The Canadian Society for Bioengineering
The Canadian society for engineering in agricultural, food, environmental, and biological systems.

La Société Canadienne de Génie Agroalimentaire et de Bioingénierie
La société canadienne de génie agroalimentaire, de la bioingénierie et de l'environnement

Paper No. CSBE09- 601

Isolating the effect of material properties in the wear of soil engaging tools

Lyndon Graff, MSc Candidate

Department of Agricultural and Bioresource Engineering, University of Saskatchewan, 57 Campus Drive Saskatoon, Saskatchewan S7N 5A9

Trever Crowe, Professor

Department of Agricultural and Bioresource Engineering, University of Saskatchewan, 57 Campus Drive Saskatoon, Saskatchewan S7N 5A9

Martin Roberge, Sr. Project Engineer, Digital Prototyping and Simulation

CNH Canada Ltd. 1000 - 71st St. Saskatoon, Saskatchewan S7K 3S5

Written for presentation at the
CSBE/SCGAB 2009 Annual Conference
Rodd's Brudenell River Resort, Prince Edward Island
12-15 July 2009

***Abstract*.**

The processes by which wear can occur on a tillage tool include abrasion, impact, fretting and chemical action. Of these, abrasion typically dominates but rarely do these processes act independently. It is because of the variable nature of wear in tillage settings and the number of factors which influence tool wear that prediction and comparison of wear performance are difficult. The application of discrete element modeling (DEM) may provide the opportunity to simulate wear conditions to allow accurate tool life prediction. The role of tool material in wear performance was isolated using a lab experiment while maintaining a typical soil-tool interaction from a practical field scenario. Changes in the profile of soil-engaging tools, as a function of distance travelled and material type, were explored. Cylindrical bars of 6061 aluminum and 1018 steel were pulled through a sandy soil under controlled and consistent operating conditions. Wear was documented using a coordinate measuring machine (CMM) capable of detecting differences in cylinder radius on the order of 0.001 mm. The purpose of this study was to create a set of data which could be used comparatively in further study of computer simulated wear. The wear rates and profiles of the different bars are presented and compared.

Keywords. *Abrasive wear, tillage, soil bin.*

Introduction

Wear will occur in any situation where materials with different hardness are in contact during relative motion. The asperities of the harder surface deform those of the softer material (Kragelskii 1965). It is this very condition which exists during tillage. The soil particles, which can be 2-5 times harder than the metal (Swanson 1993), abrade the metal surface through impact abrasion. Although abrasion is most prevalent, many processes act to remove metal from the tillage tool (Bayhan 2005).

Unlike typical wear studies of metal-metal contact, tillage wear involves low stress abrasion, much harder abrading particles, and an absence of lubrication. For this reason, wear studies of tillage tools cannot be carried out in the same manner as other wear experiments. To increase the intricacy of the tillage wear scenario, soil texture (Yu 1991), soil particle angularity (Swanson 1993), and soil moisture (Zhang 1992), all of which can vary widely, also affect the type and speed of tool wear.

Although many types of wear tests for tillage tools exist, the nature of the soil-tool interaction makes results difficult to predict. Even though laboratory methods can effectively isolate certain conditions, they do not provide realistic scenarios as would be experienced by a tillage tool in the field. The primary drawback of any of these investigations is that they are time consuming. However, the application of DEM may solve both these issues. With the increase in computing power, DEM simulations could become a realistic replacement for traditional physical tests involving a bulk granular medium such as soil (Krause 2007).

The objective of this research was to create a baseline set of data from a soil bin experiment for use in later computer DEM simulations. Two materials were tested to demonstrate the effect of material properties on wear rates. Through precise measurements of tool dimensions, the change in profile was quantified and available for comparison with the results of computer simulations.

Methods and Materials

Wear Specimen Design

As a compromise between simplicity for future modeling and ease of use in the soil bin, a cylindrical rod pulled horizontally was chosen as the tool shape (Fig. 1). The rounded profile allowed soil to move freely past the tool and there was no effect of a corner or sharp edge that would wear differently over time. As the leading profile remained relatively consistent, little change in soil pressure would be present.

