mm with a high speed recording frequency of 100 Hz over 3 minutes, corresponding to a speed of 1.06 mm/s. The large number of recordings and the low speed ensured that all surface irregularities were measured.



Figure 4. Equipment for friction measurements (left) and blow up of the “claw” section (right).

2.3 Shock absorption

The elasticity of floors depends on both the softness of the floor material and also on the suspension of the floor. Concrete slatted floors have normally very low elasticity, due to rigid slats and slat supports, whereas e.g. plastic slats are more elastic. It is assumed that some elasticity also is preferable for pig pens to avoid leg damages in pigs.

For evaluation of the twelve pen floors the device shown in Figure 5 was developed according to



Figure 5. Device (DIN 18 032, 2001) to measure shock absorption (left) and a close up showing the unit with disc springs to the left and the load cell (right).

a German model (DIN 18 032, 2001). The principle of the device was to measure the maximum deceleration force when a mass of 20 kg was released from a fixed height of 100 mm. To avoid extremely high forces exposed to the load cell when testing rigid materials, a disc spring section was incorporated in the system (Figure 5). A 22 mm thick steel plate was used as a reference, on which the test facility was placed.

2.4 Ammonia Emission

In respect to both the indoor concentrations and the mass being emitted to the environment, it is important that the ammonia generated from pig pens is low. Different factors as indoor temperature, ventilation rate and floor type affect the ammonia emission. Nimmermark and Gustafsson (2005) found that the ammonia emission in a house for laying hens with manure conveyors decreased when ventilation rate were lowered and Gustafsson et al. (2005) found that the ammonia emission was reduced by 25 to 38 % when a tie-stalls cowshed with 740 mm open manure gutters and solid manure was replaced with 310 mm slats behind the cows.

It is preferable that the urine deposited on slatted floors move directly to the slurry channel avoiding evaporation of ammonia from the floor. The best substance for testing the ammonia emission from different types of slats is to use pig manure, however, it was assumed that it would be difficult to standardize pig manure in respect to composition and especially moisture content in such a way that the test floors could be evaluated properly. Therefore it was decided to use as a standard, ammonia water with an ammonia content of 8 %. The advantage of ammonia water is that it is reproducible while the disadvantage is that it does not fully representative normal pen conditions with urine and faeces on the floors.

The procedure for measuring the ammonia emission was to wet the floor surface completely by brushing the surface. Depending on the shape of the slatted floors the sides of the test floors were, to some extent, wetted too. Because the ammonia evaporated quickly from the surface, the ammonia wetting procedure was done on a table near the testing apparatus and then immediately moved to the wind tunnel. The wind tunnel shown in Figure 6 measured 0.5 m x 0.5 m. It was equipped with a fan, which could maintain a fixed airflow, corresponding to an average air velocity of 0.15 ms⁻¹ along the floor surface. The background ammonia concentration in the test hall was measured a minimum of 30 minutes before each measurement. The background concentration, which was about 1 ppm or less, was subtracted from each measured concentration. Due to instability in the measured ammonia concentration, the ammonia emission was only taken from the third minute of sample period. Altogether four repetitions were made for each floor type, but the first measurement of all floors was eliminated due to doubt about sufficient wetting of the floors. The measuring period lasted until the ammonia concentration reached the background concentration, which occurred after 1 to 2 hours. Because the ammonia emission was simulated by means of ammonia water, the ammonia emission is only shown as relative values.

2.5 Heat conduction

The heat transfer from the animals to the floor when pigs are lying in the pen depends on various factors, such as the initial floor temperature, the heat capacity of the floor, and the insulation of the floor. In the present study, the heat transfer from a pig lying in the pen was simulated by a heated artificial body placed on the test floor. The body consisted of a water heated rectangular box (0.21

m²) simulating a growing pig lying on the side with a frame (0.37 m x 0.57 m) of expanded polystyrene and a plastic foil bottom to make the contact with the test floor. Inside the box was a grid



Figure 6. Test of ammonia emission.

of 8 copper water tubes connected to a precision Heto KB 21 heating unit, where the water temperature could be kept constant at 35°C +/- 0.1 °C. The energy transferred to the floor was measured as electric power consumption to maintain this temperature. Due to convection heat loss from the heating unit, heat loss from the insulated water circuit and the heated body, there was a basic heat consumption of approximately 75 W with the body placed on expanded polystyrene. That basic consumption was measured before each individual test and subtracted. The test procedure was to keep the heated body on the well-insulated surface of expanded polystyrene until the temperature and energy consumption was stable. Then the heated body was moved to the test floor and at the same time the measurements were started. The heat transfer to the floor started lowering the water temperature in the heated body and the heating unit started heating it. In respect to allow convection, the test floors were elevated 0.4 m above the room floor.

