Properties and cleanability of new and traditional surface materials in cattle barns — a field study

Risto Kuisma¹, Hanna-Riitta Kymäläinen¹, Maarit Hellstedt², Pekka Jauhiainen², Jenni Määttä¹, Anna-Maija Sjöberg*¹

¹Department of Agrotechnology, PO Box 28, FI-00014 University of Helsinki, Finland
²MTT Agrifood Research Finland, Animal Production Research, Vakolantie 55, FI-03400 Vihti, Finland
*E-mail: anna-maija.sjoberg@helsinki.fi

In this study surface properties and cleanability of new and traditional surface materials in cattle barns were examined in a field test. The concrete and plastic-coated samples were placed on a walking path on the floor and on a feeding table in a cattle barn. The surfaces were characterized using colorimetric and gloss measurements and determination of topography. In most cases, the colour of the surfaces placed on the floor darkened during the one year study period, whereas the colour changes of the samples placed on the feeding table did not show a similar trend. However, in both locations the plastic-coated surfaces were generally the easiest to clean, and the highest colour changes indicating soil residues were detected on the uncoated and silane-impregnated concrete surfaces. The difference between the locations was also seen in the gloss values, which increased in the samples placed on the floor during the one-year test period but varied considerably between the different materials on the surfaces placed on the feeding table. This field study confirmed the observation from earlier laboratory studies that plastic coatings improved the cleanability of concrete cattle barn surfaces. Silane impregnation was not functionally competitive with the plastic coatings. In general, the cleanability results were in accordance with the results of previous laboratory experiments but the field study provided practical information about the behaviour of the surface materials examined.

Key-words: cleanability, cattle barn, flooring, colorimetric method, gloss, profilometry, SEM
Introduction

Material choices in agricultural environments affect animal welfare, hygienic condition of surfaces and products, and the working environment of personnel. The durability and cleanability of surfaces are aspects affecting the choice of flooring material for cattle barns (Hörndahl 1995). The importance of this subject is emphasized in large animal buildings, which are nowadays common in many countries.

Concrete is a very generally used floor material in agricultural buildings. The floors of dairy cattle houses are almost exclusively made of concrete, because it can be textured to provide a slip-resistant, non-abrasive surface or finished with a smooth surface to aid drainage and cleaning (Barnes 1989). Although concrete is often very suitable for agricultural environments, it is affected by many environmental hazards, e.g., wear caused by animals and vehicles and chemical load caused by feeds, milk, and manure (Nilsson 2005). Both chemical substances and mechanical impact on floorings cause corrosion and wear that may promote injuries to animals. In addition, it may make cleaning difficult, thus promoting the spread of diseases (De Belie 1997, De Belie et al. 2000b). Therefore, the use of coatings to protect the surface of concrete against wear is of interest. Polyurethane is an example of materials which have been used in cattle barns and horse stables, but their use in animal-floorings is not widespread (Kymäläinen et al. 2008). Recent material research has focused on searching for new materials with potential for use in animal houses. A floor surface which is too rough causes rapid wear of animal hooves and causes grazes on other parts of the body (De Belie 1997). Floors with an initially ideal surface may become too rough or slippery because of degradation (De Belie 1997). A summary of earlier studies concerning cleanability of different kinds of agricultural surfaces and methods is presented in Table 1 (Määttä 2007).

In our earlier laboratory studies, new surface materials for use in floors and feeding tables in cattle barns were developed. In these studies, surface properties and cleanability of several new and traditional surface materials were examined as new (Määttä et al. 2008a) and when chemically and mechanically worn (Määttä et al. 2008b). The materials examined were basic cement paste, both uncoated and treated with inorganic sealants or with fluorochemical coatings of concrete including epoxy, polyurethane, polyester, and acrylic, and three different jointing materials.

There is some evidence from public office buildings that despite the fact that numerical results of laboratory experiments may not straightforward correlate with the values obtained from field experiments carried out in use conditions, materials can be compared and ranked according to both laboratory and field experiments (Kuisma et al. 2008).

