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CONTACT PRESSURES AND DEFORMATION OF CATTLE CLAWS IN CONTACT WITH A CONCRETE FLOOR

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ABSTRACT

Inadequate properties of floors in cattle houses seem to be the primary cause of most claw problems, resulting in economic losses and impaired animal welfare. Many claw diseases are sequels of an extreme local overload, due to the roughness of the concrete floor.

In earlier research, the pressure distribution between cattle claw and concrete floor was studied. In this paper, the strains occurring in the horn wall were measured and related with the floor finishing method and the load. Deformation of the claw was quantified by analysing computer tomography scanner images of loaded and unloaded claws.

Strain gauge measurements indicate that it is difficult to predict what kind of deformation of the claw wall will occur at a certain location. For different floor finishing methods different strains will occur. The deformation of a bovine claw under a load of 3 kN showed a considerable volume and contact area increase.

Computer tomography images proved to be a good basis for assessing the deformation of a loaded bovine claw; they can also be used to produce the geometry of the claw horn shoe which can be used to create a finite elements model. This will be done in a future study.

INTRODUCTION

Inadequate properties of floors in cattle houses (e.g. too rough, too slippery …) seem to be the primary cause of most claw problems (McDaniel & Wilk, 1991). These floors are almost exclusively made of concrete, which is a very hard and rough but sometimes also very slippery material. A better understanding of the interaction between concrete floors and bovine claws will result in better designed floors and improved animal welfare.

The pressure distribution between the floor and the claw is the key parameter in this research. Monitoring of foot-to-ground pressure distributions may provide insight in the relation between high local pressures and foot lesions.

The determination of the roughness of the concrete floor samples and the contact pressures was already described in previous publications (Franck et al., 2004a, b & c). In this paper, these findings are further elaborated with the study of the strains and the deformation occurring in a loaded bovine claw. Strains were recorded with strain gauges and deformation was visualised by using image processing on CT (Computer Tomography) scans of bovine claws.

MATERIALS AND METHODS

Samples of concrete floors were made with five different kinds of texture, obtained by varying the finishing method: metal float, wooden float, brushed, mildly and heavily sandblasted. The roughness of the samples was determined in earlier experiments using a laser sensor for contactless profile measurements (Franck et al., 2004a, b & c). The same concrete samples were used in this study.

The contact pressures and the pressure distributions that occur between the cattle claw and the concrete floor were studied by pressing a well formed bovine claw, embedded in epoxy resin (Fig. 1), on the concrete samples in a hydraulic testing machine (Fig. 2). Between the bovine claw and the concrete sample, a thin film consisting of several electronic sensors (Tekscan® 5101) was placed in order to record the pressure distribution, which is influenced by the contact area, contact pressures and the substrate roughness. A thin rubber sheet (thickness: 1.5 mm) was placed between the concrete floor sample and the film sensor in order not to damage the sensors. Since this was done for all tests, the results are comparable. The contact pressures were then related with the roughness data (Franck et al., 2004a, b & c).

The previously performed research was elaborated with the study of the deformation of bovine claws, which was achieved by interpreting strain gauge measurements and processing computer tomography images.

Four bovine claws were tested and the linear strain gauges (HBM 6/120LY16: 6 mm x 2.8 mm Constantan measuring grid, 6 mm measuring length and resistance of 120 ?) were attached (with 2-component cyanacrylate glue) to the horn wall in both vertical and horizontal directions. There were 2 strain gauges on the dorsal wall and 2 on the abaxial wall (one on each toe). This is shown in Figure 1. The test setup with the tactile sensors and the strain gauges is shown in Figure 2 (during the same test the contact pressures were recorded). The load applied varied between 2 kN and 9 kN, in steps of 1 kN.

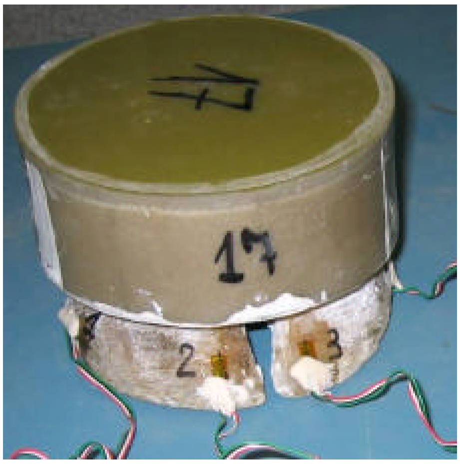

Figure 1. Strain gauges glued to a bovine claw

Figure 2. Test setup with claw placed on concrete floor sample

In Figure 3 the location and the direction of the strain gauges on the right and left toe is indicated. From left to right are claws 1 to 4.

