Wear Behavior of Bush Material Treated with Different Cryogenic Treatments

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Abstract

The current study aims to improve the wear resistance and hardness of gun metal, which is primarily used as bush material. For this purpose, the deep and shallow cryogenic treatments were conducted on the bush material. The chemical composition, wear-resistance, microstructure and microhardness have been analyzed before and after deep/shallow cryogenic treatment. The wear experiments were conducted at constant speed and at a load of 5kgf on pin -on-disc apparatus. SEM analysis were carried out to analyze the effect of multi-cryogenic heat treatment on the microstructure. The results show a significant improvement in the wear resistance and hardness after deep and shallow multi-cryogenic treatments which were attributed to the microstructural changes after such treatments.

1. Introduction

The cryogenic processing is modification of a material or component using cryogenic temperatures. Cryogenic temperatures are defined by the Cryogenic Society of America as being temperatures below 120K (-244°F, -153°C). Cryogenic processing makes changes to the crystal structure of materials. The major results of these changes are to enhance the abrasion resistance and fatigue resistance of the materials [1]. Until recently, cryogenic tempering was viewed as having little value, due to the often-brittle nature of the finished product. It is only since the development of computer modelled cooling and reheats curves that the true benefits of cryogenically treated materials have become available to industry and the general public [2]. Yugandhar et al. [3] reported that cryogenic treatment improves the mechanical properties like hardness, wear resistance, toughness, and resistance to fatigue cracking and attributed this to the transformation of retained austenite, precipitation of sub microscopic carbides and a reduction in internal stresses. Zhu et al. [4] quenched Fe-Cr-Mo-Ni-C-Co alloy in liquid nitrogen and held it for 24 hrs and found that the hardness increased by 1-2 (HRC) and the compressive strength decreases slightly after cryogenic treatment. The increase in hardness is attributed to the transformation from austenite to martensite and the precipitation of the very tiny carbides. Huang et al. [5] studied the change in microstructure of tool steel before and after cryogenic treatment. It was found that the cryogenic treatment can facilitate the formation of carbon clustering and increase the carbide density during the subsequent heat treatment. This result in increase in wear resistance of tool steels. Mohanlal et al. [2] reported that cryogenic treatment is an inexpensive one-time permanent treatment affecting the entire section of the component unlike surface coatings and improves wear resistance and tool life. Molinari et al. [6] elucidate the effect of cryogenic treatment on mechanical properties of M2 tool steel and correlated this with microstructural changes such as higher dislocation density and carbon clustering after cryogenic treatment. Barron et al. [7] studied that cryogenic treatment produces metallurgical changes in the microstructure of steel. These changes are the principal reasons for the dramatic improvement in wear resistance. As greater amounts of retained austenite are transformed, and the amount of martensite is increased, the material obtains a more uniform hardness. The cryogenic treatment is a more advanced process that has been developed as an evolution from the conventional ones. In this treatment the isothermal soak at cryogenic temperature is substituted by several cryogenic cooling/heating phases. This process is more effective but its main advantage is that it is much faster (an average of fifteen hours for the whole process) than the conventional ones. It needs shorter process time achieving the same or even better results [8]. According to Soleimany et al. [9], the cryogenic treatment can be classified into Shallow cryogenic treatment and Deep cryogenic treatment. In shallow cryogenic treatment material is cooled up to -80°C and in deep cryogenic treatment material is cooled up to -196°C followed by the tempering.

2. Experimentation

2.1. Preparation of Samples

Six pieces of Gun metal materials are machined in the cylindrical form of length 30 mm & dia. 8 mm on a

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centre lathe machine. Then out of six pieces, two pieces are used to check the microstructure, microhardness, wear resistance & chemical composition of untreated samples. And out of remaining four pieces, two pieces are deep cryogenically treated and two are shallow cryogenically treated and then their microstructure, microhardness and wear-resistance are analysed.

2.2. Cryogenic Treatment

The samples were cryogenically treated in the cryogenic chamber equipped with temperature control system, nitrogen cylinders etc as shown in Figure 1 [10]. The bush material was cryogenically treated with two different thermal cycles:

1. Shallow cryogenic treatment: In this type of cryogenic treatment, the material is cooled to a temperature of -80°C (at a rate of 1°C/min), soaked at this temperature for 3hours and further tempered at +150°C (for 3hours).
2. Deep cryogenic treatment: In this type of cryogenic treatment, the material is cooled to a temperature of -180°C (at a rate of 1°C/min) soaked at this temperature for 12 hours and further tempered at +150°C (for 3hours).

