J. Agric. Sci. Technol. (2007) Vol. 9: 199-210

Effect of Aluminide Coatings and Wheat Handling Parameters on Erosion in Wheat Storage Bins

H. Ahmadi[1]*, A. M. Borgheei[1], A. R. Alimardani[1], A. Rajabeeipour[1] and D.Y. Li[2]

ABSTRACT

Recent studies demonstrate that aluminide coatings are beneficial to wear and erosion resistance and also that oxygen-active elements such as yttrium can remarkably improve this resistance. In this research, the micro-hardness of the aluminide coatings with and without yttrium on 1045 steel was investigated using a micro-mechanical probe. Wear of the samples was measured using a pin-on-disk tribometer. The erosion loss of specimens against soft and hard wheat was also evaluated using a slurry erosion test machine. The data was analyzed statistically using a 3-factor completely randomized design to study the effect of wheat varieties (soft and hard wheat), moisture content at three levels (10±0.5, 15±1.5, and 20±2 % (wet basis)), and rotary velocity of the slurry erosion machine at three levels (200, 400, and 600 rpm) on erosion resistance. The results showed that the aluminide coatings improved the wear and erosion resistance of substrate steel 1045; yttrium markedly improved the hardness of the aluminide coating and its wear and erosion resistance. The erosion loss of materials was significantly ($p<0.01$) influenced by the type of wheat, moisture content and rotary velocity. Both aluminide coatings showed higher wear and erosion resistance than 1045 steel substrate.

Keywords: Aluminide coating, Erosion, Storage bins, Wear, Wheat, Yttrium.

INTRODUCTION

Wheat kernels are handled mechanically in storage bins using augers and conveyors, with airflow, or air allowed to flow by gravity. When wheat kernels transported through curved ducts, they may impact on the bend wall and cause serious erosion damage. Research showed that the erosion rate of the bend could be 50 times higher than that of a straight pipe [1]. For this reason, improving bend erosion protection is an urgent task.

Wear of a solid surface by particle erosion has been the subject of many studies. For a similar condition of the target pipe material and impacting particles, a decrease in the momentum of the impacting particles, a decrease in the range of the impact incidence angle [1, 2 and 3], fixed ribs on the wall of the inside bend [1, 4 and 5], and a finned pipe erosion protection method [6] could greatly reduce the erosion damage of the pipes. Surface damage due to wear and erosion may result in changes in surface conditions and the dimension of a mechanical component, and this could cause a disastrous failure of an entire mechanical system. Coating is one of the cost-effective approaches against surface failure. Steel is often used as the core material coated with different materials for applications in the mining, chemical, petrochemical and food processing industries, and in transport pipelines to protect equipment and machinery from wear, corrosion and erosion. Recent studies have shown that wear and corrosive erosion of the aluminide coating can be markedly reduced by adding oxygen-active elements. For in-

1. Department of Agricultural Machinery Engineering, Faculty of Bio-system Engineering, University of Tehran, Islamic Republic of Iran.
2. Department of Chemical and Materials Engineering, University of Alberta, Canada.
* Corresponding author, e-mail: hjahmadi@ut.ac.ir

stance, yttrium improved the resistance of the aluminide coating to wear, corrosive wear, corrosion, corrosive erosion and dry sand erosion [7-9]. The objective of this study is to investigate the application of aluminide coatings modified with yttrium to protect pipeline bends from erosion in wheat storage bins.

MATERIALS AND METHODS

The substrate material used in this study was commercial 1045 steel. The dimension of the specimens was 13×6×12 mm. All specimens were polished with 600 grit SiC sand paper and cleaned in acetone, and were then coated with Al to form an aluminide coating using a pack-cementation process. FeAl (50%Fe-50%Al) alloy powder was used as the aluminium source, NH_4Cl powder as an activator, and Al_2O_3 powder as a filler material. 3 % yttrium powder (-40 mesh) was mixed with the FeAl powder. Table 1 lists the compositions of the Y-containing and Y-free powders and the diffusion conditions for the pack-cementation. Nitrogen gas was used to protect the specimens from oxidation. The coated specimens were mechanically polished using SiC sand papers and, finally, polished using 0.05-micron alumina. The specimens were cleaned in acetone. Micro-hardness of the specimens was determined using a micro-mechanical probe.