Negative strain gauge readouts indicate a shortening of the claw wall and positive measurements mean that the horn wall elongates.

The strain was then related with the load applied on the claw and with the finishing method of the floor sample. The measurements generated by strain gauges on homologous locations on different claws were compared with each other. More precisely: the measurements of strain gauge 1 of the claws 1, 2 and 4; the measurements of strain gauge 2 of the claws 1 and 3; the measurements of strain gauge 3 of the claws 1 and 3; and the measurements of strain gauge 4 of the claws 1, 2 and 3 were compared with each other (see Fig. 3). If mirror symmetry between the two toes is assumed, then more series of measurements can be compared with each other: strain gauge 2 and 3 of claw 2 and 4; strain gauge 4 of claw 1, 2 and 3 and strain gauge 1 of claw 3; strain gauge 2 and 3 of claw 1 and 3; and strain gauge 1 of claw 1, 2 and 4 and strain gauge 4 of claw 4.

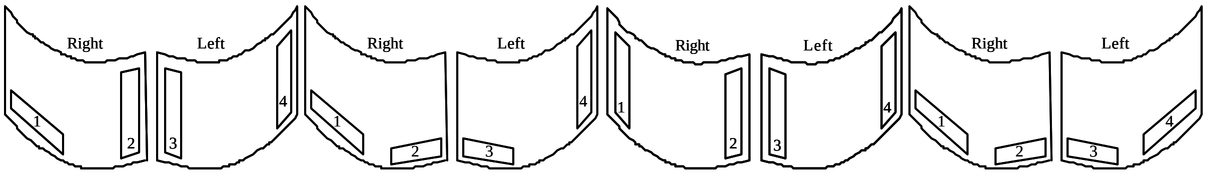

Figure 3. Location of the strain gauges on the 4 bovine claws (claws 1 to 4 are shown from left to right)

For assessing the deformation of a claw under load, different claws of calves were used. The claws had to be somewhat smaller because they needed to fit within the angle of view of the CT scanner, which is shown in Figure 4. The CT scanner is an AEA Tomohawk system with a Philips HOMX 161 X-ray source and an Adimec MX12P CCD (Charge-Coupled Device) camera. The X-ray source remains stationary but the subject (i.e. the claw) turns around by means of stepping motors. The claw was rotated over 187° and for each 0.5°, an image was taken. All these scans were then used as input for a 3D reconstruction consisting of approximately 350 slices along the height of the claw (Z-axis). The reconstruction was done with dedicated Tomohawk software. The voxel (i.e. volume pixel) size as well as the distance between the slices was around 0.25 mm. This number was not the same for all scans made and depends on the distance between X-ray source and subject and X-ray source and CCD camera plate; these distances were not exactly the same for the different scans. The Tomohawk scanning system is shown in Figure 5.

Figure 4. CT scanner with claw placed on turntable behind window

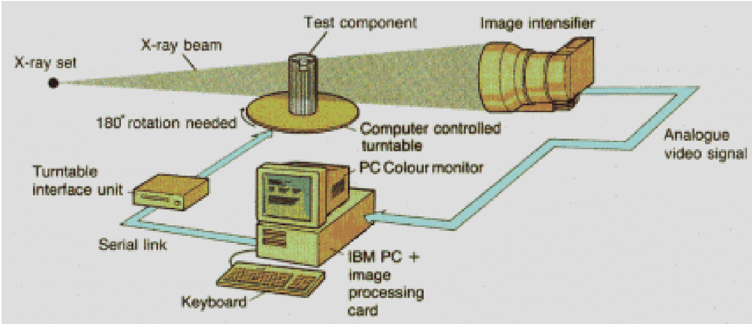

Figure 5. Tomohawk image reconstruction equipment (© AEA website)

First the claw was scanned in the unloaded situation. Figure 6 illustrates this test setup. Then the same claw was loaded in a hydraulic compression machine with a force of 3 kN, a value which corresponds to the half of the weight of a cow exerted on one limb. The load on the claw was maintained by fastening the steel frame (Fig. 7) before releasing the pressure. The claw was frozen in loaded condition and the steel frame was taken away just before scanning. Because of the frozen state, it was assumed that the claw kept its deformation during scanning. The claws were always scanned in frozen state which added to the stability of the claws during the motion on the turntable. The claw was unfrozen in between the two CT scans in order to allow deformation before the load was applied.