Figure 1. Test specimen geometry

Length of the bar was chosen to be approximately half the available width of the soil bin, 400 mm. To determine an appropriate diameter, calculations were completed to find the minimum diameter that would limit the amount of flexure. According to draft data recorded by Hunt (1983) for a rodweeder and the flexure formula,

$$\delta = \frac{wL^4}{384EI} \tag{1}$$

where δ – deflection, m
w – distributed load, N/m
L – length, m
E – elastic modulus, Pa
I – moment of inertia, m^4,

a diameter of 25 mm was found to provide less than 1 mm of deflection in the center of the bar for steel and was considered sufficient for the experiment.

Two materials were selected from which the bars would be constructed. Materials were selected based on anticipated wear characteristics and availability. To ensure that quantifiable wear would occur, one of the materials selected was 6061 aluminum. A steel sample (AISI 1018) was chosen as the other material in order to provide significant contrast in wear life. Based on hardness values (95 HB for 6061-T6 aluminum and 131 HB cold drawn AISI 1018), it was assumed that the aluminum would show much higher wear rates.

Figure 2 illustrates the mounting bracket used to hold the bars in the soil bin. A single bolt at each end of the rod gripped the rod in the bracket. The protective sleeves were also mounted via the bolts. The sleeves were added to eliminate any wear on the ends of the bar as the CMM required unaltered material in these regions for calibration during each measurement. These sleeves were replaced, as needed.

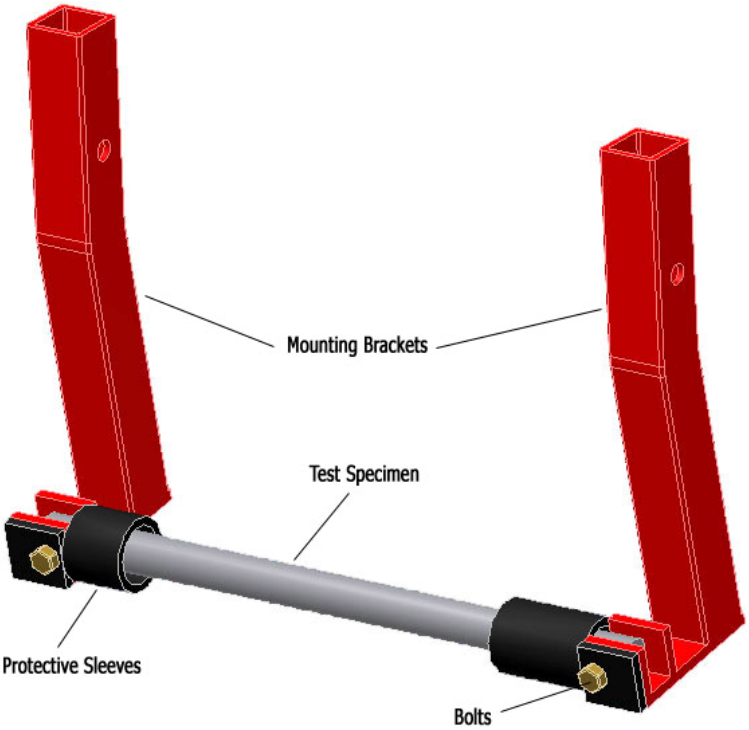


Figure 2. Bracket used to mount specimen in the soil bin

Operating Conditions

The soil bin used for these tests was located at the University of Saskatchewan, Saskatoon, SK (Graff et al. 2007). This circular soil bin pulls a tillage tool sample through a soil medium which very closely imitates field conditions. The carriage is powered using a 50-hp three-phase electric motor which runs a variable flow hydraulic power unit, controlled by electric solenoids. The hydraulic power unit serves to operate a drive train which rotates the carriage of the soil bin. The inner and outer diameters of the bin are 2.3 and 4.3 m (7.5 and 14 ft) respectively and at a working diameter of 3.2 m (10.5 ft) the working speed range is 0 to 9.7 km/h (6 mi/h). The layer of soil is approximately 0.6 m (2 ft) deep and the tool was operated at a depth of 3 cm. The bin is also designed to allow the mechanism to rotate in either direction to eliminate the effects of a circular motion. Due to constraints in the setup, only one direction was used for these trials. A magnetic pick up connected to a data logger allowed the number of revolutions of the tool carriage to be counted for tool travel distance measurement.