In order to evaluate wear resistance of the aluminide coated steel, specimens were also tested using a pin-on-disk tribometer. Volume loss of samples after 1,000 laps was measured. The sliding speed and applied normal load were 10 mm/s and 3 N, respectively. The diameter of the silicon carbide ball pin was 6 mm. The width of the wear track (W) on the target specimen and the diameter of the worn area of the ball pin (w) were measured using an optical-microscope. The cross-section area of a wear track on the target material was the shadowed area as shown in Figure 1. The volume loss of the material per unit length of the wear track is thus the shadowed area multiplied by a unit length.

Indication varieties of wheat were selected from hard and soft quality classes. The moisture content of wheat kernels was measured using the following formula:

$$MC_{wb} = \frac{M_b - M_a}{M_b} \times 100 \qquad (1$$

Where MC_{wb} = Moisture content, % w.b.;

Table 1. Conditions of the pack cementation process.

Pack composition	Diffusion temperature	Diffusion time
49%FeAl + 49%Al_2O_3 + 2%NH_4Cl	950°C	10h
47%FeAl + 47%Al_2O_3 + 2%NH_4Cl + 3%yttrium	950°C	10h

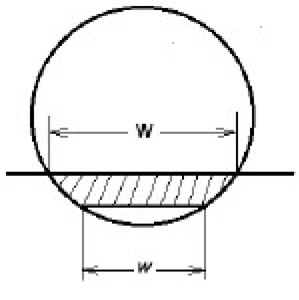

Figure 1. Schematic view of the cross-section area of a wear track (shadowed area) W- the width of the wear track on a target specimen and w- the diameter of the worn area of the ball pin.

M_b = Mass of kernels before drying; and M_a = Mass of kernels after drying.

The sphericity percentage of wheat kernels was evaluated using the following formula:

$$S = \frac{(abc)^{1/3}}{a} \times 100 \quad (2$$

Where S= Sphericity, %; a= Length of kernel, mm; b= Width of kernel, mm and c= Height of kernel, mm.

The erosion loss of specimens against soft and hard wheat was evaluated using a slurry erosion test machine. The volume loss was estimated using the following formula:

$$V = \frac{\Delta W}{\rho A t} \quad (3$$

Where V= Erosion rate, $cm^3\ m^{-2}\ hr^{-1}$; ΔW= Weight loss, g; ρ= Specimen density, gcm^{-3}; A= Eroded area, m^2 and t= Testing time, hr.

The data were analysed statistically using the 3-factor completely randomized design to study the effect of wheat varieties (soft and hard wheat), moisture contents at three levels (10±0.5, 15±1.5, and 20±2 % (wet basis)), and the rotary velocity of the slurry erosion machine at three levels (200, 400, and 600 rpm) on the erosion resistance. Results were analysed and compared using the analysis of variance (F-test) and Tuky's multiple range test.

RESULTS

Micro-hardness Properties

Figure 2 presents the hardness values of the Y-containing and Y-free aluminide coatings, at different loads from 25 mN to 750 mN. The results demonstrated that the hardness of the Y-free and Y-containing aluminide coatings was about 3 and 5 times higher than that of 1045 steel, respectively. These results demonstrated that Y significantly increased the hardness of the aluminide coating. In the figure, all values were obtained by averaging at least three measurements.

Wear Behavior

Figure 3 illustrates typical worn tracks of 1045 steel and aluminide coating without and with yttrium after 1,000 laps, respectively. The wear losses of specimens are given in Figure 4. Both yttrium-free and yttrium-containing aluminide coating showed higher wear resistance than that of uncoated material. As shown in Figure 4, yttrium markedly increased the wear resistance of the aluminide coating. The wear resistances of aluminide coatings with yttrium and

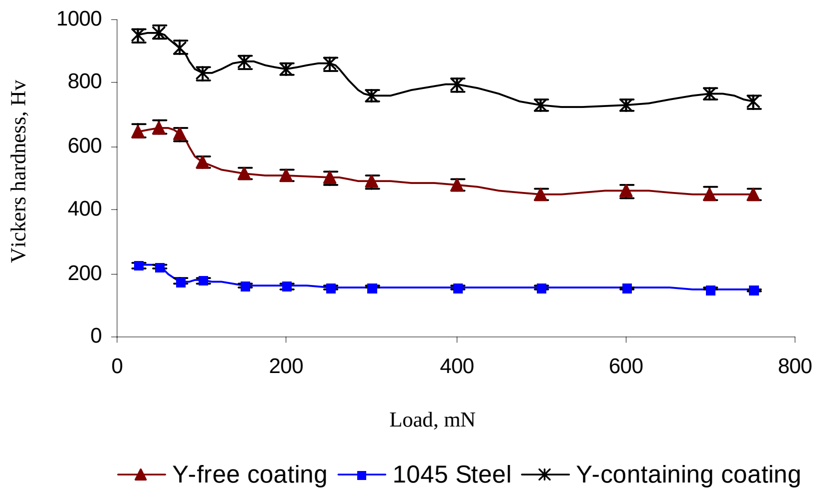

Figure 2. Hardness value of 1045 steel, Y-free coating, and Y-containing coating.