Figure 6. Unloaded calf claw in front of X-ray source


Figure 7. Claw under load in steel frame

The slices were processed with the software packages Mimics (Materialise), for which a free trial license (limited in time) was obtained, and Matlab (The MathWorks). Mimics is a 3D image processing and editing software that translates scanner data into full 3D FEA (Finite Element Analysis) meshes; it works through applying threshold masks with different grey values on the CT slices (e.g. to only retain the bone structure). The FEA mesh images of both unloaded and loaded claw were compared with each other in Mimics and some numerical data were obtained.

RESULTS AND DISCUSSION

The main conclusions of previous study (Franck et al., 2004a, b & c) are summarised here: the highest peak contact pressure measured on the concrete test panels under a load between 2 kN and 9 kN (110.7 MPa), is well beyond the yield stress of bovine claw horn. The yield stress at the physiological moisture content (approx. 30%) amounted to 14.3 MPa and

10.7 MPa for dorsal and abaxial wall horn respectively (3-point bending test) and 56.0 MPa for sole bulb horn (compression test applying a uniform load on a sample with 100 mm^2 surface area and 4 mm height). This means that the bovine claw horn can indeed be damaged in real circumstances. The average peak contact pressure at 2 kN is between 0.60 MPa (minimum) and 30.77 MPa (maximum) and at 6 kN it is between 1.12 MPa (minimum) and 20.20 MPa (maximum). Statistical analysis proved that the load, the claw, the surface finishing and the interaction of claw with surface finishing all had a significant effect (a = 0.05) on the contact area, the mean contact pressure and the peak contact pressure. The effect of the claw is 1.5 (contact area) to 2.1 (mean contact pressure) times higher than the effect of the floor. This means that the factor "claw" could even compensate for a more or less rough surface. The heavily sandblasted finishing method resulted in the highest peak contact pressures. When the results of heavily sandblasted samples were removed, then there was no significant effect anymore of the surface finishing on the peak contact pressures.

Strain gauge readouts indicate where elongation and shortening of the claw wall takes place. Sometimes the horn wall first elongates (+) and then shortens (-) or vice versa with increasing load put on the claw (see also Fig. 8). This information is summarised in Table 1.

Table 1. Elongation and shortening of claw horn wall depending on finishing method and location

Strain gauge	**Metal**	**Wood**	**Brush**	**Sand 1**	**Sand 2**
			Claw 1		
1	+	+	+	+	+
2	+	+	+	+	+
3	-	-	+ ? -	+ ? -	-
4	+ ? -	+ ? -	-	+ ? -	+ ? -
			Claw 2		
1	+	no readouts	no readouts	no readouts	no readouts
2	+	- ? +	+	- ? +	- ? +
3	- ? +	- ? +	+	- ? +	+
4	+	+	+	+	+
			Claw 3		
1	+	+	+	+	+
2	+	+	+	+	+
3	- ? +	-	-	- ? +	+
4	+	+	- ? +	+	+
			Claw 4		
1	+	+	+	+	+
2	-	-	-	-	-
3	- ? +	- ? +	- ? +	-	-
4	+	+	+	+	+

In SPSS a univariate analysis of variance – GLM (General Linear Model) was run in order to assess the effect of the surface finishing method on the strain gauge measurements. The surface finishing method was the dependent variable, fixed factors were the claw and the strain gauge number and the covariate was the load. The parameters "load", "claw" and "strain gauge" (i.e. the location) and the combination of "claw" and "strain gauge" were found to have significant effects (a = 0.05) on the measurements for different surface finishing methods.

