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THE EFFECT OF LASER SURFACE HARDENING ON THE WEAR AND FRICTION CHARACTERISTICS OF ACICULAR BAINITIC DUCTILE IRON

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ABSTRACT

Nd-Yag (Neodymium Yttrium) pulsed wave laser has been used to modify and refine the surface microstructure of acicular bainitic ductile iron. The wear characteristics evaluated by adhesion and abrasion wear tests while friction characteristics evaluated by using strain gauge technique of the laser processed and unprocessed (as-cast) specimens were studied. The wear and friction resistance of laser processed samples are significantly enhanced by their refined bainitic microstructures and improved hardness in the melted and resolidified layer. Cross-sectional optical and scanning electron microscope have been used to study the microstructure and wear mechanism of the laser processed and unprocessed surfaces while X-Ray diffraction technique has been used to study and estimate the metallurgical phases. Subsurface micro cracks generation and retained austenite phase have been observed. All specimens treated by laser showed wear and friction resistance higher than as-cast specimens at all loads, sliding speeds and sliding times used in this research work.

Keywords: Laser surface hardening, Wear& friction characteristics, Acicular bainitic_ductile iron

INTODUCTION

Cast irons are commonly used in many engineering applications because they are cheep and have good fluidity, cast ability and mechanical properties. However under demanding service conditions, such as in erosive and corrosive environments, their performance and reliability can be limited. High-power and low losses Nd: YAG laser is found as a significant technique to enhance the mechanical properties of cast irons (Chen *et al.,* 1988).

Material properties play a dominant role in determining the interaction between the laser beam and engineering materials. Many material properties change with temperature (Ion, 2005). The properties of many engineering materials may be favorably modified by application of a suitable heat treatment. One of the most important treatments is the laser transformation hardening of steel (Grootenboer, 2003). The principle of laser material processing depends on the mechanism of processing i.e. heating, melting and vaporization which occur in the solid, liquid and vapor states (Ion, 2005). Laser induced surface hardening can be achieved either with or without surface melting. In transformation hardening the surface is heated to a temperature below its melting point. On rapid cooling the laser treated layer usually develops graphite containing martensitic matrix (Wineman and Miller, 1977; Belfote, 1979; Qurik, 1978). Surface melting generally produces microstructure consisting of ferrite, cementite, martensite and retained austenite (Yessik and Scherer, 1979; Golubets *et el.*, 1972; Zhukov *et el.,* 1971; Sedonuv *et al.*,1980; Andriyakhin *et al*., 1981; Chen *et el.*, 1984). Laser transformation hardening is used a technique to obtain hard and resistant surface layers (Vollertsen *et al.*, 2005). The thing to be mentioned is laser surface hardening improves wear strength and other mechanical properties by generating compressive stresses in the hardened zone. This is generally the result of volume expansion by the martensite formation from austenite phase.

This paper is focused on the surface properties of acicular bainitic ductile iron and its changes by laser treatment, i.e. transformation hardening that led to the increment for the wear resistance for production and repair of structural parts.

EXPERIMENTAL PROCEDURE

In this study samples of acicular bainitic ductile iron in two conditions were subjected to wear studies. Two conditions included: as-cast and surface treated by laser. ND:YAG laser pulses were applied to acicular bainitic ductile iron specimen surface , laser beam energy and distance between the lens and treated surface were varied for optimum surface conditions. After microscopic inspection of heat affected zone by laser, selected laser beam energy was (11.2) J, overlapping laser pulses was 50%, distance between the lens and specimen was (25) cm, laser pulse duration (10) ms, and beam expander at (10).

The wear test specimens were (15mm) in length and (10mm) in diameter. Chemical composition of a bainitic ductile iron alloy is shown in Table 1. Pin on disc sliding machine was used for this study. The wear rate was measured by weight loss method using a Mettler AE200 microbalance of (10^-4 gm) sensitivity. The wear rate was calculated according to the following relationship:

Wear rate = ΔW/SD (gm/cm) (1)

Where: ΔW= Weight loss (gm)

SD=Sliding distance (cm)

ΔW=W1-W2 (2)

Where: W1= Initial weight of the test specimen (gm)

W2= Finial weight of the test specimen (gm)

The applied normal loads were used (10, 20, 30& 40) N and three linear sliding speeds (1.40, 2.20& 3.0) m/sec. The hardness of the counter disc was (446) Kgf/mm². The duration of each test was 30 minutes and the test was carried out at room temperature and normal atmospheric conditions. Surface roughness estimated of samples before and after laser surface hardening by A Parthen – Perthometer type: 56 P_ ISO, whenever was (Ra= 0.25) while of counter disc was (Ra= 0.35μm) respectively.