The aim of the present study was to examine the surface properties and cleanabilities of new and traditional surface materials in a field test and to compare these results with the results of the earlier laboratory experiments (Määttä et al. 2008a,b). The surface material samples were selected to this study according to the results of the laboratory experiments and placed on a feeding table and walking path in a cattle barn. A colorimetric method was used for evaluating cleanability. The surface properties were examined by determining surface roughness parameters and gloss.

Materials and methods

Laboratory-made and commercial surface materials

The materials evaluated are presented in Tables 2 and 3. Epoxy, polyester, polyurethane, acrylic, substances containing oil, and plaster were used as surface coatings. In addition, asphalt and concrete without any coating or extra treatment were examined. The surface materials were selected to this study according to previous laboratory experiments (Määttä et al. 2008a), with exceptions as mentioned in Table 2. In all experimental materials, the basic concrete was laboratory-made, whereas commercial versions of the other materials were examined. However, not all...
### Table 1. Cleanability studies concerning agricultural surfaces (mostly according to Määttä 2007)

<table>
<thead>
<tr>
<th>Materials</th>
<th>Soil</th>
<th>Methods</th>
<th>Results</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete, ceramic, steel, aluminium, wood, glass, plastics, asphalt, rubber</td>
<td>Manure (cow, pig)</td>
<td>Visual, microbiological</td>
<td>Pig manure was removed more easily from surfaces than cow manure</td>
<td>Sundahl 1974</td>
</tr>
<tr>
<td>Concrete, plastic coatings</td>
<td>Artificial soil</td>
<td>Visual</td>
<td>Coatings improved cleanability</td>
<td>Puumala and Lehtiniemi 1993</td>
</tr>
<tr>
<td>Asphalt, concrete</td>
<td>Manure (cow)</td>
<td>Visual</td>
<td>Smooth surfaces were cleaned more easily than rough ones</td>
<td>Hörndahl 1995</td>
</tr>
<tr>
<td>Concrete, timber, rubber, aluminium</td>
<td>Organic wastes</td>
<td>Microbiological</td>
<td>The optimal temperature for liquids used in cleaning and disinfection was 40°C</td>
<td>Böhm 1998</td>
</tr>
<tr>
<td>Concrete, wood</td>
<td>Manure (pig)</td>
<td>Microbiological</td>
<td>The main findings were that cleanliness was improved by regularly cleaning and soaking of the pens with water before cleaning</td>
<td>Larsson 2000</td>
</tr>
<tr>
<td>Rubber solid floor, solid stall floor</td>
<td>Manure (cow)</td>
<td>Visual, scoring cleanliness and health of cows</td>
<td>Cows that used standings with rubber-slatted floor were cleaner than those on fully solid rubber mat</td>
<td>Hultgren and Bergsten 2001</td>
</tr>
<tr>
<td>Concrete, epoxy-coated concrete</td>
<td>Manure (pig)</td>
<td>Microbiological</td>
<td>Epoxy-coating improved cleanability</td>
<td>Pelletier et al. 2002</td>
</tr>
<tr>
<td>Concrete, plastic, wood, metal</td>
<td>Manure (pig)</td>
<td>Visual sensor system, Spectral characterisation</td>
<td>The determination method was able to locate dirty areas</td>
<td>Braithwaite et al. 2005</td>
</tr>
<tr>
<td>Concrete, plastic, wood, steel</td>
<td>Manure (pig)</td>
<td>Visual and optical</td>
<td>The determination method was able to locate dirty areas</td>
<td>Zhang et al. 2006</td>
</tr>
<tr>
<td>Concrete, several plastic coatings</td>
<td>Manure (pig), coloured saw-dust mixture</td>
<td>Colorimetric, radiochemical</td>
<td>Coatings improved cleanability of concrete</td>
<td>Kymäläinen et al. 2008</td>
</tr>
<tr>
<td>Concrete, surface treatments, plastic coatings, joint materials</td>
<td>Partly radiochemically labelled model soils based on manure (cow), feed, chemical compounds</td>
<td>Radiochemical, biochemical</td>
<td>Coatings improved cleanability of concrete</td>
<td>Määttä et al. 2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radiochemical</td>
<td>Mechanical wear decreased cleanability of all materials, particularly in the case of joints.</td>
<td>Määttä et al. 2008a</td>
</tr>
</tbody>
</table>
### Table 2. Codes and compositions of the evaluated surface materials and their use in the cattle barn in the study.