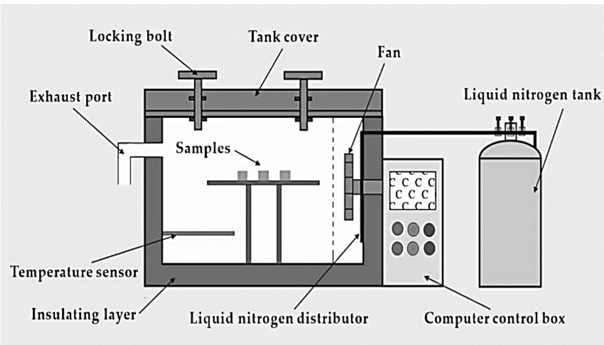

Figure 1: Schematic diagram of cryogenic heat treatment system

2.3. Chemical Analysis

The chemical composition of the bush samples is determined with the help of the Spectrometer (Model DV4) available at the R & D Centre for Bicycle & Sewing Machine parts, Ludhiana. The chemical composition of samples is given in Table 1. This information about the chemical composition is necessary to determine how the presence of certain elements as well as their percentage composition can influence the properties of the material thereby affecting the wear rate.

Table 1: Element's composition of gun metal in percentage (by weight)

Element	%Cu	%Sn	%Pb	%Zn	%Fe
%age	64.14	0.52	4.06	29.8	0.9

2.4. Micro Hardness Analysis

The microhardness (HV) analysis has been done to note down the changes in hardness values of cryogenically treated samples and the untreated samples. The equipment used for the micro hardness analysis was the hardness tester of Shimadzu, Japan with a capacity between 25 grams to 500 grams.

2.5. Micro Structural analysis

The microstructural analysis was carried out to study the micro-structural changes after the samples were treated with shallow and deep cryogenic heat treatment. The microstructural analysis was done on Scanning Electron Microscope (SEM) and micrographs were taken from surface.

2.6. Wear analysis

The wear analysis for all the samples is done on Pin-on-Disc apparatus (Figure 2a). For calculating the wear rate, the workpieces were weighed before and after the wearing of a pin on the rotating disc and the difference between the initial and final weight was calculated. The weighing was done on a weighing machine with a least count of 0.0001gm (Figure 2b).

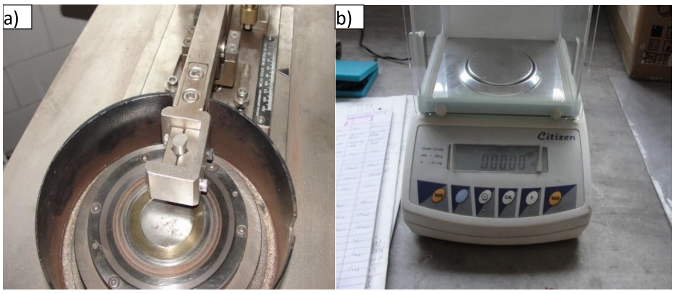

Figure 2: (a) Pin-on-disk apparatus; (b) Weighing machine

3. Results & Discussions

3.1. Micro Hardness Analysis

The micro- hardness of gun metal, has increased approximately 15-30% after shallow and deep cryogenic treatment as shown in Figure 3. This is because of the precipitation strengthening that creates fine dispersion of precipitated particles in the metal and hinder dislocation movement [11]. As we have earlier discussed that cryogenic treatment is an irreversible treatment lasts for the life of an object and improves the entire structure, not just the surface. The samples get stronger and tougher from the densification of the molecular structure after cryogenic heat treatment and also all internal stresses are revealed [12, 13]. The effect of deep-cryogenic treatment is dominating over shallow-cryogenic treatment. However, the hardness values are uniform throughout the length, which is also supported by uniform microstructure.