The heat transfer must be evaluated in respect to the available animal (sensible) heat, because the heat accumulated in the pen floor must be covered by the animal sensible heat. For a pig of 50 kg, the total animal heat production is 175 W on a diurnal basis, of which 100 W is sensible heat and 75 W is latent heat (Pedersen and Sallvik, 2002). The heated body is shown without cover in Figure 7 to the left.



Figure 7. Test of heat dissipation. The heated body without cover (left), and in the test situation (right)

Due to heat dissipation to the test floor and restriction in the water circulation capacity, the body temperature was slightly lower than 35 °C.

The heat loss to the test floor was calculated as the total heat loss for the system, subtracted the basic heat loss due to heat transmission and convection, when the body was placed on a well-insulated foam “floor”.

3. RESULTS AND DISCUSSION

3.1 Friction

Figure 8 is a measurement of a slatted floor of cast iron showing that the friction coefficient increased rapidly to nearly 3, when the “claw” passed the slats in the slatted floor.

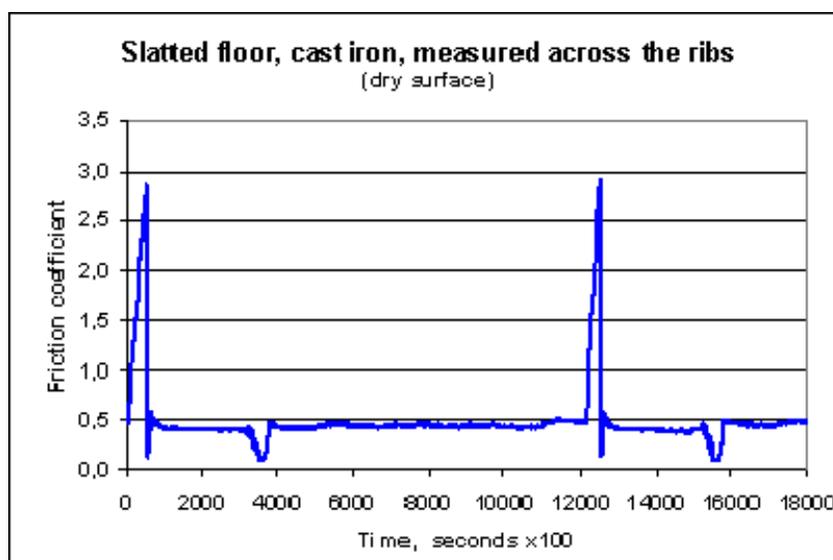


Figure 8. Example of friction measurement perpendicularly to the slats of cast iron slatted floor

Investigations were carried out for each of the twelve floors under dry conditions and wetted with water or rapeseed oil. Furthermore, the friction coefficients were measured under static conditions for dry floors. Table 3 shows the dynamic friction coefficients as average of ten repetitions, including five parallel and five perpendicularly to the slats. Each repetition comprises the total measuring distance, including the peaks when the “claw” is passing from one beam to another.

The standard deviation (s.d.) in Table 3 is common for all ten repetitions and was in most cases below 0.04, showing good reproducibility. Higher standard deviations were due to inherent differences between the group of five measurements parallel and five measurements perpendicular to the slat direction. For example, the friction coefficient for floor number 2, the five repetitions parallel to slat direction was 0.64, but 0.78 for measurements perpendicular to the slat direction resulting in a standard deviation of 0.09 for dry conditions.

Table 3. Dynamic friction coefficients and the increase from dynamic to static friction for dry floors

Floor Number	Dynamic friction coefficients for different floor surfaces									Increase from dynamic to static Friction (dry surface) %
	Average						Maximum			
	Dry		Wet		Oil		Dry	Wet	Oil	
	Avg	s.d.	Avg.	s.d.	Avg	s.d.	Avg.	Avg.	Avg.	
1	0.49	0.01	0.43	0.03	0.24	0.01	0.55	0.47	0.29	34
2	0.71	0.09	0.79	0.04	0.77	0.03	0.91	0.96	0.92	36
3	0.38	0.08	0.30	0.05	0.26	0.03	0.81	0.48	0.44	27
4	0.47	0.02	0.50	0.01	0.50	0.02	0.58	0.59	0.60	21
5	0.67	0.04	0.73	0.02	0.61	0.02	0.83	0.86	0.70	15
6	0.71	0.05	0.70	0.01	0.51	0.01	0.77	0.76	0.65	20
7	0.73	0.03	0.77	0.02	0.59	0.08	0.95	0.93	0.92	38
8	0.71	0.04	0.74	0.03	0.58	0.07	0.79	0.78	0.71	16
9	0.46	0.09	0.48	0.02	0.36	0.03	1.06	0.94	0.63	20
10	0.49	0.02	0.44	0.02	0.48	0.01	2.91	2.50	2.51	42
11	0.44	0.01	0.49	0.05	0.48	0.02	2.32	2.00	2.18	14
12	0.55	0.02	0.56	0.02	0.50	0.02	2.18	1.94	2.47	14