The soil bin was equipped with a set of four disks to loosen and level the soil for each pass. Following the disks were three packing wheels to provide an even level of compaction to accelerate wear and more accurately represent field conditions. Along the inner circumference of the bin, watering nozzles regularly added water to the soil to maintain a moisture content of approximately 4 % w.b. Soil texture was 7% gravel, 81% sand, 3% silt, and 9% clay which was classified as loamy sand.

The average speed of the center of the bar (located at 1.64 m from the center of rotation) was set at 8 km/h. Based on the dimensions of the bin, 50 km of travel could be completed each day. As such, measurement intervals were set at 50 km. Three replications of each material were used and each was worn using a random order for eight days to a total of 400 km each.

Data Acquisition

The level of wear was determined from the change in radius of the circular bar near the center of its length. Twenty points around the circumference of the bars were measured at the middle of the bar (z = -200 mm) in addition to 2 regions on either side of the middle (z = -174.6 mm and z = -225.4 mm). Figure 3 illustrates these measurement areas labeled A, B, and C. Because the soil bin was rotating in a single direction, the linear speed and total linear distance varied over the length of the bar. For this reason, measurements were limited to an area close to the middle where variations would be minimal. Location A was at the outer radius which resulted in a slightly higher speed and distance with respect to location C.

Radii of the test specimens were determined using a CMM. By calibrating to known, unchanging locations on the bar, precise measurements of the x-y coordinates of each of the 20 points at the three locations could be recorded. Angles were measured beginning at the leading edge (-12.7, 0, $Z_{A.B,C}$) and increasing counterclockwise such that 90 degrees would be at the bottom (0, 12.7, $Z_{A.B,C}$), etc.

In addition to profile measurements, the mass of the bar was also recorded. Because the bars were constructed of a single material, the amount of mass loss could be converted to a loss of volume using the material density. The densities used for calculations were 2.70 and 7.87 g/cm^3 for 6061 aluminum and 1018 steel, respectively.

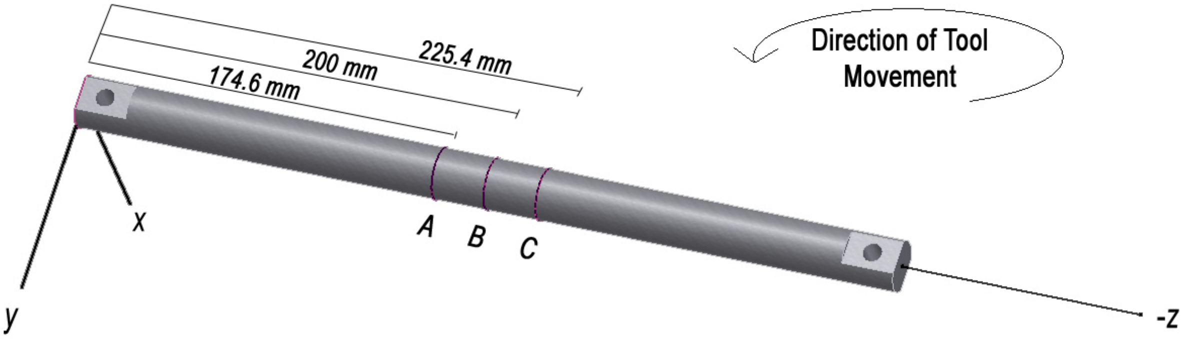


Figure 3. Coordinate system for test specimen

Results and Discussion

Each of the six bars exhibited visible wear following 400 km of travel. Visual inspection showed that wear was concentrated at two particular locations around the circumference of the bar (Fig. 9). Along the leading edge (defined as 0 degrees), the bar was still in its original state and completely unaffected by wear. This phenomenon could be confirmed from the state of the bar in the soil just prior to removal from the soil bin (Fig. 4). The leading edge of the bar was covered with a layer of soil, thereby protecting the bar from abrasion.

