Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 32 ISSUE 1 January 2009

Experimental investigation of effects of external loads on erosive wear

H. Imrek*, M. Bagci, O.M. Khalfan
Department of Mechanical Engineering, Selcuk University, 42075, Konya, Turkey
* Corresponding author: E-mail address: himrek@selcuk.edu.tr

Received 07.11.2008; published in revised form 01.01.2009

Properties

ABSTRACT

Purpose: The purpose of the paper is to investigate effects of external loads on erosive wear.
Design/methodology/approach: In this experimental study, specimens were placed on specially designed a specimen holder and then, external tensile loads corresponding to 0%, 20%, 40% and 60% of the specimen's yield strength were applied on the specimens. For every load step, the specimens were subjected to 15º, 30º, 45º, 60º, 75º and 90º of erodent impact angles. At the end of the tests, effects of external loads and impingement angles on erosive wear were studied. In the experimental set, dry and compressed air was used to impinge erodents onto the test specimens and subsequent wear was investigated. During the tests, the impingement angles were adjusted by turning the specimen holder around its axis. Erodent particles used were SAE G40 having internal uniform martensitic structure and angular geometry. Determination of erodents speed was achieved with the help of the Rotating Double Disc Method. The speed used in the tests was 30 m/s.
Findings: At the end of the tests, erosive wear rates were obtained as functions of stresses and impingement angles. Graphs showing variations of erosive wear rates for load values obtained against every impingement angle and yield stress were drawn. Critical impingement angle and load values at which maximum erosion rate was obtained were determined.
Research limitations/implications: In researches made on erosive wears so far; there are only few studies dealing with the effects of external loads on the specimens subjected to erosive wear. By considering that stresses may affect the erosive wear, the stress state around contact area as well as material properties, this experimental study has thus, investigated likely effects of stresses on the erosive wear. With the help of the designed special specimen holder, the specimens were subjected to tensile stresses that are lower than the yield strength of the material and then the erosive wear was investigated.
Originality/value: The investigations of effects of external loads on erosive wear.
Keywords: Erosive wear; Yield strength; Impingement angle; Erodent speed; Erosion rate

1. Introduction

Because of the multitudes of physical and chemical changes observed on contact surfaces as a result of hard impinging particles, wear formed under external loads consists of many types of wear and not just one type. Adhesion, abrasion, mechanical corrosion, fatigue (pitting) and erosive wear are classified as the most encountered types of surface damages [1, 2].

Erosive wear is formed when a fluid containing hard solid particles strikes a surface. In other words; when solid particles moving at a certain speed strikes a metal surface, the wear formed there as a result of material loss in the metal upper surface layer is called erosive wear [3, 4].

If material loss on the upper surface layer continues, serious mechanical damages may appear depending on the place the component is used. Machine components suffer life shortage when exposed to liquid drops or striken by solid particles under erosive environment. Impinging angle, erodents' speed, type, shape and their dimensions together with the nature (properties) of the target material are among the factors affecting erosive wear.

Material loss resulting from solid particles impinging the surface of a material is the most adverse process of erosive wear and has had an increasing interest among researchers nowadays. This is probably due to the fact that it is possible to encounter this type of wear in applications of spacecrafts, energy conversion systems, jet engines, helicopter rotors, turbines and in coal mines. Here abrasive particles strike moving blades, valve orificies, pipe connections and fittings as well as other surfaces, thereby forming significant wear damages.

When mechanical properties of materials are investigated it is assumed that a steady (uniform) state is the case and the internal structural changes of the materials are hence studied according to this assumption. In reality there is a close correlation between internal structures and mechanical properties and therefore any factor that affects the internal structure will most likely alter the material properties too. In applications various industrial processes have been developed by making use of this correlation. With these processes, material properties can be adjusted with respect to intended goals.

For example, an annealed steel is mild, easily machined but wears most. This steel can easily be shaped when mild and then its wear resistance can be improved by quenching in water. These important changes in the mechanical properties can only be well explained if the changes in internal structures are taken into account. Even tensile forces applied to specimens create stress effects on the latter and bring about changes in mechanical properties of the specimens [5, 6].

In researches made on erosive wears so far; there are only few studies dealing with the effects of external loads on the specimens subjected to erosive wear. By considering that stresses may affect the erosive wear, the stress state around contact area as well as material properties, this experimental study has thus, investigated likely effects of stresses on the erosive wear. With the help of the designed special specimen holder, the specimens were subjected to tensile stresses that are lower than the yield strength of the material and then the erosive wear was investigated.