Then a oneway ANOVA was run in order to compare the readouts of strain gauges at the same location and with the same direction. Significant differences (a = 0.05) were found between following series of measurements: with strain gauge 3 between daw 1 and 3 for surface finishing "Sand 2" and with strain gauge 4 between claws 1, 2 and 3 for all finishing methods. For the finishing methods "Metal", "Wood" and "Brush" significant differences were found between claw 1 and 3 and between claw 1 and 2. For the finishing methods “Sand 1” and “Sand 2” significant differences were found between claws 1, 2 and 3. These findings were supported with the Student-Newman-Keuls test. Before conducting the tests, no significant differences were expected because the strain gauges were placed on the horn wall in the same direction and on the same location. Another ANOVA was run in order to check for significant differences between strain gauge readouts when mirror symmetry was assumed. Following significant differences were found: with strain gauge 2 and 3 of claw 2 and 4 for all finishing methods; with strain gauge 4 of claw 1, 2 and 3 and strain gauge 1 of claw 3 for all finishing methods; and with strain gauge 2 and 3 of claw 1 and 3 only for finishing method “Sand 2”.

Figure 8 illustrates the different slopes of the strain gauge readouts of claw 1 on a “Metal”-finished concrete panel. Gauge 4 passes from elongation to shortening at around 5 kN. The jumps in the graphs indicate that the load was kept at the same level for a short period of time in order to be able to record the contact pressures.

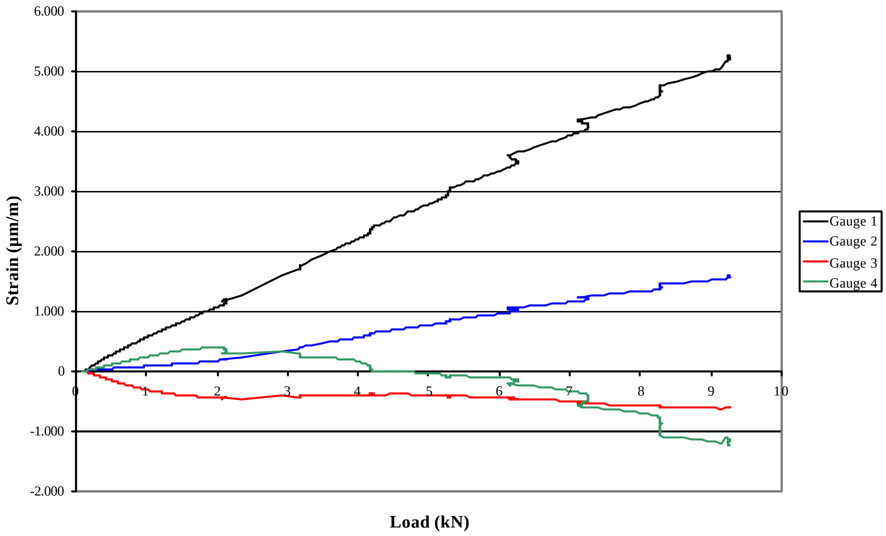

Figure 8. Strain gauge measurements depending on the load (claw 1 on “Metal”)

An example of a CT slice is shown in Figure 9. This slice was made by importing the Tomohawk data file of a slice in Matlab and then exporting the file to bitmap format. Figure 10 shows the same slice, but the grey values above 152 (= threshold) were converted to white while the lower grey values were converted to black. This operation was done with Matlab in order to be able to distinguish the bone structure and the claw wall more easily. Mimics works in the same way, but operations are much more automated. In Figure 10 there is still some “noise” (isolated white specks between bone and claw wall) which can not be removed by purely changing the threshold value (it could be removed by manually editing the bitmap slice images). This noise occurs due to the very low contrast between the tissue surrounding the bone and the claw wall horn. Mimics offers tools for refurbishing the images, e.g. masks with different thresholds can be subtracted from or added to each other and small cavities in the structures can be filled. These tools were used for making the pure horn shoe structure shown in Figure 12.