This is also the cause of the difference between the straight wear scar edge at the back side of the bar and the jagged surface at the leading edge of the scar (Fig 5). Because the soil stuck to slightly different areas on the bar with each run, the shape of the wear scar changed (Fig. 6) and layers of wear could be seen.

It could also be noted that the steel bars were affected by corrosion as well as abrasion. When cleaning the bars before measurement, soil was easily removed from the aluminum bars but was firmly attached to the steel. Due to the moisture in the soil and lack of movement where the soil stuck to the bar, small amounts of rust began to form at the edges of the wear scar (Fig. 7).

Figure 4. Soil formation after completion of a run.

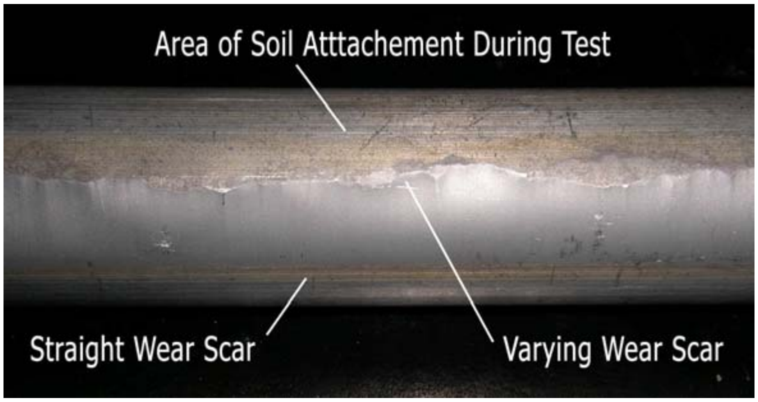


Figure 5. Variance in soil attachment creates an uneven wear edge as seen from the bottom of the specimen (90 degrees).

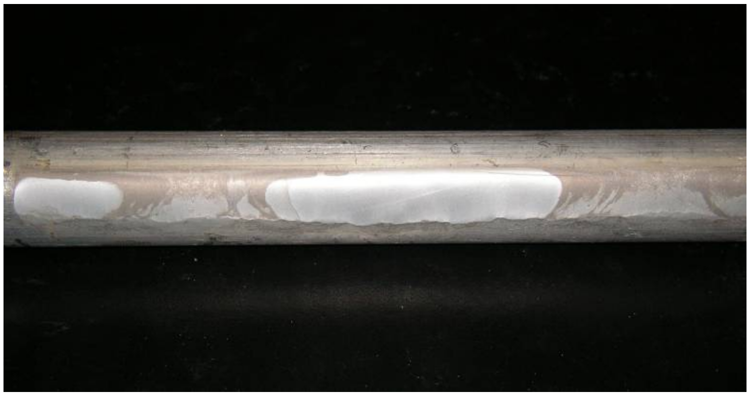


Figure 6. Wear scar layering caused by differences in soil attachment over a set of runs.

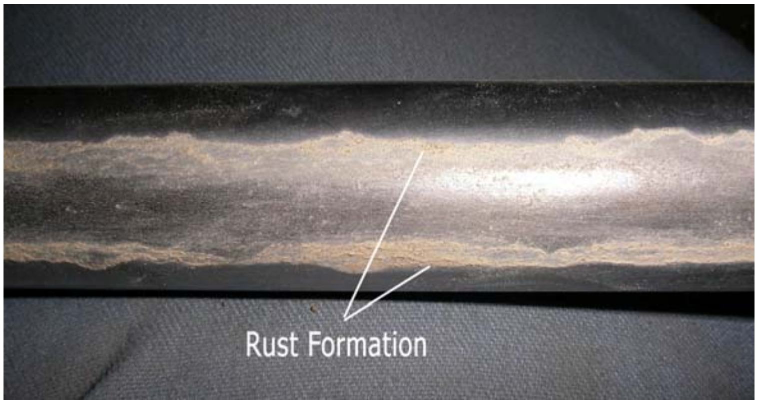


Figure 7. Rust formation at edge of wear scar for steel specimens.