Table1: The Chemical Composition of Acicular Bainitic Ductile Iron Alloy.

Composition (%)	
C.E.	4.13
C	3.20
Mg	0.0327
Si	2.77
S	0.01
Cr	0.05
Mn	0.3
Ni	3.8
P	0.02
Mo	0.28
Al	0.002
Cu	0.08

RESULTS AND DISCUSSION

Effect Of Load On The Wear Rate And Coefficient Of Friction

The effect of the loads on the wear rate is shown in Figure 1. The specimens were in a two conditions; as – cast and laser surface hardened condition. The wear rate increases with increasing applied normal load. The curve of as cast condition of specimen shows three distinct regions; mild, transition and metallic (severe) wear. The mild wear is explained in terms of oxide layer formation which reduces the true contact area of the matting surfaces, thus leading to a low wear rate at the load range of (10-20) N (Rac, 1985; Kheder *et al.*, 1991). The transition wear occurs within the load range of (20-30) N where a change from elastic to plastic deformation takes place and causes the fracture of the brittle oxide layer, leading the virgin metals to come into contact which increase the wear rate. The metallic wear starts after 30 N load. The increase of wear rate in this region is less than of the wear rate in transition stage due to work hardening. These results in general are in agreement with the published data (Kheder *et al.*, 1993a, b; Shepperson and Allen, 1988).While the curve of laser surface hardened specimen condition shows only mild wear and low wear rates at all loads used in this research work because of the best wear resistance was obtained in specimens hardened by laser, wherever this observation is explained in terms of the microstructure obtained in each case which gives varying hardness and different amounts of retained austenite (from 14.47% to 8.35%) and stress induced phase transformations that occur during the tests [1, 20] which reduces the amount of retained austenite to 1.79% after test. The microstructure studies showed that the contributions to the wear resistance come from the acicular matrix of martensite, work hardened structure, stress induced transformed phases and very fine acicular structure after laser treatment. The laser hardening treatment produces hardness value varying 380Hv up to 606 Hv. Figure 2 shows the micrograph of two states of specimen: as-cast and laser hardened specimen in which the acicular microstructure and graphite nodules with some retained austenite (14.49%& 8.35 respectively) are clear and contribute to the high wear resistance of acicular ductile iron.

The coefficient of friction (μ) of both conditions (as-cast and laser hardened) increases slightly with increasing load from 10N to 20N. This explained in terms of temperature increase of the opposing surfaces up to 120°C which leads to the formation of thin oxide layer on the specimen surface and prevents the direct contact of the metallic matrices. The graphite nodules provide a lubricant layer, then the overall increasing in (μ) is small, although some cracks form in the oxide layer because of its brittleness which may contribute to higher values of (μ), Figure 3. At loads of 30N and 40N the surface of the specimens are subjected to more plastic deformation including the graphite nodules which causes smearing of the surface with graphite resulting in lower (μ) as shown in Figure 3. Best lower in (μ) was obtained in specimen hardened by laser comparison with as –cast specimen , this observations is explained in term of the microstructure obtained in each case which gives varying hardness from 381 Hv up to 599 Hv , with increasing surface hardness of specimen the (μ) deceases.

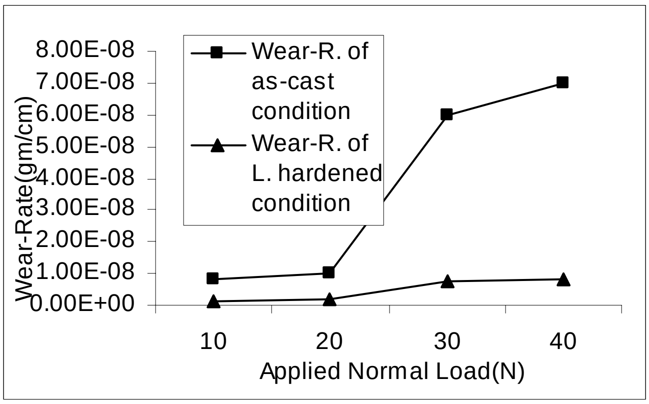
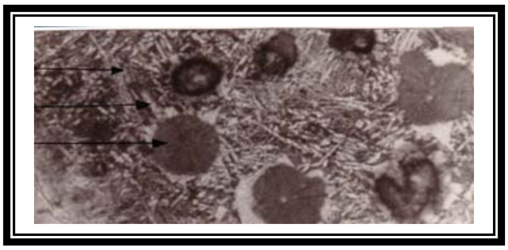


Figure 1: Shows the Effect of Load on The Wear Rate.