[DOR: 20.1001.1.16807073.2007.9.3.1.0]

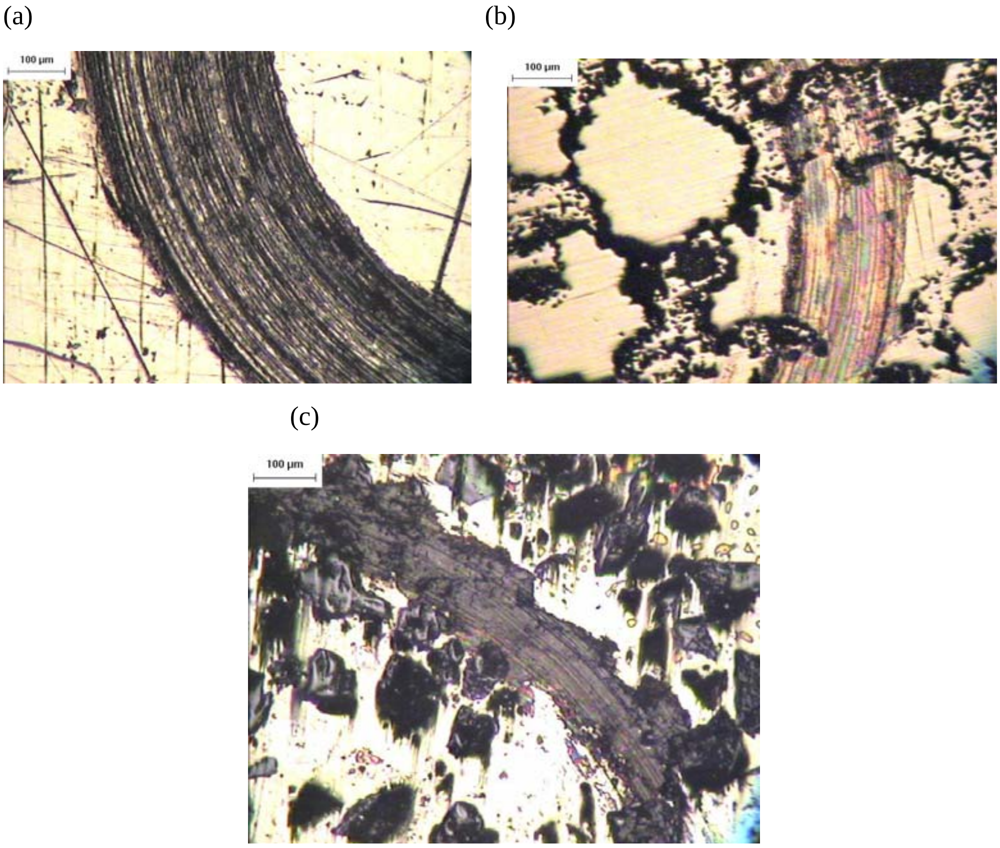

Figure 3. Typical wear tracks of (a) 1045 steel; (b) Y-free coating and (c) Y-containing coating (pin-on-disk).

without yttrium were approximately 7 and 4 times as high as that of the substrate steel, respectively. Each value is an average of five measurements

Water Absorption Diagram

To prepare the sample at different moisture levels, wheat kernels were soaked in water for 5 to 240 minutes and then their moisture contents were determined by standard air oven method at 103^{o}C for 24 hours. Figure 5 shows a wheat-absorption diagram for both types of wheat. The moisture absorption of soft wheat was a little higher than that of hard wheat. Table 2 gives some physical properties of the two varieties of wheat that used for the tests.

Humidity Diagram

To measure the humidity of wheat kernels during the test, wheat kernel samples with 18±0.5 % and 25±1 % moisture content were put in the slurry erosion test machine. The machine was rotated at different velocities and then moisture content was measured at one-hour intervals. Figure 6 shows the humidity loss diagram for soft wheat kernels over time. Figure 6 (a) shows that between 3 and 11 hours of slurry erosion operating time the moisture contents were stable at about 15±1.5 % for the 18 % wheat sample. Figure 6 (b) shows that, between 2 and 11 hours of slurry erosion operating time, the moisture contents were almost constant at about 20±2 % for the 25% wheat sample.