2. Material and method

2.1. Test method

The test method used was the one where dry and compressed air is used to drive the abrasive particles to impinge the surface of the specimen and the wear formed is studied [7]. In addition, this contact geometry can serve both studying the solid erodent wear condition and investigation of surface properties like wear performance of the surface and effects of surface coatings etc. This type of test configuration is suitable for conducting bulky tests due to their being simple and cost effective. In this method, wear resistances of metals, plastics, composites and ceramics can be determined. The method also offers the possibility of acquiring sensitive measurements of wear rates and dimensional changes due to the fact that the specimens accommodated are simple and small in size.

2.2. Experimental set

The tests were conducted on the specially designed erosive wear test rig shown in Figure 1.

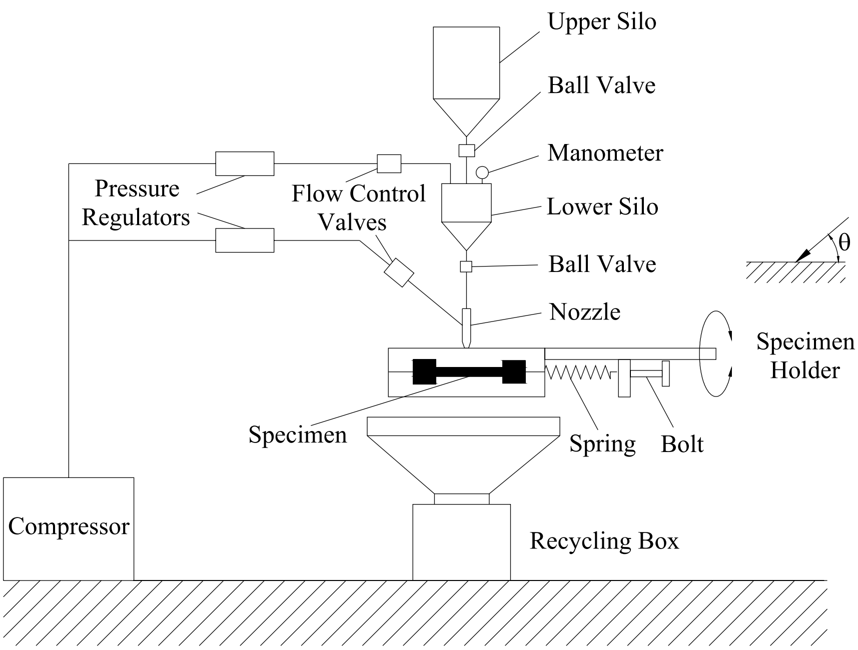

Fig. 1. Schematic view of the test rig

The test rig consists of two silos for collecting the abrasive particles (erodents). The upper silo which is open to atmosphere and where the particles are first poured is interconnected to the lower high pressure silo with the help of a valve. Before the tests start, a needed amount of the abrasive articles are poured into the upper silo and from there the particles flow down the lower silo and the valve is closed to prevent the compressed air from fuming out of the upper silo. In this way, the lower silo becomes exempted from outer surrounding air. The pressure regulators used in the test set help with adjusting the pressures in the silo and that in the nozzle. The system pressure in the lower silo is measured with the manometer found on the test rig.

The particles used in the tests are collected into the recycling box underneath. To speed up the abrasive particles down the nozzle, dry and compressed air from a 10 bar compressor was used.

Another important apparatus in the test rig is the specially designed specimen holder. Test specimens are located on this apparatus and suitable stresses as per required test conditions are exerted on the specimens. At the same time the impinging angles are adjusted by turning this apparatus around its axis.

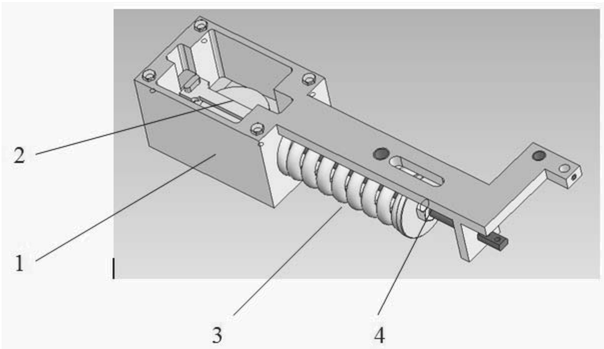

Fig. 2. Specimen holder used in the test set

The specimen holder used in the test rig is shown in Figure 2. With the help of a cylindrical helical spring (3) and a nut (4), load is applied on the test specimen (2) located into the compartment (1) of the apparatus. The value of exerted load is adjusted based on the deformation extent of the calibrated cylindrical helical spring.