<table>
<thead>
<tr>
<th>Code</th>
<th>Substrate</th>
<th>Components</th>
<th>Experimental material (E) or material already in use (U)</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Concrete</td>
<td>None</td>
<td>U</td>
<td>X X</td>
</tr>
<tr>
<td>C2</td>
<td>Concrete</td>
<td>Plaster and silane</td>
<td>E</td>
<td>X X</td>
</tr>
<tr>
<td>Co1</td>
<td>Concrete</td>
<td>Acrylic coating</td>
<td>U</td>
<td>X X</td>
</tr>
<tr>
<td>Co2</td>
<td>Concrete</td>
<td>Polyurethane coating</td>
<td>U</td>
<td>X X</td>
</tr>
<tr>
<td>Co3</td>
<td>Concrete</td>
<td>Epoxy coating</td>
<td>U</td>
<td>X X</td>
</tr>
<tr>
<td>Co4</td>
<td>Concrete</td>
<td>Polyester coating</td>
<td>U</td>
<td>- X</td>
</tr>
<tr>
<td>Co5*</td>
<td>Concrete</td>
<td>Oil based coating</td>
<td>E</td>
<td>X -</td>
</tr>
<tr>
<td>Co6*</td>
<td>Concrete</td>
<td>Oil based and rubber coating</td>
<td>E</td>
<td>X -</td>
</tr>
</tbody>
</table>

- *Not included in the laboratory study.

### Table 3. Manufacturing and formulation of substrates and surface coatings or treatments.

<table>
<thead>
<tr>
<th>Code</th>
<th>Substrate</th>
<th>Manufacturing of components</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Concrete</td>
<td>Components (kg m⁻³): Rapid cement 333.6, sand 1836.1, water 183.5, VB-Parmix (=plasticizer) 1.33. Trowelled</td>
</tr>
<tr>
<td>C2</td>
<td>Concrete</td>
<td>See Co3 Cement-based coating (7–10 mm) and silane treatment (StoFinexter) StoCryl CP -primer + StoCrete VM Hard-cement based coating + StoCryl HP 200 (StoFinexter) hydrophobic impregnation (primer and impregnation agent were applied by brushing, coating was trowelled)</td>
</tr>
<tr>
<td>Co1</td>
<td>Concrete</td>
<td>See Co3 Acrylic coating (5-6 mm) (Nanten) Primed with acryl; acryl DC 305, Sand addition (7 kg m⁻², granule size 0.6–1.2 mm)</td>
</tr>
<tr>
<td>Co2</td>
<td>Concrete</td>
<td>See Co3 Polyurethane coating (3 mm) (Nanten) Primed with thinned PU 710 sand addition (0.5 volume-% of amount of polyurethane, grain size 1 mm), paint rolling of PU 710</td>
</tr>
<tr>
<td>Co3</td>
<td>Concrete</td>
<td>Same composition as in C1. Surface was sand blasted and vacuum cleaned before coating. Epoxy coating (2 mm) (DeLaval) Mixture of transparent epoxy and sand (3 kg m⁻², granule size 0–0.9 mm), spread with a spatula</td>
</tr>
<tr>
<td>Co4</td>
<td>Polyester</td>
<td>Prefabricated element (DeLaval) No information available</td>
</tr>
<tr>
<td>Co5</td>
<td>Concrete</td>
<td>See Co3 Oil-based SE Biomassa (1.4 mm) (Suomen Elektrodi) Priming with thinned SE Biomassa (plastic:hardener = 50:100). Coating with SE Biomassa (plastic:hardener = 70:100). Spreading of quartz granules (0.8–1.2 mm)</td>
</tr>
<tr>
<td>Co6</td>
<td>Concrete</td>
<td>See Co3 Primer SE Biomassa, coating SE Biomassa and rubber (0.7 mm) (Suomen Elektrodi) Priming with thinned SE Biomassa (plastic:hardener = 50:100). Coating with SE Biomassa (plastic:hardener = 70:100) containing quartz grains (0.2 mm) and rubber grains (0.7 mm)</td>
</tr>
</tbody>
</table>

- no surface coating
the materials are used in animal houses or marketed for that use at present (Table 2). The coded samples as three replicates were placed in a metal frame in random order and fastened on the floor (sorting gate) and feeding table.

