Trakia Journal of Sciences, No 2, pp 197-204, 2013

Available online at:
http://www.uni-sz.bg
ISSN 1313-7050 (print)
ISSN 1313-3551 (online)

Original Contribution

ASSESSING FRICTIONAL PROPERTIES OF RUBBER FLOORS IN FREE HOUSING SYSTEMS FOR DAIRY COWS

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ABSTRACT
The investigation was conducted in a dairy cow free-stall barn. The resting area of was in individual cubicles, and walking alleys were covered with two types of rubber mats – with and without abrasion lining. An electric scraper system was used for manure cleaning, and cows were received a total mix ration ad libitum. The coefficients of static and dynamic friction of both rubber mat types when dry, wet or covered with manure were compared. It was established that static and dynamic coefficients of friction of dry rubber mats without abrasion lining were very good. Wetting reduced the frictional properties of this type of flooring. The measured static and dynamic coefficients of friction - $\mu = 0.44$ and $\mu = 0.41$ respectively, indicated a good contact between the non-abrasive rubber mat and hooves and no significant risk from slipping. The manure spilled on this flooring type compromised considerably the cohesion between hooves and rubber mat, and the measured static and dynamic coefficient of friction ($\mu = 0.4$) indicated poor cohesion, and risk from slipping and falling of cows. The dry rubber mat with abrasive lining exhibited very high static ($\mu = 0.59$) and dynamic ($\mu = 0.56$) coefficients of friction. Wetting of these rubber mats resulted in slightly higher static friction ($\mu = 0.61$), and lower dynamic friction ($\mu = 0.52$). The presence of manure mass on the abrasive flooring reduced substantially ($P<0.05$) static ($\mu = 0.49$) and dynamic ($\mu = 0.46$) coefficients of friction. Nevertheless, manure spilled on rubber mats with abrasive lining provided an optimal coefficient of friction, but possibly diminished their primary purpose, i.e. claw horn abrasion.

Key words: rubber mats, claw horn, static friction, dynamic friction

INTRODUCTION
The free housing of dairy cattle in boxes is widely implemented in many countries. This production system offers a possibility for mechanization and automation of main technological processes. From building materials, concrete is preferentially used in construction of facilities of this type. It is used for making the floors of walking alleys, feeding alleys and cubicles for rest, as it is hard, waterproof and easily available (1). The hardness of concrete floors provokes an enhanced abnormal hoof horn growth, which predisposes to lameness (2). During their use concrete floors become polished and slippery, so animals could fall and injury themselves (3). Telezhenko et al. (4) demonstrated lower stride lengths when cows walk on a concrete floor. The presence of manure mass (MM) on concrete floors there is

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another important factor making cows' gait unnatural (5). The disadvantages of concrete floors necessitate designing floorings, which reduce or eliminate unwanted effects. One option is using epoxy resin with abrasive surface particles (1). The authors demonstrated that the increased size of particles bound to epoxy resin increased the coefficient of friction. Nevertheless, this flooring was not commonly used in cattle farming due to several drawbacks related to its maintenance, life expectancy and higher costs. In cattle farms, rubber mats are widely used as floorings, as they are easily laid down, have a long life and allow for a better distribution of cows' weight on feet and thus, for more confident locomotion (6, 7). At present, rubber mat types of various lining, thickness and shape are designed to ensure a maximum comfort and welfare of animals. In some rubber mats, abrasive elements are incorporated for claw horn abrasion and less trimming procedures. When animals walk on rubber mats, they are covered with manure mass, which could alter the locomotion comfort and confidence.

The purpose of the present study was to investigate the coefficients of static and dynamic friction on two rubber mat types in free-stall barns with cubicles for dairy cattle, and their change under the influence of water and manure mass spilled on them.