The dynamic friction coefficients (Figure 9) for dry slatted floors of plastic (polyethylene) and of cast iron were about 0.5, whereas for the concrete slatted floors the dynamic friction was about 0.7, which are respectively below and above the static friction threshold of 0.63 for pig pens, suggested by Thorup et al. (2007). The friction coefficient was not sensitive when the surface was wetted with water or dry, but it decreased to about 0.25 for plastic slats wetted by rapeseed oil and to about 0.55 for concrete slats wetted by rapeseed oil, while cast iron seems unaffected to rapeseed oil treatment. Slatted floor of plastic with sand incorporated in the surface had friction characteristics like concrete. Moreover, concrete slats with plastic covered surface had lower friction coefficient than slats of concrete. Plastic slats wetted with oil may be considered too slippery. Another parameter under discussion is the maximum values measured when passing an obstacle, such as from one slat to another, which showed five-fold increases.

The static friction coefficient was defined as exactly the point when the “claw” started to move. The increase in the friction coefficient from static to dynamic friction for dry conditions is also shown in Table 3 and Figure 10 shows an example from measuring static friction. On average, the static friction coefficients of all test floors were about 25% higher than their dynamic friction coefficients.

The friction a surface poses in a given situation depends not only on its general friction properties but also on how the animal applies the slipping load (i.e. contact surface, contact angle, speed etc.) and whether the surface is dry, wet or soiled (Nilsson, 1988). Also the normal load influences the

friction. Higher load results in penetration in soft materials causing a higher friction coefficient. By studying animal behavior and performing friction measurements on a series of flooring materials for animal housing Nilsson (1988) recommended a minimum friction coefficient of 0.35 when using a friction tester according to the drag method. Richter (2002) made a guideline on the friction

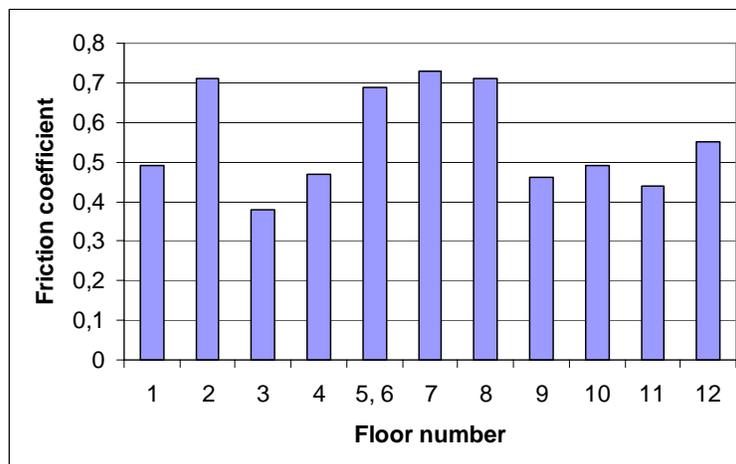


Figure 9. The dynamic friction coefficient for dry surfaces as average of floors with similar surfaces.

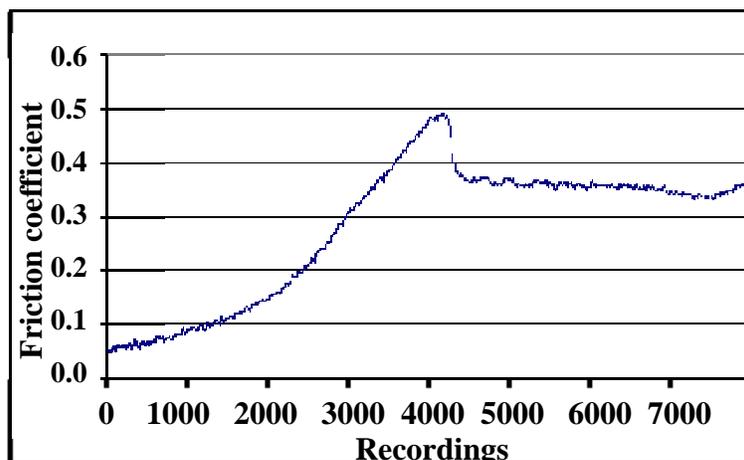


Figure 10. Example of static friction measured at 100 Hz. The peak corresponds to the static coefficient of friction.