Cleanability experiments and characterization of surfaces

The experimental design of determination of cleanability and surface properties is presented in Fig. 1. Cleanability was examined using a colorimetric method. A similar method was also used in the study by Kymäläinen et al. (2008), which focused on flooring materials for use in piggeries. Surface properties were examined using a laser profilometer, a scanning electron microscope (SEM) and a gloss meter. The similar SEM measurements were carried out as in the earlier laboratory studies for the same surface materials as unused (Kymäläinen et al. 2008) and worn (Määttä et al. 2008b). Topography, colour and gloss of the samples were measured in situ at 3-month intervals between March 2006 and November 2007.

Measurement of cleanability using the colorimetric method

The cleaning efficiency was measured with a Minolta Chroma Meter CR-210 colorimeter (Minolta Co Ltd), equipped with Standard Illuminant D65 as described previously (Pesonen-Leinonen et al. 2003, Redsven et al. 2003). In this study the L* (lightness) value was used for assessing the soiling and cleaning properties of the plastic surfaces. Measurements were performed after the cleaning, which was made using running water and a scrubbing brush. The results were expressed as soil residues, calculated from the means of the L* values of the sample:

\[
\Delta L^* R = L^*_{unsoiled} - L^*_{cleaned}
\]

Gloss measurements

The gloss of plastic surfaces was measured using a three-angle glossmeter Picogloss 503. The main principle of this device is based on measuring the amount of reflected light directed to a surface at a specified angle from its normal. The amount of light reflected from the surface under investigation is divided by the amount of light reflected from the surface of a reference smooth black glass plate (de-
livered by the manufacturer of the glossmeter) and the specular gloss is obtained by multiplying this intensity ratio by 100. The readings are expressed in GU (gloss units). All the measurements were carried out using an incidence angle of 85°. Measurements were performed after the cleaning.

### Topography assessment

The roughness of new and worn surface materials was measured using a laser profilometer (Micro-Epsilon ILD1400-100) by running it four times for 100 mm over the tested surfaces, varying the scan location. The data analysing method was the same as presented by Kymäläinen et al. (2008). The results are averages of all scans of the studied material as new and during the test (3, 6, 9 and 12 months). Change due to wear was calculated from the results of 9 months (floor) or 12 months (feeding table) of use. One image at each magnification was recorded and from each image five line profiles were measured. The high spot count (HSC) and peak average height values (Rpm) were derived from the line profiles. In addition, images of the surfaces were taken using a scanning electron microscope (JEOL JSM-840, USA) at 100×, 500× and 1500× magnifications. The magnification 500× illustrated the surface best and was used for each material.

### Results

As can be seen in the colorimetrically determined soil residues in Fig. 2a, C1 (30–50%), C2 (15–30%) and Co4 (10–25%) showed the greatest colour changes, indicating soil residues on the feeding table.

**Fig. 2a.** Cleanability as soil residue of the surfaces placed on the feeding table as estimated by colorimetric methods. The results are expressed as means (columns) and standard errors of means (±SE, bar) of five replicates. The codes of surfaces are presented in Table 3.

**Fig. 2b.** Cleanability as soil residue of the surfaces placed on the sorting gate on the floor as estimated by colorimetric methods. The results are expressed as means (columns) and standard errors of means (±SE, bar) of five replicates. The codes of surfaces are presented in Table 3.
Changes during the 12 month test period varied. Only a minor amount of soil, with soil residues below 5%, was detected on Co3 and Co1 surfaces on the feeding table (Fig. 2a).

