INVESTIGATION OF EROSIVE WEAR ON AL2O3 COATED CAST IRON USING RESPONSE SURFACE TECHNIQUE

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ABSTRACT

Centrifugal pump made of high chrome cast iron is generally used in thermal power plant to dispose ash slurry from power station to ash pond. Erosive wear occur on the impeller of the pump during its continuous use. D-gun sprayed Al_2O_3 coating is suggested to reduce the erosive wear and hence to improve the performance of centrifugal pump. In the present work, three significant parameters were selected to investigate the erosive wear i. e., rotating speed, ash concentration and ash particle size. The experimentation on high speed slurry erosion tester has been carried out to test the erosive wear. The erosive wear behavior of coating was investigated by Response surface methodology (RSM). Statistical analysis was performed in the form of the analysis of variance (ANOVA) to determine the interaction of experimental parameters. The result shows that the increase in each parameter contributes to erosive wear of pump impeller.

KEYWORDS: *Erosive wear, slurry, detonation gun, response surface methodology*

I. INTRODUCTION

In thermal power plant, large amount of ash is produced due to the burning of coal. The ash which is collected at the bottom of the coal furnace is called bottom ash and which is raised with flue gases is called fly ash. Bottom ash is bulky (up to 4 mm) and having clinkers whereas the fly ash is having fine spherical particles of size range from 10 µm to 100 µm. Fly ash is collected by electrostatic precipitators. The major constituents of fly ash are SiO_2, Al_2O_3 and Fe_2O_3. Pump Impeller is generally made of high chrome cast iron.

In the past few decades, research has been done on the study of material loss in order to conserve material and energy [1]. A variety of methods were adopted to protect materials from damage due to erosive wear, by the use of efficient materials [2], processing techniques [3], surface treatment [4] of the exposed components and use of engineering skill leading to less impact of wear on the material, such as appropriate impingement angle of erodent and velocity of slurry. Studies provide information about the mechanisms of material removal during the erosive wear [5]. There are a number of methods to test the erosive wear of materials using equipment, such as small feed rate erosion test rig [6], particle jet erosion test rig [7], coriolis erosion tester [8] and slinger erosion test rig [9]. Study has been carried out for various slurries from low to medium concentration range and found that none of the correlation is universally applicable for modeling slurries for well graded particle size distribution [10].

Ceramic coating can be applied to increase the performance of a slurry pump by reducing the erosive wear [11-12]. Before applying coating, specimens should be cleaned by acetone and abrasive shot blast [13]. The detonation gun thermal spray technique may be used for applying coating. The extreme hardness and high density of Al_2O_3 leads to a superior erosion and corrosion resistance at both high and low impact angles [14]. The detonation gun thermal spray technique provides the dense microstructure with less porosity [15].

II. PROBLEM FORMULATION

The problem was the high wear rate of the pump impeller during its continuous use. The suggested solution to this problem is applying ceramic coating on the surface of the impeller so as to reduce the wear rate on the surface by keeping the mechanical properties of the impeller material unchanged. Rotation of specimen, ash concentration in slurry, and particle size are considered to be significant factors. Three levels are taken for each factor as shown in Table 1.

Table 1: Significant factors with levels

Sr. No.	Factors	Level 1	Level 2	Level 3
1	Rotation of specimen (rpm)	1200	1400	1600
2	Ash concentration (ppm)	$100x10^3$	$200\ x10^3$	$300\ x10^3$
3	Particle size (µm)	50	75	90

First of all, the test specimens of high chrome cast iron were prepared and cleaned mechanically and chemically. Then coating was provided on the surface by detonation gun thermal spray. Modeling was done by response surface technique for 3^3 factorial experimental design [16]. ANOVA was used for statistical analysis and the modeled values for the response were obtained with the help of modeled equation. Finally the graphs ware plotted to get the result.

III. EXPERIMENTATION

Experiments were performed on the high speed slurry erosion tester (DUCOM Bangalore make, Model TR 401). The experimental set-up of high speed slurry erosion tester is shown in figure 1.