(A)



(B)

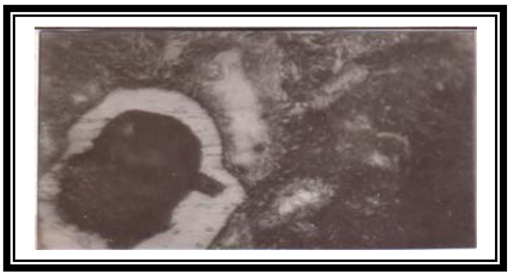


Figure 2: Shows the Micrograph of (A): Specimen: As-Cast and (B): Laser Surface Hardened Specimen. Magnification Power (1383X) and at B (588X).

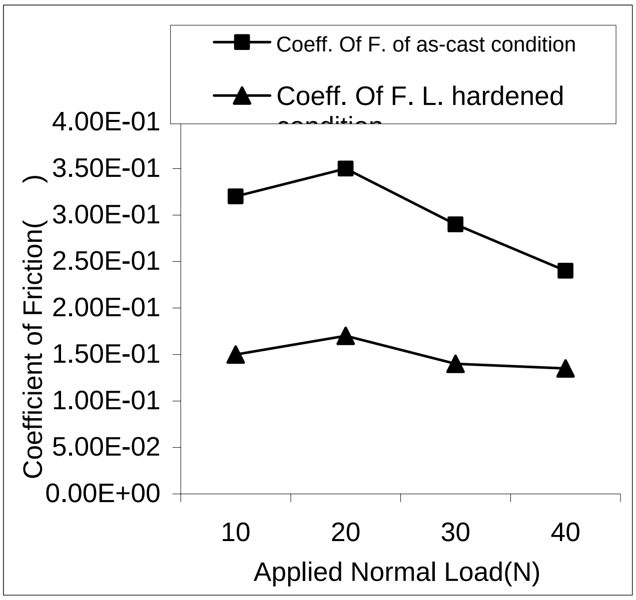


Figure 3: Shows the Effect of Load on The Coefficient of Friction.

EFFECT OF SLIDING SPEED ON THE WEAR RATE AND COEFFICIENT OF FRICTION

The effect of sliding speed on the wear rate is shown in Figure 4. The wear rate decreases with increasing sliding speed. This behavior can be explained by taking the flash temperature into account. The flash temperature increases with increasing sliding speed up to melting point at asperities (Kawamoto and Okabayashi, 1980). The surface temperatures were measured in this research work and they were: (374,382, 408) °C at sliding speed of (1.40, 2.20 & 3.0) m/sec respectively at the load of 40 N. The heat dissipation at higher sliding speed is lower than at lower sliding speed (Kheder *et al.,* 1991). This causes softening of the asperities and reduces the forces required to shear the welded points so the wear rate will be lower. Laser surface hardened specimen showed wear rates lower than as-cast specimen because of the fines microstructure obtained in laser hardened specimen which gives higher surface hardness consequently, best wear resistance.

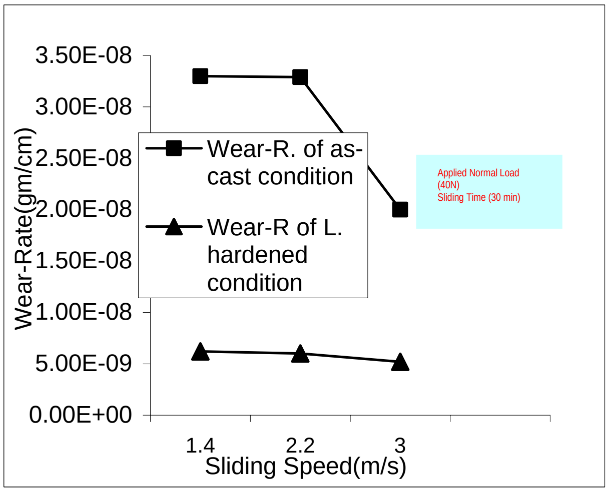


Figure 4: Shows the Effect of Sliding Speed on the Wear Rate.

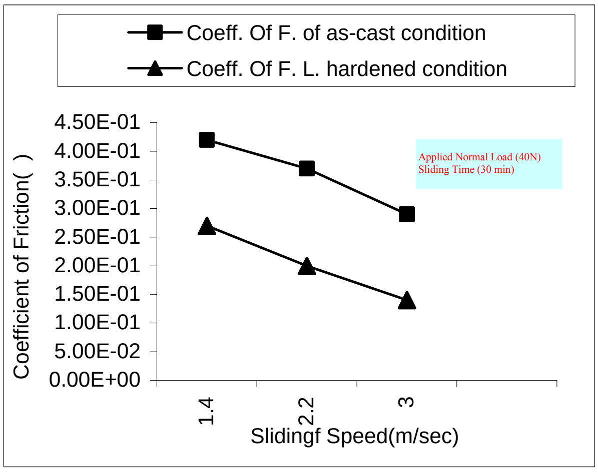


Figure 5: Shows the Effect of Sliding Speed on the Coefficient of Friction.