As in the case of the feeding table, the greatest soil residues on the flooring were detected on C1 (35–40%) and C2 (25–30%) (Fig. 2b). On the floor, Co3, Co1 and the Co5 had the lowest soil residues, below 5%, and that of Co2 was not much greater (<10%). Particularly on the C1 and C2 concrete samples, the soil residues had a slightly increasing trend during the 9 month test period.

In most cases the mean gloss of the surfaces placed on the floor increased during the one-year test period (Fig. 3b), whereas the gloss changes of the surfaces placed on the feeding table varied considerably between the different materials (Fig. 3a).

Surfaces of two replicate samples of the rubber-coated concrete (Co6) were totally worn out between 6 and 9 months of use. Wear caused varying changes in roughness for other floor and feeding table surfaces (Tables 4 and 5). In most cases the number of HSC increased on the feeding table, although the variation between the materials was great, from 5% (acrylic coating) to over 800% (silane-impregnated concrete) (Table 4). The magnitude of changes was similar for the feeding table and floor samples, with the exception of Co2, on which HSC increased on the feeding table but decreased at the sorting gate. The effect of wear on surface roughness was lowest on the acrylic coating. Changes in the Rpm of the surfaces varied, and only weak correlation between HSC and Rpm was observed ($r = 0.424$ for all samples, statistically significant at the 0.01 level).

![Fig. 3. Gloss of the samples placed on the feeding table (a) and on the floor (b). Results are means of the gloss values (as gloss units, 85° measurement angle) of five measurements (column) and standard errors of means (±SE, bar). The codes of surfaces are presented in Table 3.](image-url)
Qualitative SEM micrographs of different types of feeding table and sorting gate floor surface materials are presented in Fig. 4a and 4b. The most typical images were selected from the replicate measurements of magnification at 500×. When compared with the new surfaces (Määttä et al. 2008a), clear changes due to wear were observed on all surfaces (Fig. 4a and 4b). As new the plastic coatings (Co1–Co4) were among the smoothest surfaces (Määttä et al. 2008b), but after wearing only the acrylic coating (Co1) on the floorings and acrylic and polyurethane (Co2) coatings on the feeding table were ranked as smooth (Fig. 4b) according to the SEM pictures. There were some differences between the effect of wear in the two locations: Co2 was worn more on the flooring than on...
Fig. 4a. SEM micrographs of the mechanically worn surface materials on the feeding table (a-f), magnification 500×. The codes of surface materials are given in Table 3.

Fig. 4b. SEM micrographs of the mechanically worn surface materials on the sorting gate on the floor (a-g), magnification 500×. The codes of surface materials are given in Table 3.
the feeding table, whereas in the case of Co3 and Co1 no clear differences in the SEM figures taken from the two locations were observed. Changes were also observed on the surfaces C1 and C2, but it is difficult to say how much these were caused by wear and how much by the absorption of soil into the surface.

**Discussion**

Soil residue has been considered to be the most valuable parameter calculated from the L*-value because it indicates whether the surfaces can be cleaned easily and economically. The surface colour offers an easy way to compare the cleanability of agricultural surfaces, but does not necessarily correlate with the absolute amount of soil attached to the surfaces. Cleanability of agricultural surfaces has earlier been examined with radiochemical methods in the laboratory (Kymäläinen et al. 2008, Määttä et al. 2008a). Measuring the amount of soil on the surface with radiochemical methods would provide quantitative information useful for studying different cleanability performances. However, in field studies it is not possible to use radiochemical methods and colorimetric method was a promising alternative.

The soil residue results show that in general the best cleaned surfaces were the plastic coatings. This is in accordance with previous studies by Puumala & Lehtiniemi (1993), Kymäläinen et al. (2008) and Määttä et al. (2008a). Most of the best cleaned surfaces in this study were non-porous, in contrast to the uncoated and silane-impregnated concrete. On the feeding table polyester (Co4) coating could not be kept as clean as the other plastic coatings. This difference can be seen in the SEM pictures, showing that the Co4 coating was more porous than the other plastic coatings. Considering the other materials, the differences in cleanability could be explained by differences in their roughness observed from the SEM pictures but could not be explained by the HSC and Rpm roughness parameters. In our previous study the contact angles of uncoated concretes were low or even unmeasurable due to porosity or brittleness of the materials (Määttä et al. 2008a). According to these results the differences in cleanability of surfaces may be partly explained by the absorptivity or repellency of the surface to soil. Furthermore, coatings sealed and smoothened surfaces thus improving their cleanability.