Table 2. Physical properties of wheat kernels.

Wheat variety		Hard	Soft
Initial moisture content, % w. b.		10.3	10.8
	a	4.90	5.10
Kernel dimensions, mm	b	2.65	3.10
	c	2.30	2.45
Thousand kernels weight, g		38.32	42.11
Sphericity, %		63.2	66.3

Slurry Erosion Test

The erosion loss of specimens against soft and hard wheat was evaluated using a slurry erosion test machine. The materials used were aluminide coatings with and without yttrium, and steel 1045. Two wheat varieties were selected from hard and soft quality classes for the test. The rotary velocities of the slurry erosion test machine were 200, 400, and 600 rpm. The moisture contents were 10±0.5, 15±1.5, and 20±2 % (wet basis).

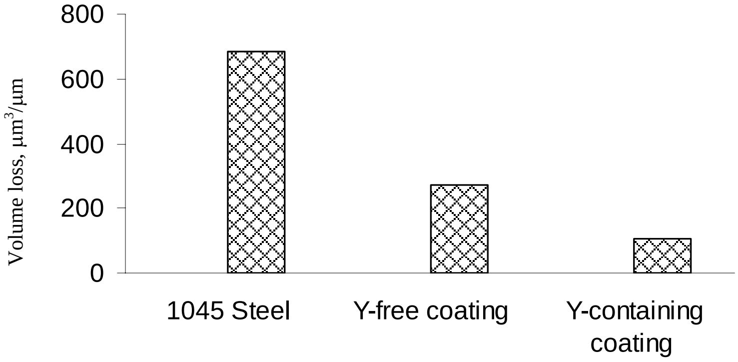

Figure 4. Volume loss of the aluminide coatings with and without yttrium, and 1045 steel after 1,000 laps (pin-on-disk, per unit length of wear track).

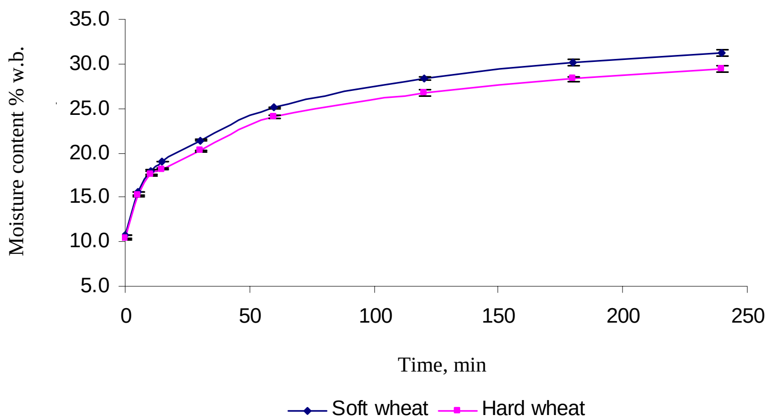

Figure 5. Wheat-absorption diagram for both varieties of wheat.