MATERIAL AND METHODS

The investigation was conducted in a free-housing cattle farm with individual cubicles in the region of Asenovgrad. The cubicle floors were concrete and lined with straw. The alleys were lined with two types of rubber mats. Near to drinking bowls and at walking alleys' ends, where the direction of locomotion is changed, the concrete floor was covered with rubber mats with abrasive lining (pediKURA – KRAIBURG®), whose purpose was to wear the claw horn. The other parts of alleys were covered with rubber mats without abrasive lining (KURA P – KRAIBURG®). The slurry was cleaned with electric scraper system. The cows were fed a total mix ration ad libitum. The coefficients of static and dynamic friction were determined by a modification of the tribometer described by Phillips and Morris (8). On a 1×0.45 m platform, four pipes 105 mm in diameter and 200 mm long were attached. Into the pipes, four cow's feet (two forelimbs and two hind limbs) obtained from a slaughterhouse were inserted. A cow with a normal gait was chosen, without signs of lameness and whose hooves were with a normal shape. The carpal and tarsal joints were removed and hooves were fixed into the pipes by auxiliary devices in a way that the weight of the platform was carried by the sole surface of the four hooves after placing it the floor **(Fig. 1).**

The platform weight was 30 kg, and during the experiments it was further loaded with 50, 100 and 150 kg. According Phillips et al. (9) and Phillips and Morris (1) the weight of 150 kg applied to the platform reflects friction of the claw and there is no need of further loading. The prepared platform was pulled on floor's surface to determine the coefficients of static and dynamic friction.

The force necessary to move the platform was measured by means of a dynamometer **(Fig. 2),** provided by the Centre for Testing and European Certification www.ctec-sz.com.

The coefficients of static and dynamic friction between hooves and both rubber mat types were determined when floorings were dry, wet or covered with manure mass. The coefficients of static and dynamic friction (μ) were determined as the ratio between the minimum force for moving the platform and platform's weight (coefficient of static friction) and the ratio between the minimum force needed to maintain the platform in motion and platform's weight (coefficient of dynamic friction).

The platform weight was a sum of its own weight and the load added. The coefficients of static and dynamic friction of both rubber mat types for the three flooring condition variants were determined with additional loads of 50, 100 and 150 kg on the platform.

The coefficient of friction was calculated according to the formula:

$$\mu = \frac{F}{M}$$

where:

μ – coefficient of friction
F – the load recorded by the dynamometer [kg]
M – the platform mass with the applied load [kg]

Fig. 1. Tribometer for determination of coefficient of friction between the hooves and the floor (Philips and Morris, 2000).

Fig. 2. Dynamometer for measuring applied force

Data were statistically processed by the STATISTICA 6 software, and graphs were made in Microsoft EXCEL.

RESULTS AND DISCUSSION

Table 1 presents the coefficients of static and dynamic friction when the rubber mat floor without abrasive lining is dry, wet or covered with manure mass. The static friction coefficient of the dry floor was equal or higher than 0.5, indicating a good floor friction and support (1).

It is thought that the coefficient of dynamic friction is more important for cows with regard to floor safety and the risk for slipping (1). This coefficients for dry floor under different weights was within the optimal range ($0.4 < \mu < 0.5$), so cows moved with optimal velocity, stride length and number of steps (1).

Table 1. *Coefficients of static and dynamic friction on a dry, wet and manure mass (MM) -covered rubber mat without abrasive lining.*