coefficients for floor surfaces for animals stating that friction coefficients in the range of 0.5 to 0.7 were suitable for floor surfaces. Friction coefficients below 0.5 were estimated to be too slippery, whereas friction coefficients above 0.7 were considered to be too abrasive. Caenegem et al. (2004) investigated the efficiency of grooved floors in dairy cattle houses and found friction coefficients around 0.4 for both standard and grooved concrete floors. Rushen and Passillé (2006) examined the effect of roughness on the locomotion of dairy cows and found that the use of commercially available soft rubber flooring material decreased slipping, but also that a thin layer of slurry increased

the frequency of slipping. Hansen et al. (1999) tested 14 different mattresses for cubicle dairy houses and found that the friction coefficient was 0.6 or above for four out of five tested hard mattresses of rubber but below 0.5 for soft mattresses. Franck et al. (2007) examined the frictional interaction between bovine claw and concrete floor and found that mattresses caused less, but enough friction compared to floors with synthetic coverings. They also found that the static friction was consistently higher than the dynamic friction. Moreover, growing pigs walking on solid concrete floor under different conditions have been investigated in a biomechanical gait analysis (Thorup et al., 2007). This study showed that on dry floor the pigs' progression length was 0.75 m, which decreased to 0.70 m on a greasy floor, meaning that the pigs reduced their progression length on a potentially slippery floor. Moreover, the pigs adapted to contaminated floor conditions by reducing their walking speed and peak utilized friction coefficient both on wet and greasy conditions compared to dry condition. Thorup et al. (2007) also suggested a static friction coefficient threshold of minimum 0.63 to ensure safe walking, which lies in the high end of the dynamic friction coefficient range suggested by Richter (2002).

Concrete slats with plastic covered surface has lower friction coefficient than slats of concrete. Plastic slats wetted with oil may be considered as too slippery.

3.2 Shock absorption

Figure 11 shows an example of a measurement including dampening of the jumps. The final relative absorption for the resting body corresponds to the body mass of the released mass.

With reference to a 22 mm thick steel plate, the shocks on plastic slatted floors are reduced to about 40% and for slatted floors of cast iron to about 65%.

Fulwider and Palmer (2004) examined the softness of different types of mattresses for cows and found that the cow preference was highly correlated to the softness measured by the deceleration of a 20-kg hammer from a height of 0.3 m. Also from sports halls it is well-known that the floor needs some elasticity, meaning that the bearings of the floors in combination with compressibility of the floor materials in some extent must be elastic. The results of the shock absorption test of the 12 floors are shown in Table 4.

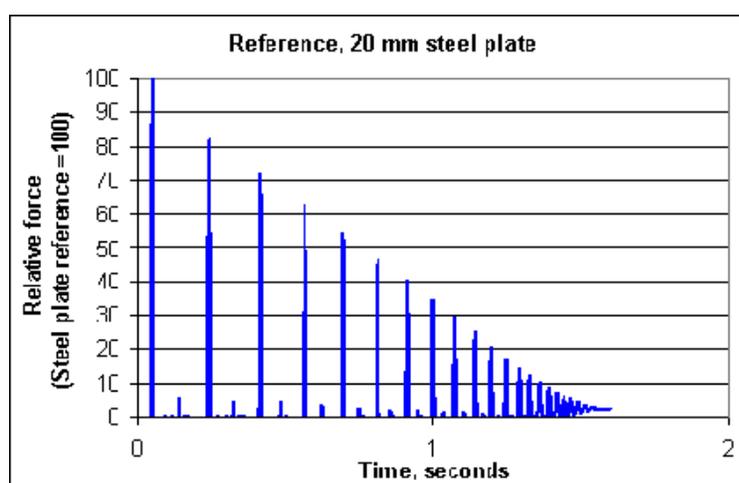


Figure 11. Measurement of shock absorption for a 22 mm rigid steel plate.

Table 4. Shock absorption with reference (100%) to a 22 mm steel plate

Floor type	Floor Number	Shock	Variation
		Absorption (%)	Coefficient (s.d./average)
Plastic (polyethylene) slats, standard	1	40.5	0.3
Plastic slats with grouted sand in the surface	2	40.0	0.8
Plastic slats with rubber strips in milled grooves	3	36.6	0.5
Solid concrete flag	4	95.3	1.3
Concrete slats, short element	5	85.8	0.7
Concrete slats, long element	6	70.8	0.6
Concrete slats with brushed surface	7	76.7	1.1
Concrete slats with incorporated plastic granulates	8	74.4	0.9
Concrete slats with plastic studded cover	9	68.2	0.4
Cast-iron slats, standard	10	63.8	1.0
Cast-iron slats with polished surface	11	63.5	0.2
Cast-iron slats with milled grooves	12	66.0	0.8

Francis et al. (1988) examined 13 floors in different types of halls and found a big variation in shock absorption from one floor to another, thus expressed by gravity ($1\text{ g} = 9.81\text{ms}^{-2}$) the absorption was 20 to 120 g.