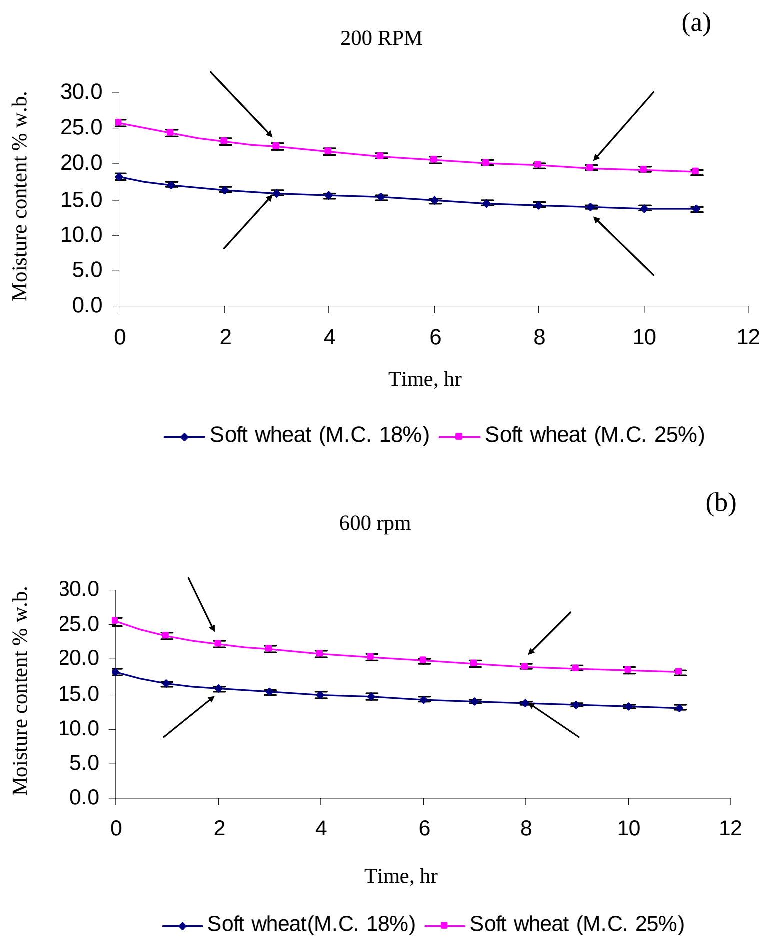

Figure 6. Humidity diagram for wheat kernels over time at the different rotary velocities (a) 200 RPM and (b) 600 RPM.

DISCUSSION

The analysis of variance test showed that erosion loss of different materials (Figures 7 and 8) was significantly different (α=0.01), but for the first measurement (Figure 7) of Y-free coating and Y-containing coating the volume loss was not significantly different (α=0.01). It may be shown that when these two samples held a high moisture content in the wheat kernels, corrosive erosion occurred during the test, and it can be shown that the corrosive erosion resistance of Y-containing coating was higher than that of Y-free coating. Figure 7 shows that the slope of volume loss of Y-containing coating between the third and fourth measurements was much lower than that of between pervious steps, it can be showed that this coating had a good erosion resistance. Both aluminide coatings showed higher erosion resistance than that of uncoated material.

The results showed that yttrium significantly improved the erosion resistance of the aluminide coating in both soft and hard wheat, respectively. The erosion resistances of aluminide coatings with and without yttrium were approximately 4.5 and 3 times as high as that of the steel substrate. Data given represent the mean of sample volume loss

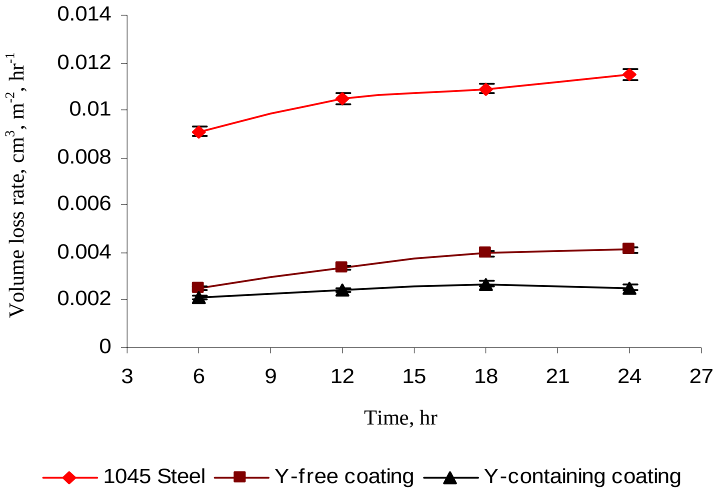

Figure 7. Volume loss of the aluminide coatings with and without yttrium, and 1045 steel (slurry erosion test machine).

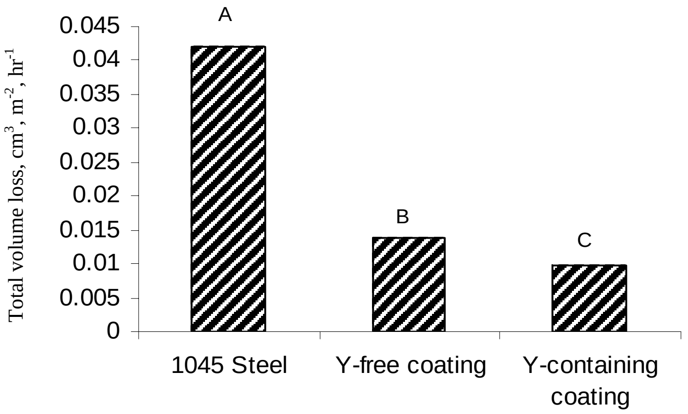

Figure 8. Total volume loss of the aluminide coatings with and without yttrium, and 1045 steel (slurry erosion test machine).

against different wheat verities, moisture content and machine velocity.