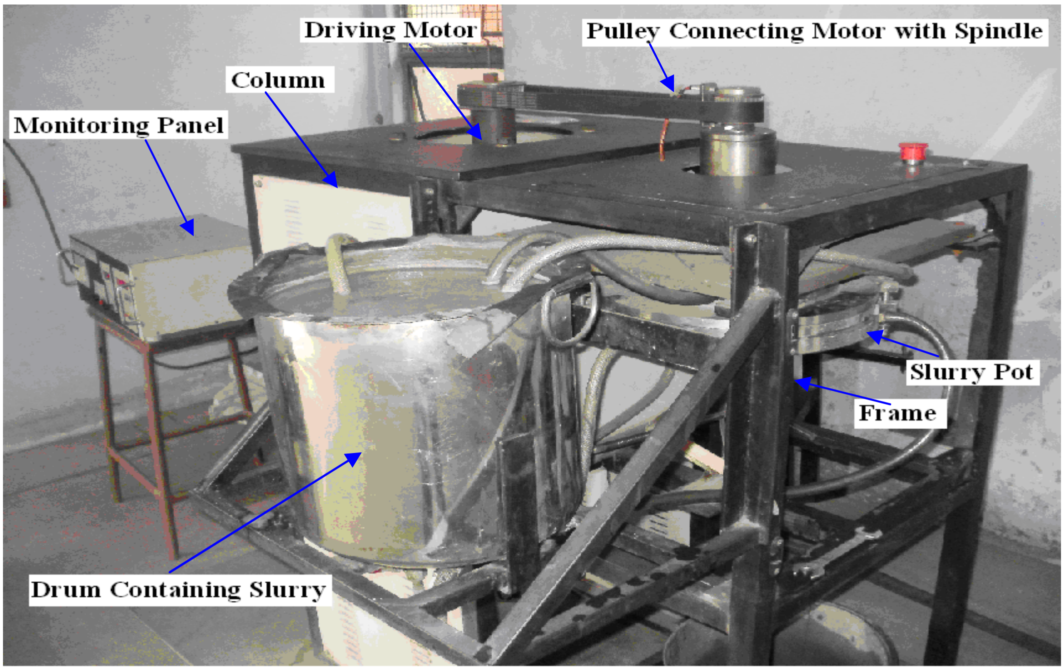

Figure 1: Experimental set-up of high speed slurry erosion tester

Total number of experiments was decided by the Response surface technique. After performing experiments, ANOVA is used to calculate the modeled value of the response. Response was the weight loss of the material due to erosive wear. Weight of the specimens was taken before and after the experimentation to get the weight reduction of the material. No. of runs given by Response surface method are shown in Table 2.

Table 2: Number of runs given by Response surface

Run	Rotational Speed (rpm)	Ash Concenteration (ppm)	Particle Size (µm)
1	1600	100000	75
2	1400	200000	75
3	1200	300000	75
4	1600	200000	90
5	1400	300000	50
6	1400	200000	75
7	1200	100000	75
8	1600	200000	50
9	1400	100000	50
10	1400	100000	90
11	1200	200000	50
12	1400	200000	75
13	1600	300000	75
14	1200	200000	90
15	1400	300000	90
16	1400	200000	75
17	1400	200000	75

3.1 High Speed Slurry Erosion Tester

In slurry erosion tester, a specimen, fixed to the specimen holder, is rotated in a circular container (slurry pot) filled with the slurry which is made homogeneous. In slurry erosion test, the amount of material removed from the specimen is determined by the weight loss. The samples are weighed before and after the tests.

Slurry pot tester is simple in design and easy to operate. In a slurry pot tester, generally two specimens have been rotated in solid-liquid mixture. The rotational movement of specimens keeps the solid (ash) particles suspended in the liquid (water). The rotating test specimens move at a velocity relative to the solid-liquid suspension.

High chrome cast iron specimens before applying ceramic coating are shown in figure 2. Experiments were performed on the Al_2O_3 coated specimens and affected by erosive wear as shown in figure 3.

Figure 2: Specimens before applying coating

Figure 3: Al_2O_3 coated specimens affected by erosive wear

3.2 Procedure

The fly ash which was collected directly from thermal power plant was used as the erodent. Ash was sized by using sieves and the particle range was selected from 50 µm to 90 µm with the mean particle size of 75 μm. The test specimens of impeller material (High Chrome Cast Iron) were prepared and cut into cylindrical pieces of OD 12 mm × ID 6 mm × length 10 mm and polished using emery paper. Specimens were cleaned with abrasive shot blast before applying coating. Specimens were then coated with Al_2O_3 using detonation gun thermal spray technique. Coating thickness was maintained to be 0.5 mm. The rotation per minute maintained as 1200, 1400 and 1600. Specimens were cleaned with acetone and weighed before and after the experimentation. The weight of the specimen material is reduced due to erosion.