In conclusion, the ability to absorb shocks was good for suspended slatted floors of plastic and acceptable for cast iron, but poor for slatted floors of concrete, which were very rigid.

3.3 Ammonia Emission

The results of measurement 2, 3 and 4 are shown in Table 5.

Table 5. Ammonia emission per treatment in mg NH₃ per 0.24 m² floor surface

	Floor	Measurement			Average mg NH ₃ per 0.24m ²	Standard Deviation s.d.
		2	3	4		
Plastic	1	191	153	179	174	20
“	2	178	155	252	195	51
“	3	209	193	250	217	29
Flag	4	165	201	211	192	24
Concrete	5	205	248	364	272	82
“	6	242	321	337	300	51
“	7	331	537	430	432	103
“	8	183	424	284	297	121
“	9	360	330	488	393	84
Cast iron	10	123	204	215	181	50
“ “	11	148	146	196	163	28
“ “	12	95	175	281	184	93

Figure 12 shows the ammonia emission for one out of four repetitions on measurements in wind tunnel for the twelve tested floor types.

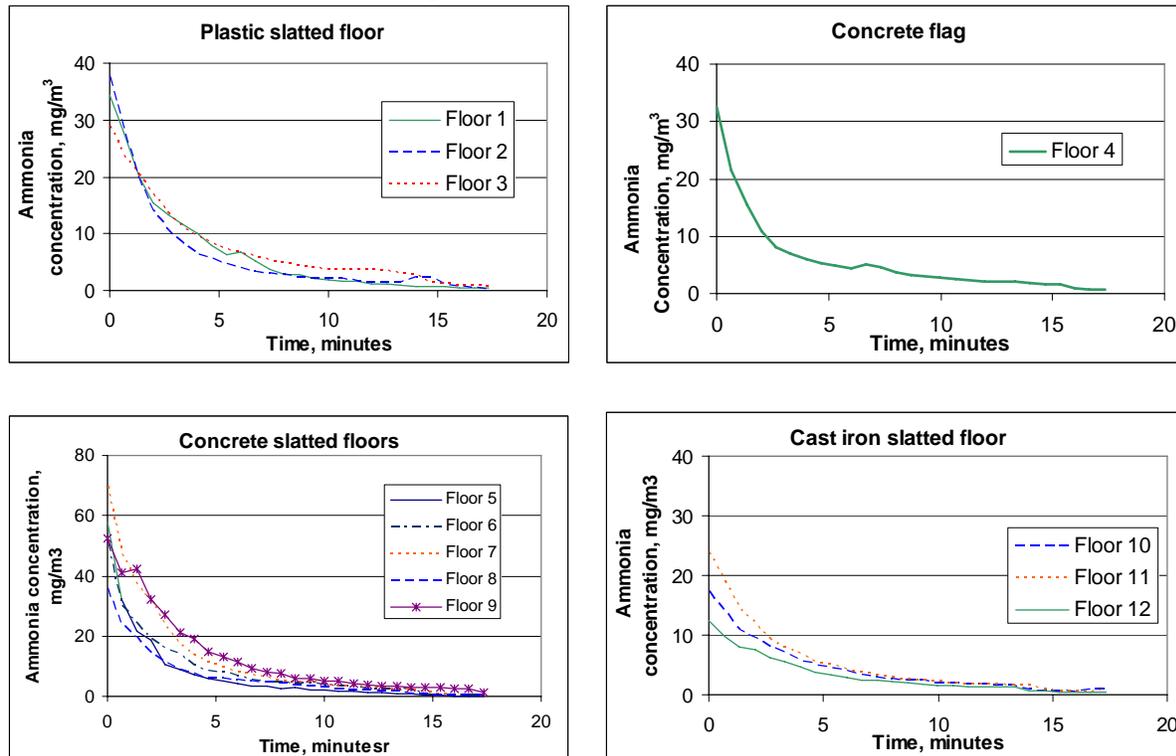


Figure 12. Ammonia concentrations for measurement two out of four repetitions.

Figure 13 shows the results grouped by surface similarity.