The coefficient of friction (μ) in as cast and laser hardened condition, decreases with increasing sliding speed as shown in Figure 5. This explained in terms of combined action of both oxide layer and graphite layer formed on the specimen surface which works as an interface and solid lubricant result in decreasing the coefficient of friction (μ). Also the specimen was hardened by laser showed coefficient of friction lower than that as-cast specimen because of has higher surface hardness than as-cast condition.

EFFECT OF SLIDING TIME ON THE WEAR RATE AND COEFFICIENTOF FRICTION

The effect of sliding time on the wear rate is shown in Figure 6. It is clear that the accumulative wear rate decreases with increasing sliding time, this decreasing being more pronounced after 20 minutes for as-cast specimen, while for laser hardened specimen the decreasing being more pronounced at the beginning of the test, then a study state is reached after 20 minutes. This behavior is explained in terms of the even distribution of the wear debris and smearing of the graphite which result in even surfaces (Kheder *et al.,* 1991). Also laser surface hardened showed a better wear resistance than the as-cast specimen at all sliding times used in this study.

After initial increase of coefficient of friction (μ) with increasing sliding time the (μ) tends to be in steady state for two cases of specimen (as-cast and laser hardened) after 20 minutes as shown in Figure 7. This observation is due to the gradual flattening of the asperities with sliding time and increasing the contact area. This change over occurs after about 20 minutes. The increase of the real contact area was mentioned by some other investigations (Kheder *et al.,* 1991; Sugishita and Fujiyoshi, 1981).

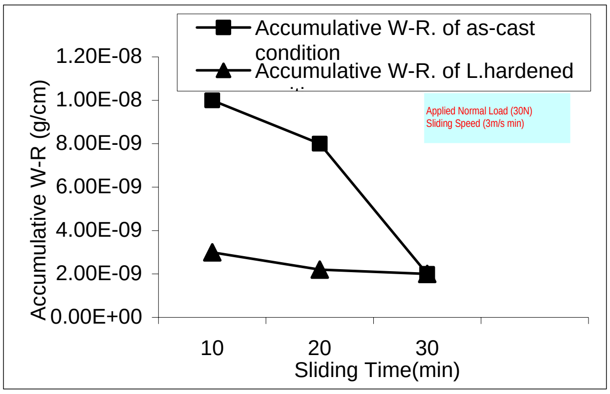


Figure 6: Shows the Effect of Sliding Time on the Wear-Rate.

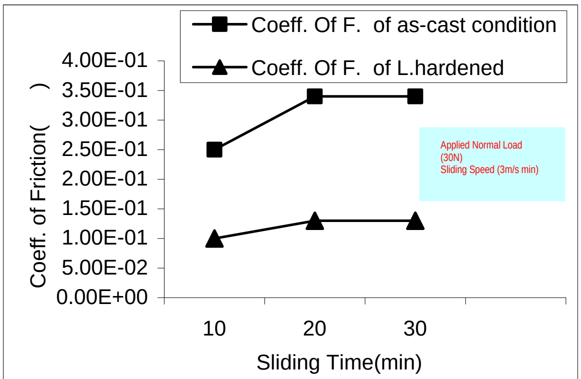


Figure 7: Shows the Effect of Sliding Time on the Coefficient of Friction.

CONCLUSIONS

Wear rate increases with the increasing normal loads at constant sliding speed and sliding time of both cases of acicular bainitic ductile iron (as- cast and laser hardened). The matrix of as-cast specimen showed three stages of wear: mild, transition and severe, while the laser hardened specimen showed two stages of wear: mild and transition only.

Coefficient of friction of both cases as- cast and laser hardened increase with increasing applied normal load up to 20 N after that decrease.

Wear rate and coefficient of friction of two cases of acicular bainitic ductile iron decreases with increasing sliding speed at constant applied normal load and sliding time. Wear rate decreases with sliding time while the coefficient of friction increases until a study state is reached.

The best results of wear resistance were obtained after laser surface hardening treatment at all conditions of the test (normal loads, sliding speeds and sliding times), these results are explained in terms the fines microstructure obtained after laser surface hardening treatment which gives vary hardness from 381Hv up to 606Hv, work hardened structure and stress induced phase transformation of retained austenite phase to martensite.

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