Figures 9 and 10 show that erosion loss against hard wheat was higher than that against soft wheat. This can be the result of a lower sphericity percent of hard wheat kernels than that of soft wheat kernels. The hard wheat kernels were sharper than the soft wheat kernels. The data are the mean of sample volume loss against different wheat verities, moisture content and machine velocity but, in this figure especially, they show the effect of wheat varieties on volume loss.

The erosion loss of materials was significantly ($p<0.01$) influenced by moisture content and rotary velocity. The results demonstrated that, by increasing the moisture content, the erosion loss increased (Figures 11 and 12). It can be show that, during the test, when the wheat kernels had a high moisture content, the specimens could be attacked by

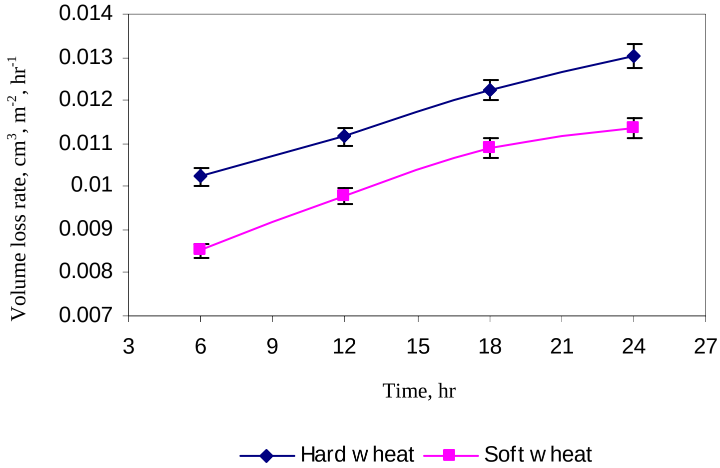

Figure 9. Volume loss of specimens against hard and soft wheat.

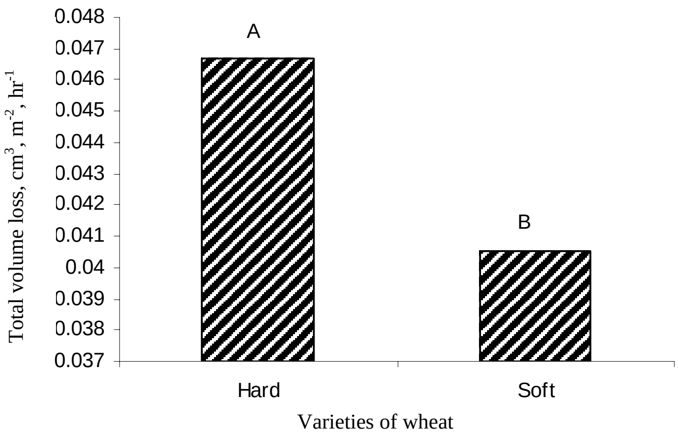

Figure 10. Total volume loss of specimens against hard and soft wheat.

corrosive erosion, because the moisture content of the wheat kernels could cause corrosion. The data given are the mean of sample volume loss against different wheat varieties, moisture content and machine velocity but this figure shows the effect of moisture content on volume loss in particular.

Figures 13 and 14 show that, with increasing rotary velocity, erosion loss increased. It can be shown that when the rotary velocity of the slurry erosion test machine increased, the impact force of wheat kernels on specimens and, so, the erosion loss increased. The data represent the mean of sample volume loss against different wheat verities, moisture content and machine velocity but, in this figure especially, they show the effect of machine velocity on volume loss.

CONCLUSION

This research was conducted to investigate the beneficial effect of aluminide coatings on the resistance of 1045 steel to erosion. Results of the present research demonstrated that:

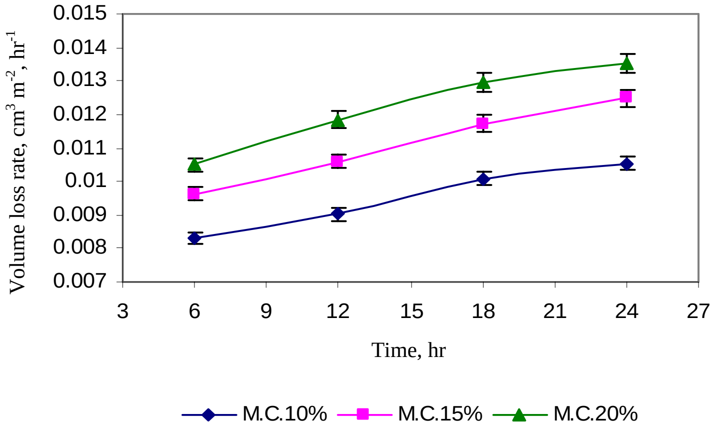

Figure 11. Volume loss of specimens for different moisture contents.