Two test specimens were tightened opposite to each other. The test specimens were tightened properly to the specimen holder with the help of the screws. There was a drum of water carrying capacity of 30 liters was properly cleaned and slurry was prepared and drawn into the drum. The specimens were rotated in the slurry for 30 minutes. The slurry was made homogeneous in the drum by rotating it continuously during experimentation. The test specimen holder is shown in figure 4.

Figure 4: Specimen holder

The total number of tests and the values of variables for each test were determined with the help of Response Surface Method. Table 3 shows the analysis of variance for response surface quadratic model. The modeled values for the response were calculated and tabulated in Table 4 along with the experimental values for the weight reduction due to erosion.

No. of test pieces = 34

Size of cylindrical test pieces = OD 12mm, ID 6mm, length 10mm

No. of runs = 17 (2 pieces in each run)

Type of ash = Fly Ash

Specimen material = Al_2O_3 coated high chrome cast iron having 14.64% Cr and 0.42% Ni as alloying elements

Table 3: ANOVA for Response Surface Reduced Quadratic Model

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	1.889E-003	6	3.149E-004	10.84	0.0007	significant
A-rotational speed	*7.313E-004*	*1*	*7.313E-004*	*25.17*	*0.0005*	
B-ash concenteration	*6.301E-004*	*1*	*6.301E-004*	*21.69*	*0.0009*	
C-particle size	*2.101E-004*	*1*	*2.101E-004*	*7.23*	*0.0227*	
AC	*5.455E-007*	*1*	*5.455E-007*	*0.019*	*0.8937*	
A^2	*1.540E-004*	*1*	*1.540E-004*	*5.30*	*0.0441*	
C^2	*1.765E-004*	*1*	*1.765E-004*	*6.07*	*0.0334*	
Residual	2.906E-004	10	2.906E-005			
Lack of Fit	*2.694E-004*	*6*	*4.490E-005*	*3.47*	*0.1289*	*non-significant*
Pure Error	*2.120E-005*	*4*	*5.300E-006*			
Cor Total	2.180E-003	16				

The Model F-value of 10.84 implies the model is significant. There is only a 0.07 % chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.05 indicate model terms are significant. In this case A, B, C, A^2, C^2 are significant model terms. The "Lack of Fit F-value" of 3.47 implies the Lack of Fit is not significant. There is only a 12.89% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good.

Std. Dev.	5.39E-03		R-Squared	0.8667
Mean	0.024		Adj R-Squared	0.7267
C.V. %	22.8		Pred R-Squared	0.6665
PRESS	1.38E-03		Adeq Precision	11.319

The "Pred R-Squared" of 0.6665 is close to the "Adj R-Squared" of 0.7267 as one might normally expect. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Ratio of 11.319 indicates an adequate signal. This model can be used to navigate the design space.

3.3 Final Equation in Terms of Actual Factors:

Weight reduction = 0.30368 - 3.80604 x10^{-4} x (rotational speed) + 8.87500 x 10^{-8} x (ash concenteration) - 2.32409 x 10^{-3} x (particle size) + 9.09091 x 10^{-8} x (rotational speed) x (particle size) + 1.50987 x 10^{-7} x (rotational speed^2) + 1.75219 x 10^{-5} x (particle size^2)

Table 4: Experimental and Modeled Values of Response

Run	Rotation	Ash concentration	Particle size	Experimental Values (Wt. reduction)	Modeled Values (Wt. reduction)
	(rpm)	(ppm)	(microns)	(gms.)	(gms.)
1	1600	300000	75	0.053	0.043
2	1400	200000	75	0.02	0.018
3	1200	200000	90	0.027	0.025
4	1400	200000	75	0.014	0.018
5	1600	200000	90	0.041	0.045
6	1200	100000	75	0.006	0.006
7	1200	200000	50	0.013	0.015
8	1200	300000	75	0.023	0.023
9	1400	200000	75	0.017	0.018
10	1600	200000	50	0.028	0.034
11	1400	100000	50	0.013	0.010
12	1400	100000	90	0.026	0.020
13	1600	100000	75	0.025	0.025
14	1400	300000	90	0.033	0.038
15	1400	200000	75	0.015	0.018
16	1400	200000	75	0.016	0.018
17	1400	300000	50	0.032	0.027