The average peak height (Rpm) of the trowelled concrete (C1) and polyurethane coating (Co2) measured from new surface is in accordance with those measured in the study by Norring et al. (2006). Surface properties of new and worn floors in production buildings have earlier been studied with profilometric measurements by Kymäläinen et al. (2008). The artificial wear induced in that study was very mild. Therefore comparison between the two sets of results is rather difficult. However, Rpm of epoxy (Co3) and polyurethane (Co2) coatings both on the feeding table and on the sorting gate decreased similarly in both locations.

It is evident that consideration of the durability of building materials and components is an important aspect of design (De Belie et al. 2000a). In this study the laboratory experiments prior to the field test for pre-selecting surfaces to resist mechanical and chemical wear were shown to be valuable. Table 6 shows the order of superiority of the surface materials according to the colorimetric results in this study and to the radiochemical results from the previous laboratory studies (Määttä et al. 2008a,b). It can be seen that the results showed similarity between the laboratory and field experiments. Accordingly, when the materials were ranked in order of superiority according to the soil residues, the order was exactly the same according to both the feeding table and sorting gate floor surfaces (Table 6). In a comparison of colorimetric results in non-agricultural buildings it was similarly observed that plastic flooring materials could be ranked in the same order according to both laboratory and field experiments (Kuisma et al. 2008). However, the wear, soiling and cleanability methods differed from the methods used in the present study.

Similar changes in colour and gloss were observed on the flooring, but not on the feeding table. This could be explained by the dominating role of manure soil in the colour measurements on the
flooring, whereas components on the feeding table are less colourful. Chemical loads and wearing were different in the two locations: wear at the sorting gate due to manure and cow claws was more intensive than that at the feeding table caused by fodder and cows licking the surface. Manure contains organic acids (acetic, propionic, lactic etc.), which constitute a severe chemical challenge to the concrete of agricultural structures (Berton et al. 2005). The quality of the concrete used in the floor can be selected to offer the best resistance to organic acids and aggressive conditions (Barnes 1989).

Material selection including corrosion-resistant materials and surface coatings is one means of preventing the formation of biofilms and extending the life-span of barn structures. Other parameters include designing against corrosion and control of aggressive environments (De Belie et al. 2000b). In this study the main focus was on cleanability, but depending on location thermal comfort, softness, friction, abrasiveness, surface profile and contact pressure should also be considered in material selection. However, floors which are hard to clean encourage the transmission of diseases in floors in animal buildings (De Belie et al. 2000c) and cleanability is thus one important factor determining the hygienic properties of surfaces in cattle barns.

## Conclusions

This field study confirmed the observation from earlier laboratory studies that plastic coatings improved the cleanability of concrete cattle barn surfaces. Silane impregnation was not functionally competitive with the plastic coatings. The materials were ranked in the same order of superiority according to the colorimetric results in this field study and radiochemical results from previous laboratory studies. The field study provided practical information about the behaviour of the surface materials examined.

### Acknowledgements

Financial support from the Ministry of Agriculture and Forestry in Finland (project Easy-to-clean surfaces in farm buildings) and the Finnish Cultural Foundation is gratefully acknowledged. DeLaval, Nanten, Suomen Elektrodi and Lujabetoni are acknowledged for providing surface materials. We are grateful to Lippo Sundberg for help in practical work with the samples and measurements and for fruitful discussion during the study.
References


Tutkimuksen tavoitteena oli selvittää uusien ja perinteisten pintamateriaalien ominaisuudet ja puhdistettavuus navetassa - kenttätutkimus

Risto Kuisma, Hanna-Riitta Kymäläinen, Maarit Hellstedt, Pekka Jauhiainen, Jenni Määttä, Anna-Maija Sjöberg

Helsingin Yliopisto ja MTT

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