Mass data were collected at each 50-km interval. Volume loss was then determined using the material density. Although mass data were very similar initially, with approximately 1 g of material removed at each interval, the difference in densities proves obvious when volume loss is considered (Fig. 8). The general history of mass loss was exponential for the aluminum as the rate of wear increased with each measurement. For the steel, the rate of volume loss remained quite consistent which may be a result of the low wear rate. It could be assumed that the exponential type wear would also occur in the future but over the interval of study, this level of wear was not yet reached. Over the entire exposed area of the bar, the aluminum lost approximately 6.8 cm^3 while only about 1.1 cm^3 was removed from the steel after 400 km of travel.

More importantly to the objective of this study, bar radii were measured using a coordinate measuring machine (CMM). From the x-y coordinates provided by the CMM, changes in radii could be analyzed. Figure 9 illustrates the locations of wear on the bar. The upper and lower front surfaces experienced the majority of the wear.

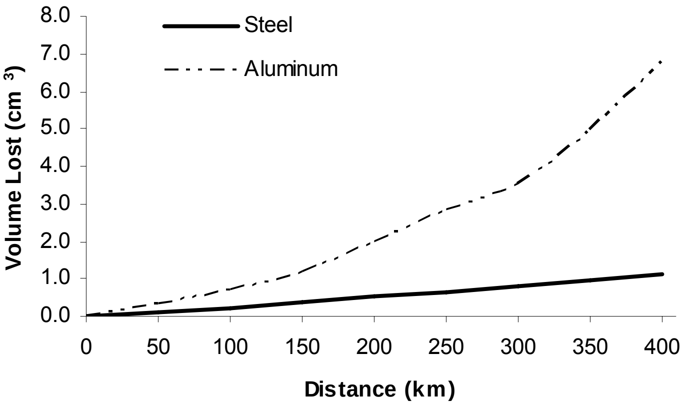


Figure 8. Average volume lost calculated from mass change

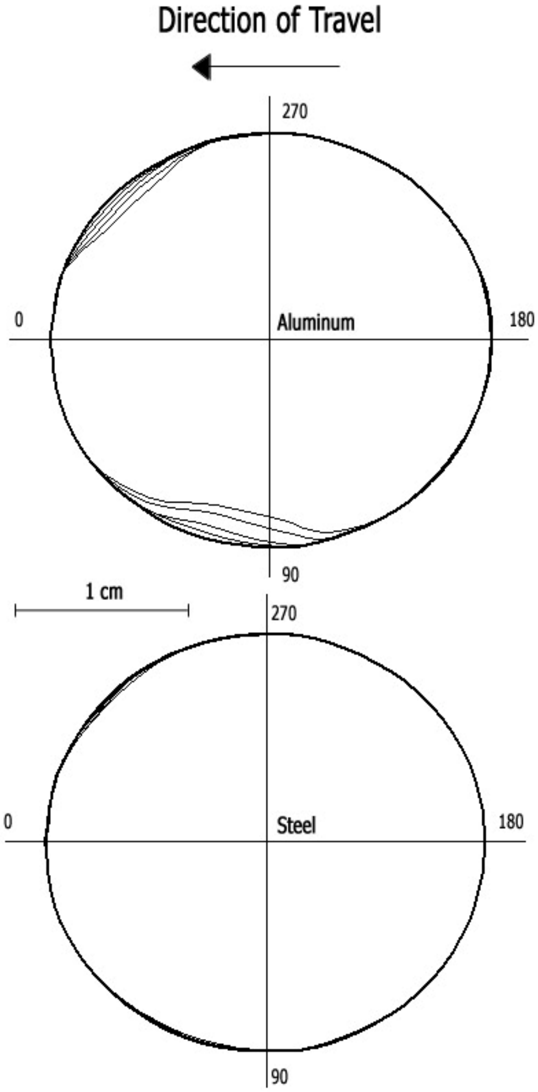
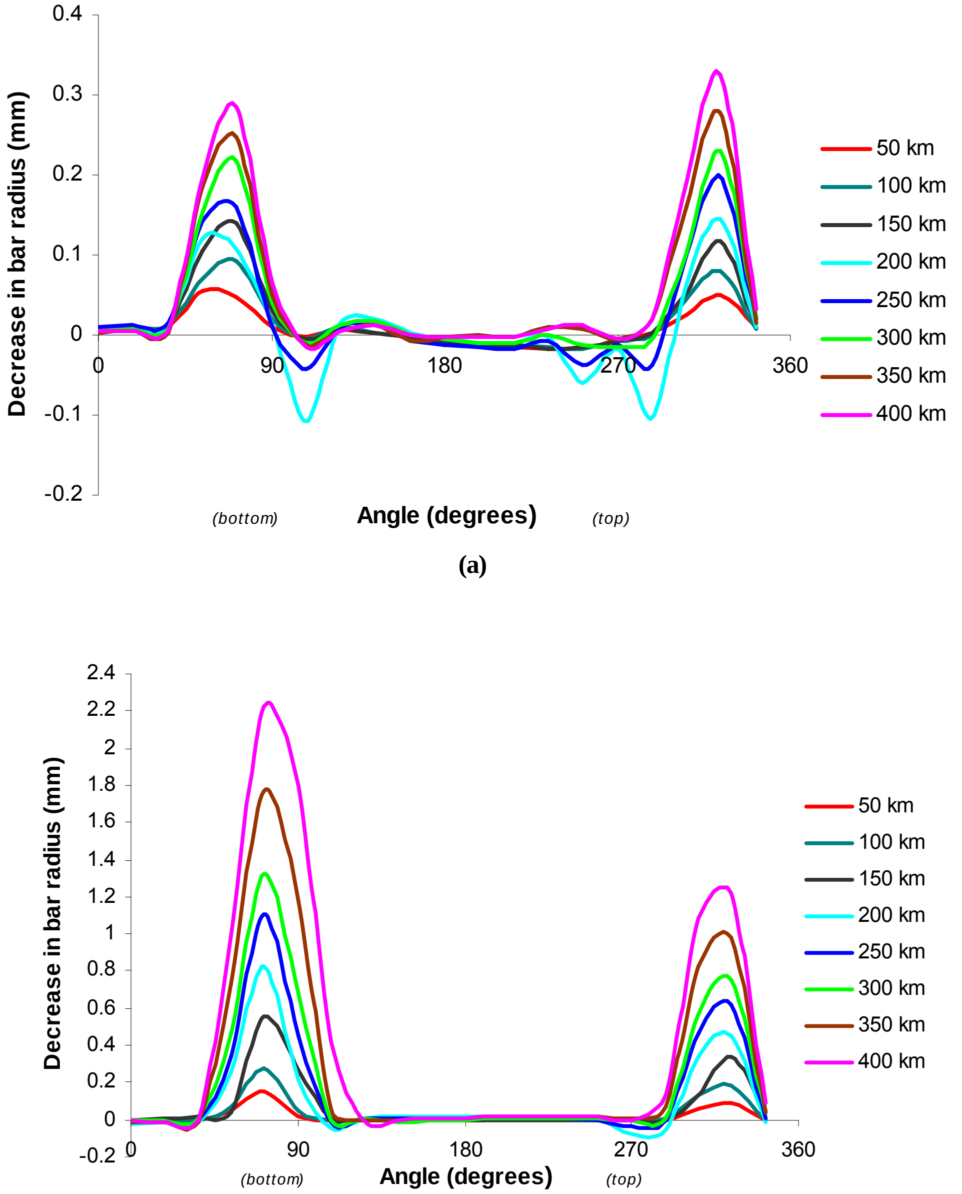


Figure 9. Wear profile of steel and aluminum bars (lines indicate 100-km intervals)

When plotted as a function of the measurement angle, Fig. 10 illustrates that wear was concentrated at about the 72 and 324 degree marks. While most of the bar did not wear, the wear measurement came to a distinct maximum which indicates that material was not removed evenly from the entire surface. Instead, as is seen in Fig. 9, it is a segment of the profile which is worn. With regard to the aluminum, the area at 72 degrees experienced more wear as it was located on the lower edge of the profile where higher soil pressures would exist. Soil could easily flow above the bar but at the lower edge compaction was required to allow the bar to pass through the soil. This extra pressure increased the abrasive wear which occurred.