IV. RESULT

Graphs were plotted between the factors affecting erosive wear and the weight reduction of specimen. It shows that at 1200 rpm and 100000 ppm ash concentration, the weight loss of the material due to erosive wear is very less. For 1400-1600 rpm, the erosive wear increases exponentially. As the rotational speed of the impeller increases, the force with which slurry strikes the impeller increases which in turn increases the erosive wear (Figure 5). The weight loss of the material increases linearly with the increase of ash concentration as shown in figure 6. Particle size does not show a significant effect on weight loss due to erosive wear in a range of 50 µm to 75 µm but increases exponentially from 75 µm up to 90 µm (Figure 7).

A high erosive wear is observed at high rotation speed. The ash particles at high velocity were associated with more kinetic energy, causing severe impingement on the specimen surface [17–18].

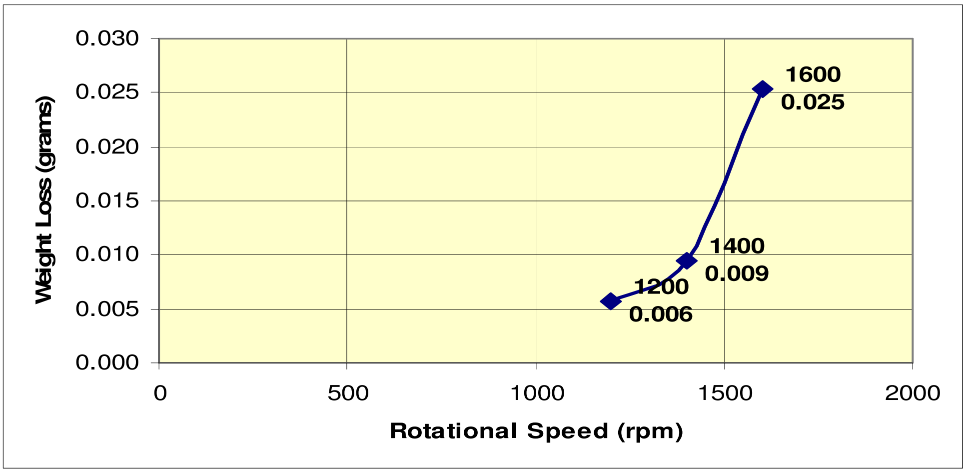

Figure 5: Weight Loss vs. Rotation

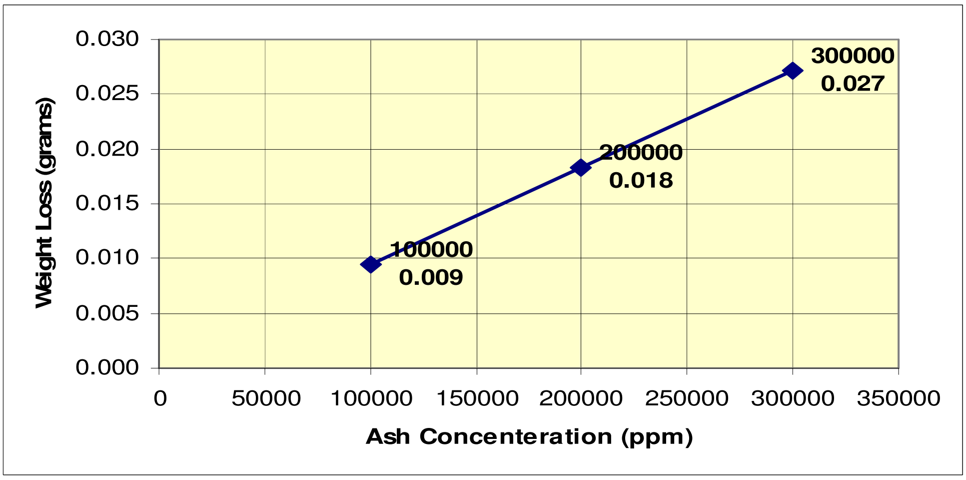

Figure 6: Weight Loss vs. Ash Concentration

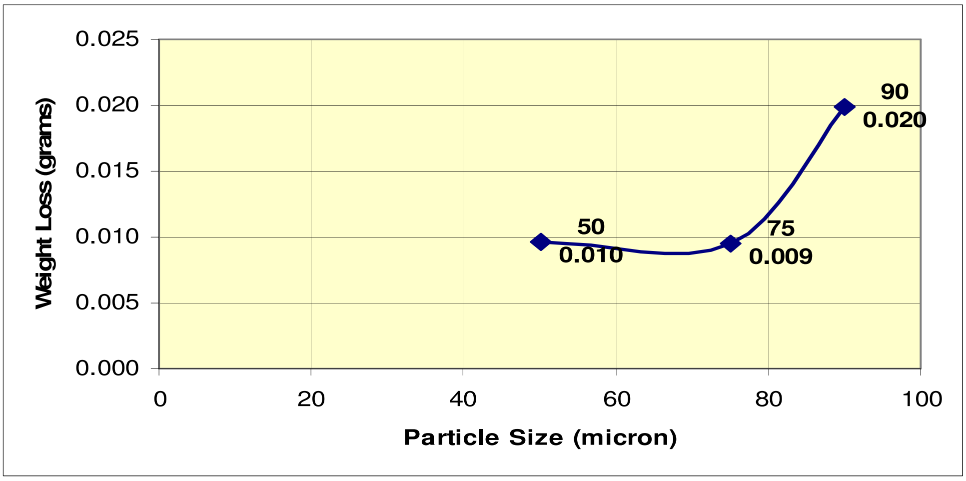

Figure 7: Weight Loss vs. Particle Size

Result shows that the increase in each parameter leads to increase wear rate. The purpose is to dispose large amount of ash with less wear rate of the impeller. At the rotation can be taken as 1200 rpm to 1400 rpm, ash concentration should be 100,000 ppm and the particle size range should be 50 μm to 75 μm for a considerable material loss due to erosion. As the particle size increases from 75 μm, the wear would increase rapidly.

V. CONCLUSION

The conclusion is this that if the slurry pumps has to work the range where the erosive wear is less; the performance of the slurry disposal pump may be improved. Erosive wear of the pump impeller would decreases with decreasing rotation speed, ash concentration and particle size.