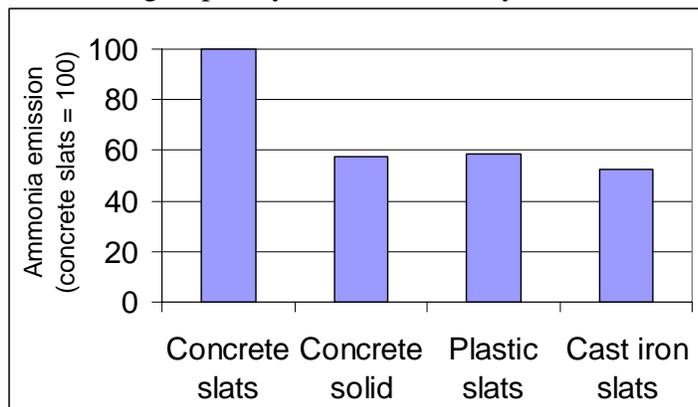


Figure 13. Ammonia emission relative to concrete slatted floor

The ammonia emission from solid concrete (flag) was only 57% compared to concrete slatted floors, because the total exposed surface is smaller than for slatted floors, since the sides are wetted too. The ammonia emissions from slatted floors of concrete wetted with ammonia water were nearly double the ammonia emission from slatted floors of plastic and cast iron. In comparison Elzing and Swierstra (1993) also found that steel slatted floor emitted less ammonia than concrete

floors. Aarnink et al. (1997) found that the floor porosity affected the urine puddle depth and the amount of faeces present to produce ammonia. Svennerstedt (1998) measured ammonia emissions from concrete slatted floors for cows and from plastic slatted floors for pigs and found that the ammonia emission was higher for concrete slatted floors than from plastic slatted floors. Pelletier et al. (2002) found that the ammonia emission was higher from 30 MPa (30 N/mm² compressive strength) concrete than from concrete covered with epoxy. Swierstra et al. (2001) examined a grooved floor system with open perforation for cattle and found a reduction in ammonia emission of 46% compared to solid floor.

In conclusion the present work shows good agreement with reported literature.

3.4 Heat conduction

The twelve floor types were very different from one type to another, from polyethylene slatted floors with low mass and heat transmission coefficients to concrete slatted floors with high mass and transmission coefficients. One of the tested concrete floors should be considered as a two-layered floor with a low density plastic top layer on a concrete base, whereas another concrete slab is a mixture of concrete and plastic granules with the potential for lower transmission coefficient and a lower heat conduction. The measurements (Table 6 and Figure 14) of a test floor included recording the room temperature, water temperature of the heated body and the temperature in the layer between the heated body and the test floor. To allow convection below the test floors, the 12 floor types were elevated 0.4 m above the floor in test hall.

Table 6. Temperatures and heat transfer to floor over the first hour

Floor Type	Body temp. °C		Floor temp. °C		Room temp. °C		Heat transfer ^{*)}	
	Average	s.d.	Average	s.d.	Average	s.d.	W	Wm ⁻²
1 Plastic	35.1	0.1	32.3	0.6	23.6	0.2	9.7	46
2 “	35.0	0.2	33.5	1.1	20.0	0.3	9.4	45
3 “	35.2	0.2	34.0	0.3	20.5	0.2	11.8	56
4 Concrete	31.9	0.9	28.4	1.5	21.5	0.2	41.9	199
5 “	32.7	0.7	31.7	1.1	21.6	0.1	39.2	186
6 “	34.2	0.2	31.0	0.9	23.1	0.1	33.3	158
7 “	32.3	0.7	30.7	1.3	21.3	0.2	31.0	147
8 “	33.3	0.6	31.6	0.9	22.3	0.1	20.9	99
9 “	33.8	0.2	31.4	0.4	21.5	0.3	19.0	90
10 Cast iron	34.0	0.2	30.1	0.2	20.9	0.3	21.3	101
11 “	34.1	0.3	32.9	0.6	20.5	0.5	17.1	81
12 “	34.4	0.5	30.9	0.7	20.6	0.3	19.4	92

^{*)} Average for the first hour of the measuring period

It was expected that the heat transfer would be high in the first minutes of an experiment and thereafter decrease, but Table 6 and Figure 14 show that the heat transfer is nearly constant over time. One reason could be related to the time constant of the heating system which is about two minutes and is why the temperature of the heated body dropped down in the first minutes of the measuring period.