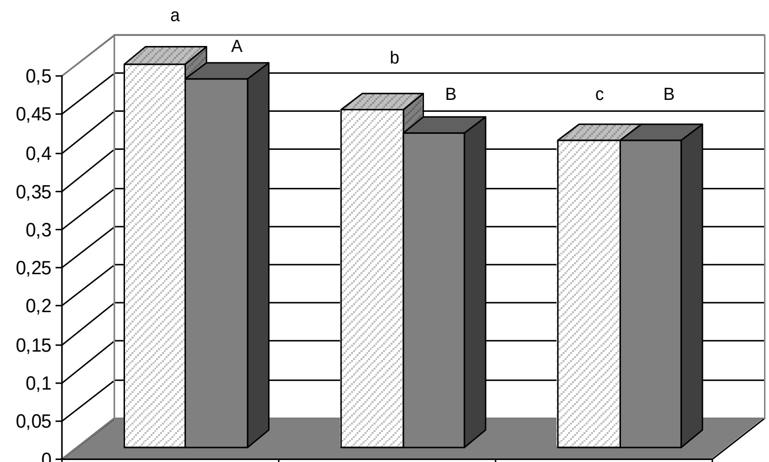
Floor type	Coefficient of static friction		Coefficient of dynamic friction	
	x ± SE	SD	x ± SE	SD
Dry floor with 50 kg	0.53 ± 0.015	0.026	0.47 ± 0.007	0.012
Dry floor with 100 kg	0.50 ± 0.007	0.012	0.48 ± 0.007	0.012
Dry floor with 150 kg	0.51 ± 0.008	0.013	0.49 ± 0.008	0.014
Wet floor with 50 kg	$0.47^{a} \pm 0.007$	0.012	$0.44^{a} \pm 0.007$	0.012
Wet floor with 100 kg	$0.45^{a} \pm 0.004$	0.007	$0.41^{b} \pm 0.003$	0.005
Wet floor with 150 kg	$0.41^{b} \pm 0.008$	0.014	$0.39^{c} \pm 0.003$	0.005
MM-covered floor with 50 kg	$0.39^{a} \pm 0.007$	0.012	$0.47^{a} \pm 0.010$	0.019
MM-covered floor with 100 kg	$0.40^{b} \pm 0.004$	0.007	$0.39^{b} \pm 0.005$	0.008
MM-covered floor with 150 kg	$0.39^{a} \pm 0.005$	0.009	$0.37^{b} \pm 0.003$	0.005

Note: Values within a column with different superscripts are statistically significantly different at $P < 0.05$.

Data from the table showed that the coefficient of static friction of wet floor was near to the lower limits of the optimal range. The coefficient of dynamic friction was comparable to the minimum value observed by Philips and Morris (1) and even lower. It should be noted that more weighted the platform; lower coefficients of static and dynamic frictions were observed. This difference for the coefficient of static friction was statistically significant between loads of 50 and 150 kg ($P < 0.05$). A significant difference was detected between loads of 100 and 150 kg ($P < 0.05$). Therefore, when the weight increases, the confidence of cows' locomotion on the floor is reduced. The values of the coefficient of dynamic friction were critical and when the platform was loaded with 150 kg, it was under the minimum (0.4). The water spilled on the floor decreased the adhesion of hooves and results in a serious risk of slipping. According to Nilsson (10), water on floors could act as a lubricant, reducing the friction between the hoof and the floor and enhancing the risk of slipping.

The data about frictional coefficients of the rubber mat covered with manure mass indicates a serious risk of slipping for cows in the farm. The coefficients of static friction were at and under the lower critical limit, and statistically significant differences were shown with the 100 kg load as compared to the other two weights ($P<0.05$). The low coefficient of static friction ($\mu < 0.4$) in the view of Philips and Morris (1) increases the risk of slipping when the limb is lifted and the hoof is still on the floor. The presence of manure mass on the rubber floor surface had also an effect on the coefficient of dynamic friction. The higher the platform weight, the lower the friction between hooves and floor. Only the 50 kg weight resulted in a coefficient of dynamic friction within the commented optimal range. The tendency towards decrease in values of this coefficient with increasing platform weight could be interpreted as a serious risk of slipping for cows weighing 600 kg. This suggestion is not in agreement with the data of Philips et al. (9), reporting that frictional coefficients were not associated to the platform weight. Nevertheless, coefficients of static and dynamic friction of the rubber floor covered with manure were small and under the critical limit of 0.4.

The difference between coefficients of static and dynamic friction of both rubber mat types is intriguing. **Fig. 3** depicts their values obtained in measurements on dry, wet and manure mass-covered rubber floors.