(a)

(b)

Figure 10. Radius change as a function of angle of measurement for (a) steel and (b) aluminum

As expected, the aluminum bars had the greatest reduction in radius. At the point of maximum wear, the radius of the aluminum bar was reduced by about 2.2 mm while the steel bars lost less than 0.35 mm. When comparing the two materials, both exhibited similar characteristics. The locations experiencing large amounts of wear were very similar but the aluminum showed much greater wear at the bottom location while the steel had similar radius change at the bottom and top wear locations.

One anomaly which is particularly obvious on the steel bar plot for the 200-km and 250-km measurement is the negative radius decrease. Physically this indicates that the bar grew in size which is not possible. As illustrated in Fig. 7, this may be due to the rust formation at the edge of the wear scar. As moist soil collected in this area it built up a very hard ridge which may have resulted in the CMM reading that the bar had an increase in radius. It is also possible that erroneous measurements were taken at these two intervals

Conclusions

As a result of 400 km of travel through loamy sand within a soil bin, significant amounts of material had been removed from the cylindrical specimens. The aluminum and steel bars showed differing trends in wear rate with the wear rate for aluminum appearing exponential in nature. Wear was still very minimal for the steel bars, and thus the volume of material removed was nearly six times larger for the aluminum.

Profile change was determined by measuring the bar radius at multiple locations around its circumference. Because of the nature of the soil flow past the bar, wear was only present in two distinct locations with the greater wear occurring on the lower portion of the bar for the aluminum but fairly equally between top and bottom for the steel. As was predicted by the volume change, the change in radius was about six times greater on the aluminum bars.

In general, the results of these tests will be sufficient for use in comparison to a computer simulation of wear. An understanding of the processes which took place will enable the simulation to create the most realistic results possible. Further to the results of this study, tools of different materials can be studied by utilizing the trends documented from the soil bin trials.

Acknowledgements

The authors acknowledge the help of Mr. Louis Roth for his assistance in preparing the soil bin. CNH Canada Ltd. provided the facilities to measure and document the wear patterns in addition to providing financial support. Financial support was also made available by a Dean’s Scholarship from the College of Graduate Studies and Research, University of Saskatchewan.

References

Bayhan, Y. 2005. Reduction of wear via hardfacing of chisel ploughshare. *Tribology International.* 39(6):570-574.

Graff, L.J., R.C. Roberge, T.G. Crowe, and M.A. Roberge. 2007. Wear of ripper point hardsurfacings. *In* Proceedings of the 2007 North Central Intersectional Conference of the ASABE, October 12-13, 2007, RRV-07120. Fargo, ND: American Society of Agricultural and Biological Engineers.

Hunt, D. 1983. Farm Power and Machinery Management, 8th edition, Ames, Iowa: The Iowa State University Press.

Kragelskii, I.V. 1965. Friction and Wear. London, UK: Butterworth and Co.

Krause, F. 2007. A research area with great prospects. *Bulk Solids Handing.* 27(1): 14-16.

Swanson, P.A. 1993. Comparison of laboratory abrasion tests and field tests of materials used in tillage equipment. *In Tribology: Wear Test Selection for Design and Application, ASTM STP 1199. ed.* A. W. Ruff and R. Bayer, 80-99. Philadelphia, PA: American Society for Testing and Materials.

Yu, H.J. 1991. Abrasive wear evaluation of tillage tool materials. Unpublished M.Sc Thesis. University of Regina, Regina, SK.

Zhang, J.. 1992. Measurement of wear and draft of cultivator sweeps with hardened edges. Unpublished M.Sc. thesis. Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Saskatoon, SK.