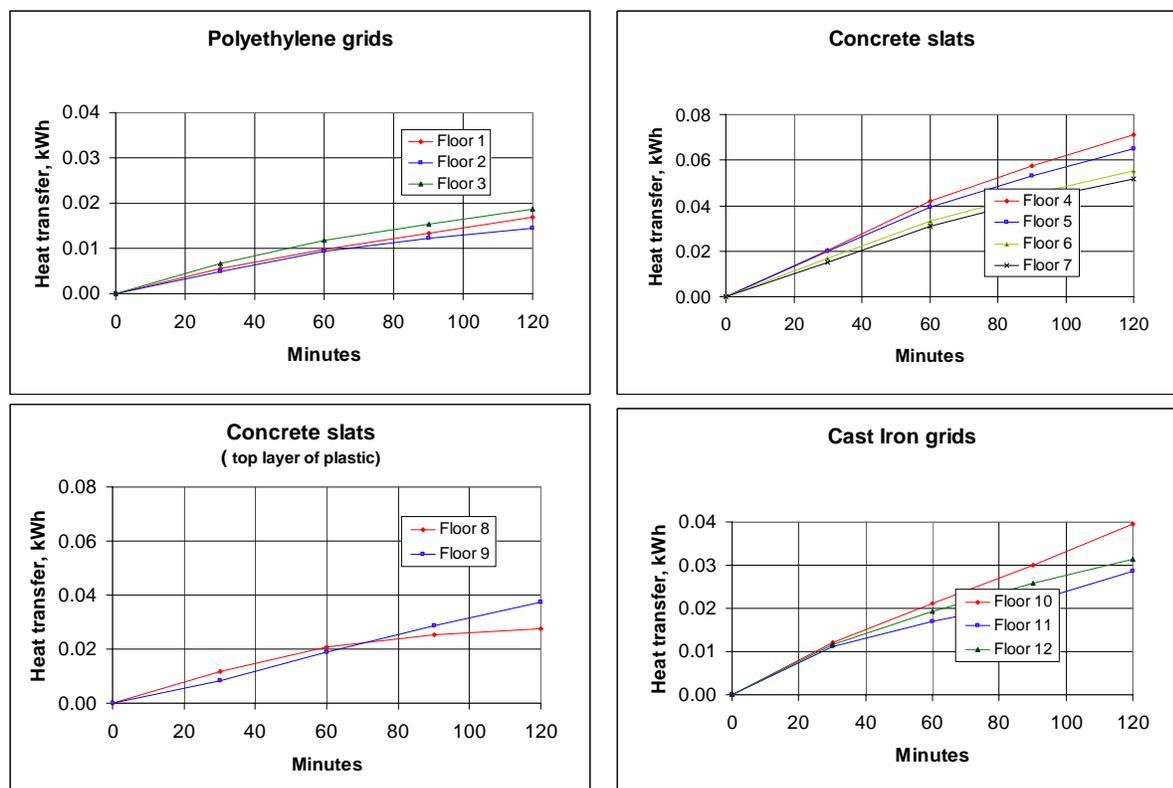


Figure 14. The heat transmission to the test floors during two hours.

Another reason could be that the heat release from the tested floors was nearly constant in few minutes after the start of measurement, due to convection. For floors of e.g. polyethylene and cast iron with low mass, the whole test floor was heated very fast. For floor 8 where 50 per cent of the concrete is replaced by plastic granules it is remarkable that the heat transfer decreases after one hour, which could partly be explained by a low heat transmission coefficient of the plastic granules. The heat dissipation over time is shown in Table 7.

Table 7. Heat dissipation over time for a 370 x 570 mm² body

Time Min.	Heat dissipation accumulated, Wh, (floor 1 to 12)											
	1	2	3	4	5	6	7	8	9	10	11	12
30	5.6	5.1	5.6	20.5	20.0	15.2	15.2	11.9	8.2	12.0	11.2	12.1
60	9.7	8.9	10.2	41.9	39.2	31.0	31.0	20.9	19.0	21.3	17.1	21.4
90	13.4	11.0	12.3	57.6	53.3	42.4	42.4	25.2	28.5	30.0	21.6	
120	17.0			71.0	65.0	51.6	51.6	27.4	37.4	39.5	28.6	

The heat transmission from the heated body placed on the floor during the first hours was 3.5 times higher for concrete slats than for slatted floors of plastic and 2 times higher for slats of cast iron than for plastic. For concrete slatted floors with plastic cover or plastic granules mixed into the concrete the heat transmission was reduced by about 40 % compared to concrete slatted floor. Compared to the animal sensible heat for a 50 kg pig, which is about 100 W at normal pig housing temperature, the heat transfer from the pig body to the concrete floor will be about 40% of its heat production the first time it lies down.

4. CONCLUSIONS

The dynamic friction coefficients for dry slatted floors of plastic (polyethylene) and of cast iron were about 0.5 and for slatted floors of concrete about 0.7. The surface friction coefficient was not sensitive by water wetted or dry, but it declined to about 0.25 for plastic slats wetted by rapeseed oil and to about 0.55 for concrete slats wetted by rapeseed oil, whereas cast iron seemed unaffected to rapeseed oil treatment. Slatted floor of plastic with sand incorporated in the surface had friction characteristics like concrete. Concrete slats with plastic covered surface had lower friction coefficient than concrete slats. Plastic slats wetted with oil may be considered too slippery.

The static friction coefficient was about 25% higher than the dynamic friction.

The ability to absorb shocks was good for suspended slatted floors of plastic and acceptable for cast iron, but poor for slatted floors of concrete, which were very rigid.

The ammonia emission from ammonia water moistened slatted floors was nearly twice the ammonia emission from slatted floors of plastic and cast iron.