	Dry floor	Wet floor	Manure mass-covered floor
Coefficient of static friction	0,5	0,44	0,4
Coefficient of dynamic friction	0,48	0,41	0,4

Fig. 3. Coefficients of static and dynamic friction for rubber flooring without abrasive lining in a different condition. Values with different letters are statistically significantly different at $p < 0.05$.

It could be seen that these coefficients decrease from the dry to slurry-covered rubber mats, with statistically significant differences between all tested surfaces (P<0.05). The coefficient of static friction was optimal for dry and wet rubber mats, whereas the presence of manure mass decreased the frictional properties to the lower acceptable limit. According to Web and Nilsson (11), the critical value for the coefficient of friction is 0.4, as lower values increase exponentially the risk of slipping of cows.

According to the study, the rubber mat without abrasive lining provided the necessary adhesion between cows' hooves and the floor. Nevertheless, data from different measurements indicated also coefficients of dynamic friction, which were lower than the critical minimum value, caused by the presence of manure mass. This necessitates measures for complete removal of manure mass on alleys during the cleaning of the farm.

The data about the coefficients of dynamic friction indicated that dry flooring provided the greatest safety during walking **(Fig. 3)**. The water of manure mass spilled on the rubber surface reduced significantly the coefficient of friction as compared to that of the dry rubber mat (P<0.05). There was not a statistical difference between rubber flooring covered either with water or manure mass, and the frictional coefficients for all three variants were within the optimal range.

The data from **Table 2** demonstrated very good coefficients of static and dynamic friction of dry and wet rubber mats with abrasive surface lining. Most probably, they resulted from the abrasive particles on rubber surface, whose purpose is to wear bovine hooves and thus, to reduce the need of their prophylactic trimming. The high static and dynamic frictional coefficients suggested that this type of rubber flooring could contribute to abrasion of the claw horn and facilitate hoof care procedures.

The presence of water on the rubber mat did not alter the coefficients of static and dynamic frictions. There was a statistically significant difference in the coefficients of static friction with the 50 kg load compared to platforms loaded with 100 and 150 kg (P<0.05). In the coefficient of dynamic friction, there were no statistically significant differences for the various weights, and the high coefficients ensured a stable gait without risk of slipping (1).

Unlike the rubber mat without abrasive lining, the presence of manure mass on the rubber mat with abrasive areas did not have such an influence on coefficients of static and dynamic friction. Their values were within the optimal range, and a statistically significant difference was observed only for the dynamic frictional coefficient under a load of 150 kg vs 50 or 100 kg. Regardless of the fact that this flooring type ensured a safer locomotion of cows, the manure reduced significantly (P<0.05) the friction of MM-covered floors compared to dry or wet floors **(Fig. 4)**. This finding raised suspicions about the ability of this rubber mat for claw horn abrasion, when it is covered with manure, thus requiring additional research to specify the effect of manure mass on the abrasive properties of rubber floorings.

Table 2. *Coefficients of static and dynamic friction on a dry, wet and manure mass-covered rubber mat with abrasive lining.*