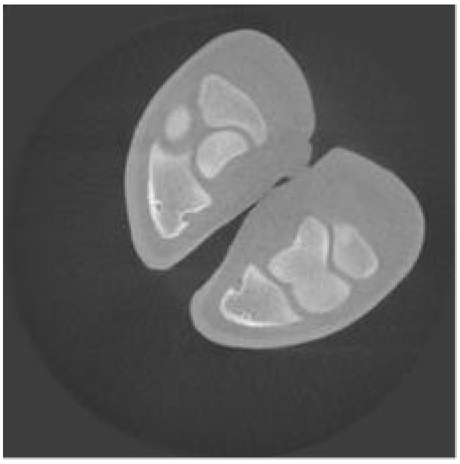

Figure 9. CT image slice of calf claw

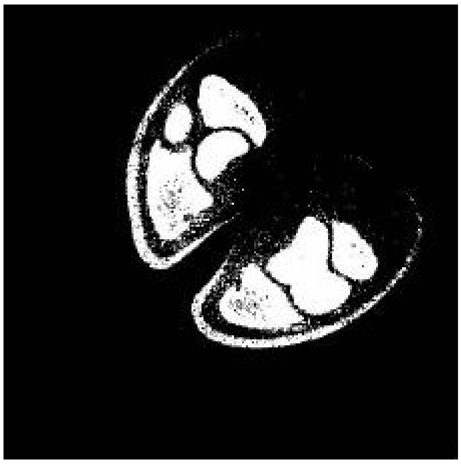

Figure 10. Slice revealing horn wall and bone structure

With Mimics the deformation of the claw could be quantified by comparing the dimensions of the unloaded with the loaded claw. The increase of the dimensions was from 110.8 mm to 115.9 mm (+ 4.6%) along the X-axis (i.e. the symmetry axis between the toes) and from 110.3 mm to 115.6 mm (+ 4.8%) along the Y-axis (perpendicular to X-axis). Along the Z-axis, the same length was kept. The volume increased from 189892 mm^3 to 231572 mm^3 (+ 21.9%) and the surface increased from 26729 mm^2 to 29048 mm^2 (+ 8.7%). The deformation of the claw is illustrated in Figure 11. One can easily see that the distance between the toes of the claw has increased.

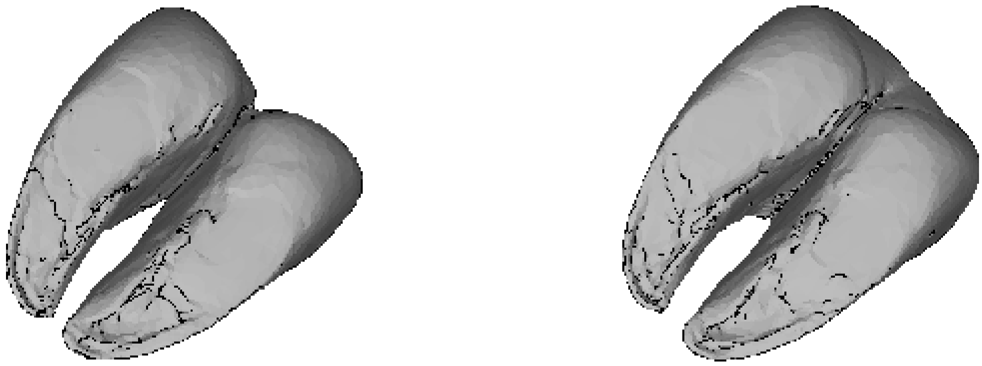

Figure 11. Claw in unloaded situation (left) and loaded situation (right)

Figure 12 shows the horn shoe of the unloaded claw in different views. This result was achieved with Mimics by subtracting different threshold masks, by manually editing the slices and by using the 3D FEA toolbox. The triangles on the surface of the horn shoe are automatically generated surface meshes. Before meshing smoothing operations were carried out on the surface and afterwards the amount of triangles was reduced. These 3D images can be exported to FEA packages (e.g. Abaqus); the triangles then will serve as a basis for creating 3D tetraeders.

Figure 12. Different views of the horn shoe

CONCLUSIONS

Strain gauge measurements indicate that it is difficult to predict what kind of deformation of the claw wall will occur at a certain location. For different floor finishing methods different strains will occur. Under increasing load, deformation can pass from elongation towards shortening or vice versa.

CT scan images proved to be a good basis for assessing the deformation of a loaded bovine claw. These images needed specific processing before the desired results could be achieved. CT scan images can also be used to produce the geometry of a bovine horn shoe which then can be used for FEA calculations.

Loading of a claw shows a big increase of the volume of the horn shoe.

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