2.3. Specifications of the test specimens and abrasive particles

In our experimental study, 3250 (DIN EN 10025–1994) quality steel test specimens were used. Dimensional specifications of the test specimens are shown in Figure 3. In addition, their chemical compositions are given in Table 1.

Table 1.
Chemical compositions of the 3250 quality steel test specimens (% weight)

Element	C	Si	Mn	P	S	Al	N
% Amount	0.2	0.4	0.9	0.025	0.03	0.015	0.009

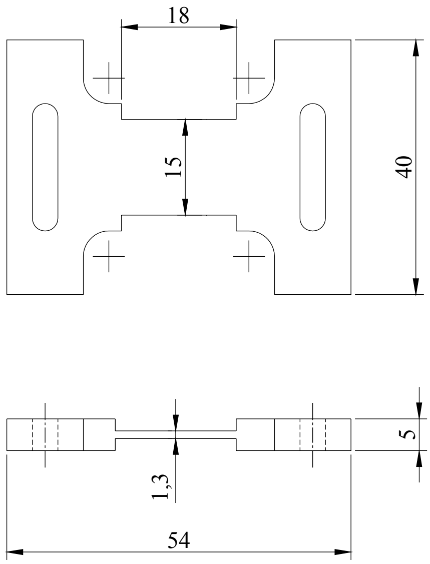

Fig. 3. Dimensions of the test specimens

The geometry of SAE G40 abrasive particles is angular with 55 HRC hardness, density of 7.2 gr/cm^3 and a uniform internal martensitic structure. General views and chemical compositions of the abrasive particles are shown in Figure 4 and Table 2 respectively.

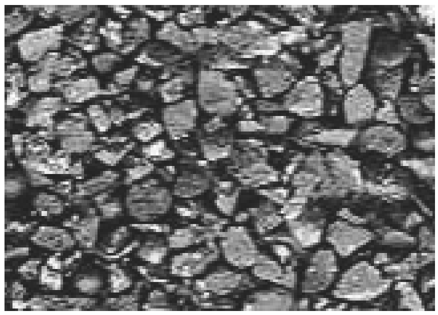

Fig. 4. General views of the abrasive particles

Table 2.
Chemical compositions of the abrasive particles (% weight)

Element	Carbon	Manganese	Silicon	Sulphur	Phosphorous
% Amount	0.85 – 1.20	0.60 – 1.20	0.40 min.	0.05 max.	0.05 max.

2.4. Test procedures

Preparation of the test specimens and the way the tests were conducted followed the below explained procedures.

- The test specimens were cut on a laser machine at the dimensions shown in Figure 3 and then their surfaces over which the tests would be conducted were ground.

- The specimens were cleaned with an aceton and then dried with compressed air in order to get rid of any possible oils or dirt.
- To obtain the initial weight of the specimen, the latter was weighed on a precision scale having an accuracy of 0.0001 gr and then the weight was recorded.
- After positioning the specimen onto its place on the specimen holder, suitable loads were applied on it in order to obtain the stress values given in Table 3.

Table 3.
Axial tensile loads applied on the test specimens

Yield strength of specimen, σ_{AK} = 295 N/mm^2, Cross section = 19.5 mm^2		
Step	Stress Value σ (N/mm^2)	Axial Tensile Load F (N)
1	$0*\sigma_{AK}$	0
2	$0.2*\sigma_{AK}$	1150.5
3	$0.4*\sigma_{AK}$	2301
4	$0.6*\sigma_{AK}$	3451.5

- In erosive wear, determination of impinging speed of the erodents is an important aspect of the test. For this reason, multi flash photographing, Laser Doppler Velocimetry (LDV) and double disc method are among the methods employed for speed measurements [8-10]. Among these methods, we used the double disc method and; by making use of pressure changes we could adjust the impinging speed of the abrasive particles in our experimental study to be 30 m/s.
- After adjusting the speed value, the impact angles were adjusted as 15^o, 30^o, 45^o, 60^o, 75^o and 90^o by turning the specimen holder around its axis.
- With application of the specific stress values on the specimen and adjustments of the impinging speed as well as the impact angels, the tests were conducted by subjecting the specimens to particle bombardments at the time interval of 600 s.
- After completion of a test, the specimens were again cleaned with compressed air in order to measure the weight loss in the specimen by weighing them on the precision scale and recording their final weights.
- By dividing the weight loss in the specimen by the weight of the abrasive particles the erosion rate, (mg/kg), as used in the literature was obtained and the plotting of the graphs was based on this entity.