Erosion is a complex process in which three co-existing phases, namely conveying fluid (water), solid particles (ash) and the surface (pump impeller) interact in many ways. The kinetic energy of the moving particles and amount of ash concentration in slurry are mainly responsible for the loss of material. The impingement attack is either by solid or by liquid.

Wear takes place by removal of material from the specimen surface. Ceramic coating has been suggested to protect the pump due to slurry erosion [19]. Instead of applying coating to whole impeller, the coating can be applied only to blades to cut manufacturing cost. The wear pattern at inlet is more severe than wear at the trailing edge of the blade [20]. Therefore the root of the blade should be round to provide smooth flow of fluid and the sharp corners should be avoided. Angle of impingement of ash particles on the impeller can also be considered. For brittle material, the high wear rate occur at 90° impingement angle and for ductile material 20° to 30° impingement angle, the wear rate is high [21-23]. Al_2O_3 is brittle, therefore at 90° degree impingement angle, the wear would be more.

REFERENCES

[1]. A. R. Harne, (1989) "Life improvement of thermal power station component: A war against wear", *Workshop on Wear and Erosion of Materials in Thermal Power Station. CPRI*, Bangalore.

[2]. T. Savaskan & S. Murphy, (1987) "Mechanical properties and lubricated wear of Zn-25 Al-based alloys", *Wear,* Vol. 116, pp. 211–224.

[3]. B. K. Prasad, S. Das, A. K. Jha, O. P. Modi, R. Dasgupta & A. H. Yegneswaran, (1997) "Factors controlling the abrasive wear response of a zinc-based alloy silicon carbide particle composite", *Composites A*, Vol. 28, pp. 301–308.