The heat transmission from a heated body placed on the floor was 3.5 times higher during the first hour for concrete slats than for slatted floors of plastic and 2 times higher for slats of cast iron than for plastic. For slatted floors of concrete with plastic cover or plastic granules mixed into the concrete the heat transmission was reduced by about 40 % compared to a concrete slatted floor.

5. ACKNOWLEDGMENT

The Danish Ministry of Food and Fisheries funded this study as part of project no. 3412-04-00114.

6. REFERENCES

- Aarnink A.J.A., Swierstra D. van den Berg. A.J. and Speelman L., 1997. Effect of type of slatted floor and degree of fouling of solid floor on ammonia emission rates from fattening piggeries. *Journal of Agricultural Engineering Research*. 66(2):93-102.
- Canegem L. van, Steiner. B. and Gygax. L., 2004 Experiences of Grooved Floors in Dairy Cattle Houses. In *Book of Abstracts. Part 2. AgEng 2004 Leuven. Belgium*. P.614-615.
- DIN 18 032, 2001. *Künstlichen Sportler Berlin KSB*
- Elzing. A. and Swierstra. D. 1993. Ammonia emission measurements in a model system of a pig house. In: *Nitrogen Flow in Pig Production and environmental Consequences*. ed. M.W.A. Verstegen. L.A. den Harzog. G.J.M. van Kempen et J.H.M. Metz 280-285. Wageningen. The Netherlands: Pudoc Scientific Publishers
- Francis. P.R., Leigh. M. and Berzins. A., 1988. Shock Absorbing Characteristics of Floors Used for Dance Exercise. *International Journal of Sport Biomechanics*. 4: 282-305.
- Franck. A., Opsomer G., de Kruif A. and De Belie N., 2007. Frictional interactions between bovine claw and concrete floor. *Biosystems Engineering* 96:565-580.
- Fulwider. W. K. and Palmer R. W., 2004. Use of impact testing to predict softness. Cow preference, and hardening over time of stall bases. *J. Dairy Sci.* 87:3080- 3088.
- Gustafsson, G., Jeppsson K-H., Hultgren J. and Sanno J-O., 2005. Techniques to Reduce the Ammonia Release from a Cowshed with Tied Dairy Cattle. Manuscript BC 04 010. Vol. VII. November. 2005

- Hansen. K., Stroem. J.S., Levring. M. and Sigurdsson, S., 1999. Karakterisering af måtter og madrasser til sengebaase for køer. in Danish. (Characteristics of mattresses for cubicles for dairy cows) Internal Report 122, Danish Institute of Agricultural Sciences
- Nilsson. C., 1988. Floors in animal houses. Dissertation. report no. 61. Swedish University of Agricultural Sciences. Department of Farm Buildings. Division of Agricultural Building Technology.
- Nimmermark. S. and Gustafsson G., 2005. Influence of Temperature, Humidity and Ventilation Rate on the Release of Odour and Ammonia in a Floor Housing System for Laying Hens. Manuscript BC 04 008. Vol. VII. March 2005.
- Pedersen. S. & Sallvik. K., 2002. Climatization of Animal Houses. Heat and Moisture Production at Animal and House Levels. 4th Report of Work. Group. www.agrsci.dk/jbt/spe/CIGRreport
- Pelletier F., DeFoy. C., Marquis. A., Godbout. S., Joncas. R., Gagné. R. and Massé. D., 2002. Effects of different concrete types on gas, odour emissions and sanitation of swine buildings. In: Concrete for a Sustainable Agriculture Agro- Aqua and Community Applications. Proceedings of the IVth International Symposium 21-24 April 2002. Ghent. Belgium. Pages 287-294
- Richter. T., 2002. Skid proofing of concrete stable floors. Concrete for a Sustainable Agriculture. Agro-. Aqua- and Community Applications. Proceedings of the IVth International Symposium. Ghent. Belgium: 61-68
- Rushen. J. and de Passillé A. M., 2006. Effects of roughness and compressibility of flooring on cow locomotion. *J. Dairy Sci.* 89:2965-2972.
- Svennerstedt. B., 1998. Ammonia Emission from Laboratory Tested slatted Floor Surfaces for Animal buildings. 13th International Congress on Agricultural Engineering. Rabat (Maroco) 2-6 February 1998. International Commission of Agricultural Engineering. Volume 2. Structures. Equipment and Environment. Pages 303-311.
- Swierstra. D., Braam C. R. and. Smits M. C., 2001. Grooved floor system for cattle housing: ammonia emission reduction and good slip resistance. *Applied Engineering in Agriculture* 17:85-90.
- Thorup. V.M., Toegersen. F. A., Joergensen. B. and Jensen. B. R., 2007. Biomechanical gait analysis of pigs walking on solid concrete floor. *Animal* 1: 708-715.