3. Experimental results and discussion

The test specimens were subjected to erosion at six different impact angles of 15^o, 30^o, 45^o, 60^o, 75^o and 90^o and under stress loads corresponding to 0 %, 20 %, 40 % and 60 % of the yield strength of the specimen. The effects of wear were investigated by keeping the impinging speed constant and varying the impinging angles and the applied loads.

Behaviour of engineering materials when exposed to bombardments of liquid drops or solid particles, by far, depends on mechanical properties of the materials (e.g hardness and micro structures of the test specimen), the environment the material is exposed to (e.g temperature, stress and surface treatments) and erosion environmental parameters. The tensile load applied on the specimen brings about structural changes in the material. As seen in Figure 5 the elastic strain formed as a result of applied load is reflected by the changes in distances between adjacent atoms. This distance increases towards the stress and decreases at right angle to the stress direction. By considering that this interatomic stress has some effects on erosive wear, the specimens in this experimental study were loaded by stresses corresponding to certain yield strength values of the material and their effects on erosive wear were investigated.

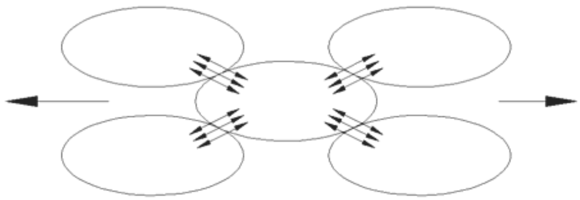

Fig. 5. Elastic Strain of material under tensile load

With the data obtained the graphs in Figures 6, 7, 8 and 9 were plotted. In these graphs, plots of erosion rate against impact angles at stress values corresponding to $0*\sigma_{Ak}$, $0.2*\sigma_{Ak}$, $0.4*\sigma_{Ak}$ and $0.6*\sigma_{Ak}$ of the specimen's yield strengths are drawn. In addition, in order to obtain better explanatory remarks of the tests made, the graphs for all the stress values against impact angles are plotted in one graph in Figure 10.

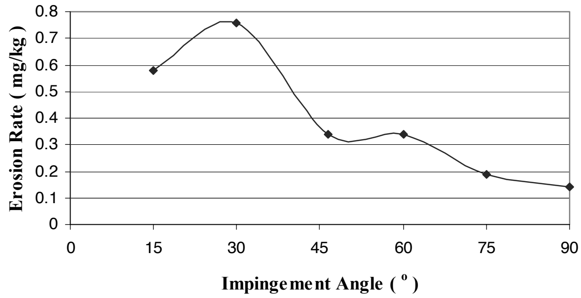

Fig. 6. Plot of erosion rate against impingement angle for a 3250 steel at $0*\sigma_{Ak}$ yield strength

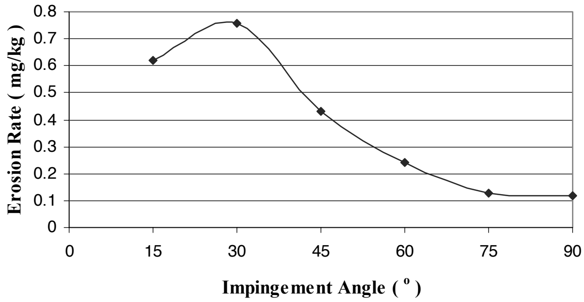

Fig. 7. Plot of erosion rate against impingement angle for a 3250 steel at $0.2*\sigma_{Ak}$ yield strength

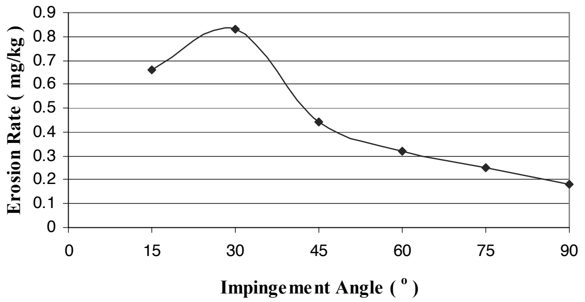

Fig. 8. Plot of erosion rate against impingement angle for a 3250 steel at 0.4*σ_{Ak} yield strength