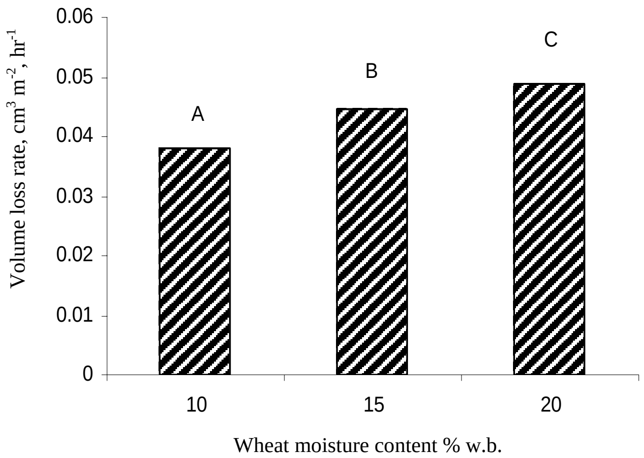

Figure 12. Total volume loss of specimens for different moisture contents.

1. Yttrium markedly improved the wear and erosion resistance of the aluminide coating.
2. Both aluminide coatings had higher hardness than that of the substrate material.
3. Yttrium increased the hardness of the aluminide coating.
4. The erosion loss of the materials was significantly ($p<0.01$) influenced by moisture content and rotary velocity.
5. Erosion loss against hard wheat was higher than that against soft wheat.
6. Erosion loss of different materials was significantly ($P<0.01$) different.

[DOR: 20.1001.1.16807073.2007.9.3.1.0]

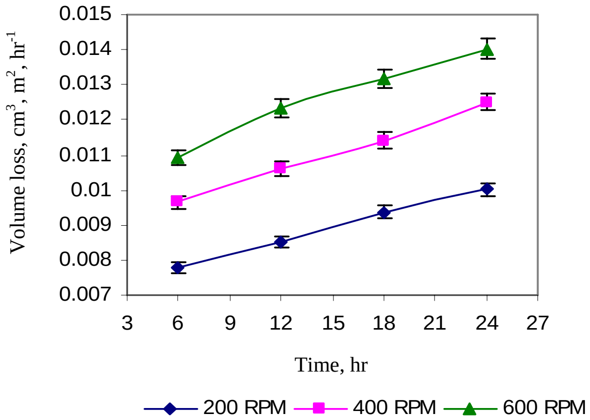

Figure 13. Volume loss of specimens for different rotary velocities.

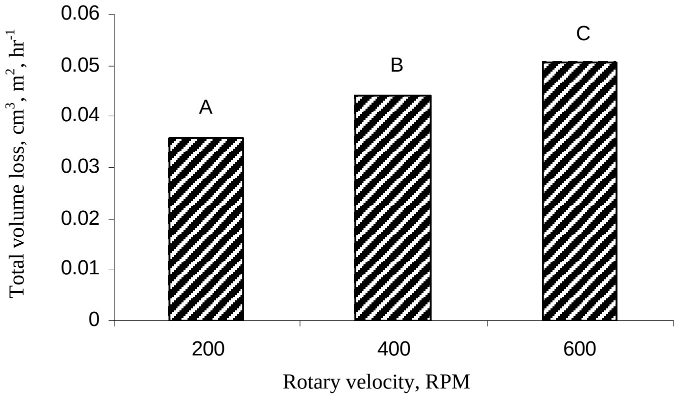

Figure 14. Total volume loss of specimens for different rotary velocities.