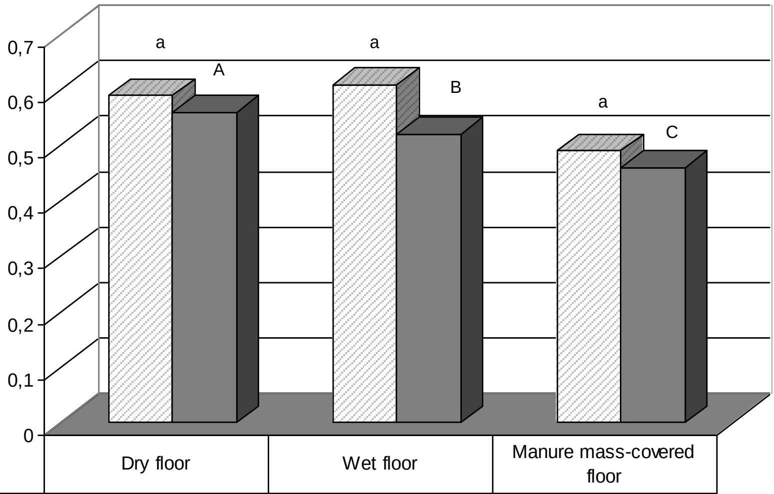
Floor type	Coefficient of static friction		Coefficient of dynamic friction	
	x ± SE	SD	x ± SE	SD
Dry floor with 50 kg	0.64 [a] ± 0.007	0.012	0.60 [a] ± 0.007	0.012
Dry floor with 100 kg	0.54 [b] ± 0.007	0.012	0.52 [b] ± 0.004	0.007
Dry floor with 150 kg	0.58 [c] ± 0.007	0.011	0.55 [c] ± 0.003	0.005
Wet floor with 50 kg	0.61 [a] ± 0.007	0.012	0.51 [a] ± 0.007	0.012
Wet floor with 100 kg	0.55 [b] ± 0.007	0.012	0.52 [a] ± 0.004	0.007
Wet floor with 150 kg	0.57 [b] ± 0.008	0.014	0.53 [a] ± 0.005	0.008
MM-covered floor with 50 kg	0.50 [a] ± 0.009	0.016	0.44 [a] ± 0.007	0.012
MM-covered floor with 100 kg	0.47 [a] ± 0.015	0.027	0.44 [a] ± 0.011	0.020
MM-covered floor with 150 kg	0.49 [a] ± 0.005	0.009	0.48 [b] ± 0.003	0.005

Note: Values within a column with different superscripts are statistically significantly different at $p < 0.05$.

The coefficient of static friction of the dry rubber mat with abrasive lining was substantially influenced (P<0.05) only by the manure mass spilled on it. Water had a positive but insignificant effect on the coefficient of static friction. The rougher surface of this rubber mat due to abrasive particles probably compensates for the effect of water on floor's frictional properties. Phillips and Morris (8) and Franck et al. (12) also established higher frictional coefficients of wet than of dry floors. When the floor surface is rough enough, water remains among the abrasive particles and does not influence the friction between the hooves and the floor (12). Despite the MM-induced lower coefficient of static friction, its values are within the optimal range.

Reduced coefficients of dynamic friction were calculated for dry, wet and manure mass-covered floors, with statistically significant differences (P<0.05). This showed that regardless of the abrasive lining, water and manure mass had an impact on coefficient of dynamic friction.

The three variants of flooring condition remained within the optimal friction range (1). It should be emphasized that the reduction of the frictional coefficient would probably decrease the extent of claw horn abrasion, which is the primary purpose of this type of rubber mats.



	Dry floor	Wet floor	Manure mass-covered floor
Coefficient of static friction	0,59	0,61	0,49
Coefficient of dynamic friction	0,56	0,52	0,46

Fig. 4. Coefficients of static and dynamic friction for rubber flooring with abrasive lining in a different condition Values with different letters are statistically significantly different at $p < 0.05$.

CONCLUSION

The dry rubber mat without abrasive surface lining provided optimal friction and safety during stepping. After wetting, the rubber floor friction decreased to fell under the critical minimum with increasing the weight on the platform, posing a serious risk from slipping and restricting the normal locomotion of cows. The presence of manure mass on floor surface results in a decreased coefficient of friction, with values below the critical minimum in most instances. Comparing the three variants of floor condition, the presence of MM is the greatest risk factor for the safety of cows. The rubber flooring with abrasive lining demonstrated very good coefficients of friction when dry, wet and covered with manure mass. It should be noted that manure mass lowered both coefficients of static and dynamic friction and inevitably lowers the rubber flooring ability for claw horn abrasion. The presence of abrasive particles keeps frictional coefficients above the critical minimum and provided a confident locomotion of cows on this type of flooring.

Abbreviations: μ = coefficient of friction; MM - manure mass

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