[4]. A. K. Jha, A. Gachake, B. K. Prasad, R. Dasgupata, M. Singh & A. H. Yegneswaran, (2002) "High stress abrasive wear behavior of some hard faced surfaces produced by thermal spray", *Journal of Materials Engineering and Performance,* Vol. 11, No. 1, pp. 37–45.

[5]. I. Finnie & K. Natesan, (1980) "The mechanism of erosion wear in ductile material: Corrosion behaviour of materials", *TMS-AIME*, pp. 118–126.

[6]. W. Zhu & Z. Y. Mao, (1987) "Wear of Material", *Proceeding of Conference, ASME*, pp. 787.

[7]. R. G. Desale, K. Bhupendra & S. C. Gandhi, (2005) "Improvement in the design of a pot tester to simulate erosion wear due to solid-liquid mixture", *Wear*, Vol. 259, pp. 96–202.

[8]. H. M. H. Throhe, Y. Xie & S. K. Yick, (2003) "A new coriolis slurry erosion tester design for improved slurry dynamics", *Wear*, Vol. 255, pp. 170–180.

[9]. T. H. Kosel, R. O. Scattergood & A. P. L. Turner, (1979) "Wear of Material", *Proceeding of Conference, ASME*, pp. 192–204.

[10]. A. W. Sive & J. H. Lazarus, (1986) "A comparison of some generalized correlations for the head loss gradient of mixed regime slurries", *Proc. Hydrotransport 10, BHRA Fluid Engineering, Cranfield, Bedford, England. Paper E2,* pp. 149-175.

[11]. Robert C. Tucker, Jr., (1994) "Thermal Spray Coatings", *Surface Engineering, ASM Handbook,* Vol. 5, pp. 497-509.

[12]. B. Bhushan & B. K. Gupta, (1991) "Metals and ceramics", *Handbook of Tribology: materials, coatings and surface treatments, New York: Mc Graw-Hill,* pp 4.53

[13]. Vasile Hotea, Irina Smical, Elena Pop, Iozsef Juhasz & Gabriel Badescu, (2008) "Thermal Spray Coatings for Modern Technological Applications" *Fascicle of Management and Technological Engineering,* Vol. VII, No. XVII, pp. 1486-1492.

[14]. http:// www. miningweekly.com/articale/ceramic-pump-impellers-reduce-costs-2010-06-11.

[15]. Frank J. Hermanek, (2001) "Thermal Spray Terminology and Company Origins", *First Printing, ASM International. Materials Park*, OH.
[16]. Andre´ I. Khuri and Siuli Mukhopadhyay, (2010) "response surface methodology- advanced review", John Wiley & Sons, Inc. *WIREs Comp Stat,* Vol. 2, pp. 128–149.
[17]. S. Turenne, D Simard & M Fisat, (1991) "Influence of structural parameters on the slurry erosion resistance of squeegee-cast metal matrix composites", *Wear*, Vol. 149, pp. 187−197.
[18]. B. Q. Wang & K. Luer, (1994) "The erosion-oxidation behavior of HVOF Cr_3C_2-NiCr cermet coating", *Wear*, Vol. 174, pp. 177−185.
[19]. H. X. Zhao, A. Yabuki, M. Matsumura, T. Takahashi & M. Yamamoto, (1999) "Slurry erosion properties of ceramic coating", *Wear,* Vol. 233-235, pp. 608-614
[20]. Li Ping, Cai Qizhou & Wei Bokang, (2006) "Failure analysis of the impeller of slurry pump used in zinc hydrometallurgy process", *Engineering Failure Analysis,* Vol. 13, pp. 876-885.
[21]. S. C. Mishra, S. Das, A. Satapathy, P. V. Ananthapadmanabhan & K. P. Sreekumar, (2009) "Erosion Wear Analysis of Plasma Sprayed Ceramic Coating Using the Taguchi Technique", *Tribology Transactions*, Vol. 52, No. 3, pp. 401 -404.
[22]. H. Imrek, M. Bagci & O. M. Khalfan, (2011) "Solid particle erosion as influenced by tensile axial loads", *Tribology Transactions*, Vol. 54, No. 5, pp. 779 -783.
[23]. G. A. Sargent & D. Saigal, (1986) "Erosion of Low Carbon Steel by Coal Particles" *ASLE Transactions,* Vol. 29, No. 2, pp. 256-266.

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