REFERENCES

1. Fan, J., Yao, J., Zhang, X. and Cen, K. 2001. Experimental and Numerical Investigation of a New Method for Protecting Bends from Erosion in Gas-Particle Flows, *Wear*, **250(K)**: 853-860.
2. Humphrey, J. A. C. 1990. Fundamentals of Fluid Motion in Erosion by Solid Particle Impact, *Int. J. Heat Fluid Flow*, **11 (3)**: 170-195.
3. Tabakoff, W. 1984. Turbo Machinery Performance Deterioration Exposed to Solid Particulates Environment, ASME. *J. Fluid Eng.*, **106 (2)**:125-134.
4. Song, X. Q., Lin, J. Z., Zhao, J. F. and Shen, T. Y. 1996. Research on Reducing Erosion by Adding Ribs on the Wall in Particulate Two-Phase Flows, *Wear.*, **193 (1)**: 1-7.
5. Yao, J., Zhang, B. Z. and Fan, J. R. 2000. An Experimental Investigation of a New Method for Protecting Bends From Erosion in Gas-Particle Flows, *Wear*., **240**: 215-222.
6. Fan, J. R., Zhou, D. D., Zeng, K. L. and Cen, K. F. 1992. Numerical and Experimental Study of Finned Tube Erosion Protection Methods, *Wear*, **152 (1)**:1-19.
7. Ahmadi, H. and Li, D. Y. 2002. Mechanical and Tribological Properties of Aluminide Coating Modified with Yttrium, *Sur. Coat. Tech.*, **161**: 210-217.
8. Zhang, T. and Li, D.Y. 2000. Beneficial Effect of Oxygen Active Elements on the Resistance of Aluminide Coatings to Corrosive

Erosion and Dry Erosion, *Sur. Coat. Tech*., **130**: 57-63
9. Zhang, T. and Li, D. Y. 2000. Effects of Yttrium on Corrosive Erosion and Dry Sand Erosion of FeAlCr (Y) Diffusion Coatings on 1030 Steel, *J. Mater. Scie. Eng.*, **A277**: 18-24.

تاثیر پوشش‌های آلومینادی و پارامترهای انتقال گندم روی فرسایش لوله‌های انتقال گندم در سیلوها

ح. احمدی، ع.م. برقعی، ع. ر. علیمردانی، ع. رجبی پور و د. یانگ لی

چکیده

تحقیقات سالهای اخیر نشان داده‌اند که پوشش‌های آلومینایدی عامل مؤثری در افزایش مقاومت به فرسایش و سایش فولاد بوده‌اند و همچنین عناصر اکسیژن فعال نظیر یتریم بطور چشم‌گیری توانسته‌اند این مقاومت را افزایش دهند. در این تحقیق سختی پوشش‌های آلومینایدی اعمال شده روی فولاد ۱۰۴۵ همراه با یتریم و بدون یتریم و فولاد ۱۰۴۵ توسط یک دستگاه ریز سختی سنج‌اندازه‌گیری شده است. میزان مقاومت به سایش نمونه‌ها توسط یک دستگاه تریبومتر چرخشی و حجم مواد فرسایش یافته نمونه‌ها در مقابل دو گونه گندم سخت و نرم توسط ماشین فرسایش‌سنج توده‌ای اندازه‌گیری شده‌اند. دو آزمایش فاکتوریل جداگانه بر پایه طرح فاکتوریل کاملاً تصادفی با تکرار مشاهدات برای ارزیابی نتایج حاصل از فرسایش نمونه در مقابل گندم در نظر گرفته شده است. متغییرهای مستقل در این آزمایش‌ها نوع گندم سخت و نرم، ظرفیت رطوبتی گندم در سه سطح ۰/۵± ۱۰، ۱/۵ ± ۱۵ و ۲ ± ۲۰ درصد (بر اساس وزن تر) و سرعت‌های دورانی دستگاه فرسایشی توده ای در سه سطح ۲۰۰، ۴۰۰ و ۶۰۰ دور در دقیقه و متغییر وابسته میزان فرسایش نمونه‌ها بوده‌اند. نتایج نشان داده‌اند، پوشش آلومینایدی اعمال شده روی فولاد ۱۰۴۵ باعث بهبود مقاومت به سایش و فرسایش فولاد ۱۰۴۵ گردیده است. همچنین یتریم بطور چشم‌گیری باعث افزایش سختی و مقاومت در برابر سایش و فرسایش فولاد ۱۰۴۵ گردیده است. میزان فرسایش نمونه‌های مختلف در سطح یک درصد ($P<0/01$) برای نوع گندم، درصد رطوبت‌های مختلف و سرعت دورانی ماشین بطور معنی‌داری اختلاف نشان داده‌اند. میزان فرسایش با افزایش درصد رطوبت دانه‌ها و سرعت دورانی ماشین افزایش داشته است. میزان فرسایش در برابر گندم سخت بیشتر از گندم نرم بوده است. هر دو نوع پوشش آلومینایدی مقاومت به فرسایش بیشتری را نسبت به دیگر مواد از خود نشان داده‌اند.