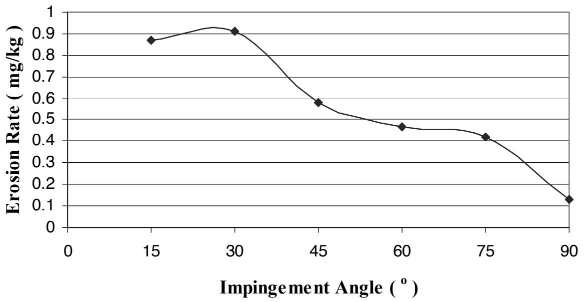

Fig. 9. Plot of erosion rate against impingement angle for a 3250 steel at 0.6*σ_{Ak} yield strength

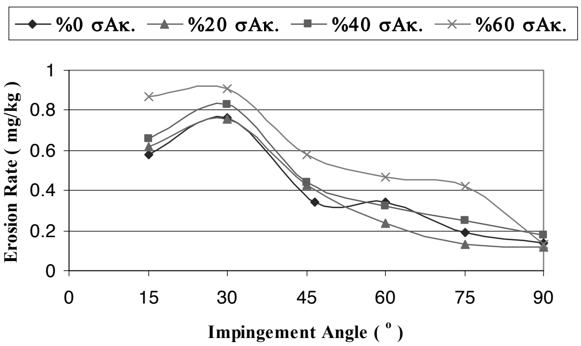

Fig. 10. Plot of erosion rate against impingement angle for a 3250 steel at 0*σ_{Ak} 0.2*σ_{Ak} , 0.4*σ_{Ak} , 0.6*σ_{Ak} yield strengths

By looking at the graphs, the results of the tests made show that, based on the applied tensile loads on the specimen, erosive wear increases from 0*σ_{Ak} to 0.6*σ_{Ak} of the yield strength. The results derived here is that the stress increase in the cross section of the specimen causes changes in the atomic lattice and this accounts for the increased erosive wear [11].

Erosion of mild materials (e.g most metals) shows an obvious variations depending on angle of impact. The maximum value lies between 20^o and 30^o; and, the maximum erosion rate at normal incident angle varies between a half and a third of the maximum erosive wear rate [12, 13].

In the tests we have conducted, when the impinging angles are studied, we come to find that similar wear structure exists in other literatures too. The maximum erosion rate in our tests was obtained at 30^o impinging angle. However; as the angle increases the erosion rate was seen to decrease and this correlates well with the results of erosion rates of mild materilas with impinging angle found in other literatures.

Acknowledgements

This paper was supported by “Selçuk University Scientific Research Projects Coordinatories” in 2008.

References

[1] M.Y. Gürleyik, Aralık, Makine Mühendisliğinde Aşınma Olayları, Mühendis ve Makine 27/323 (1986) 3-14.
[2] M. Akkurt, Makine Elemanları Cilt 1, Birsen Yayınevi, İstanbul, 1990.
[3] D. Mills, Erosive Wear, Pneumatic Conveying Design Guide, Second Edition, 2004, 498-525.
[4] G.W. Stachowiak, A.W. Batchelor, Abrasive, Erosive and Cavitation Wear, Engineering Tribology, Third Edition, 2006, 501-551.
[5] K. Onaran, Malzeme Bilimi, Bilim ve Teknik Yayınevi, İstanbul, 1993.
[6] M. Erdoğan, Malzeme Bilimi ve Mühendislik Malzemeleri, Nobel Yayınevi, Ankara, 1998.
[7] Standard Test Method for Conducting Erosion Tests By Solid Particle Impingement Using Gaz Jets, ASTM Designation: G76–95, Annual Book of ASTM Standards, 2000.
[8] I. Finnie, J. Wolak, Y. Kabil, Erosion of metals by solid particles, Journal of Materials 2 (1967) 682-700.
[9] A.W. Ruff, L.K. Ives, Measurement of solid particle velocity in erosive wear, Wear 35 (1975) 195-199.
[10] A.J. Ninham, I.M. Hutchings, A computer model for particle velocity calculation in erosion testing, Proceedings of the 6th International Conference “Erosion by Liquid and Solid Impact”, University of Cambridge, 1983, 50-51.
[11] S.A.R. Naga, S.M. Riad, M.O.A. Mokhtar, E.A. Gewfil, Wear failure as influenced by external stressing, Wear 145 (1991) 297-302.
[12] I.M. Hutchings, Tribology, Friction and Wear of Engineering Materials, St. Edmundsbury Press, London, 1996.
[13] K.C. Ludema, Friction, Wear, Lubrication, A Textbook in Tribology, CRC Press, U.S.A., 1996.