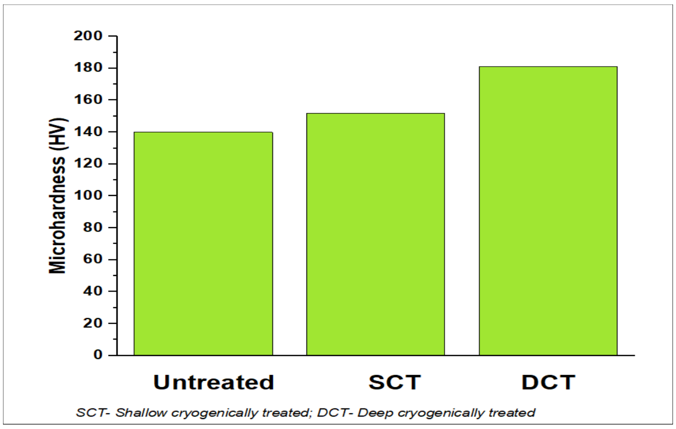

Figure 3: Microhardness comparison of Untreated; Shallow cryogenically treated; Deep cryogenically treated samples

3.2. SEM analysis

The microstructure of gun-metal sample consists of mis-aligned and unstable coarse grain particles with micro voids as shown in Figure 4(a). After shallow cryogenic heat treatment, the grain particles become fine and more stable. Also, there is a stress relief in the microstructure. The structure becomes more stable, continuous and homogenous as shown in Figure 4(b). This change in microstructure is also revealed by Alava L.A [14]. But after deep cryogenic heat treatment the recrystallization occurs as shown in Figure 4(c). This is due to the fact, that during the soaking phase and ramp up phase (at high temperature) of deep cryogenic heat treatment the recrystallization takes place by a combination of nucleation of strain free grains and the growth of these nuclei absorb the entire cold worked material. The cold worked structure is replaced by a new set of strain-free grains, so wear resistance decreases [15, 16]. Secondly, the coherency between the second-phase particle and the matrix reduces with the ageing time (when the sample was held at -180° for 10 hrs). Similar findings are also reported by kumar et al. [17].

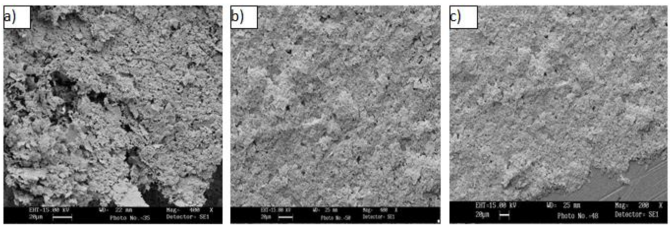

Figure 4: SEM of Gun metal (a)Untreated sample; (b) Shallow cryogenically treated sample; (c) Deep cryogenically treated sample

3.3. Wear Results

The wear results shown in Table 2, reveals that the weight loss of deep and shallow cryogenically treated gun metal sample is comparatively less than untreated one. This is due to the refinement of grain particles, increase in dislocation density as well as density of point defects. But, the results of shallow treatment are dominating over deep treatment. This is due to the fact, that during the soaking phase and ramp up phase (at very low temperature) of deep treatment the recrystallization takes place by a combination of nucleation of strain free grains and the growth of these nuclei absorb the entire cold worked material. The cold worked structure is replaced by a new set of strain-free grains, so wear resistance decreases. Second reason is the grain growth, during this stage the wear resistance continue to decrease but at a much less rate than the recrystallization stage. Energy is associated with grain boundaries. As grain size increases, total boundary area decreases and the growth of grain boundaries diminishes the cold worked structure and the sample attains its original grain size [5].

Table 2: Experimental Results of Gun Metal

Gun	HIPOJET 2700
Spray distance	180 mm
Oxygen Flow rate	260 L.min^{-1}
LPG flow rate	60 L.min^{-1}
Carrier gas- N_2 flow rate	9.4 L.min^{-1}
Air flow rate	550 L.min^{-1}
Powder feed rate	38 g/min

The wear rate of cryogenically treated samples is less as compared to un-treated sample as can be seen from the Figure 5. This is due to the refinement of grain particles and increase in the dislocation density as well as the density of point defects, such as vacancies and interstitials. But the wear rate is more in case of deep cryogenically treated sample, than shallow cryogenically treated sample. This is due to the fact, that during the soaking phase & ramp up phase (at high temperature) of deep cryogenic heat treatment the recrystallization takes place by a combination of nucleation of strain free grains and the growth of these nuclei absorb the entire cold worked material. The cold worked structure is replaced by a new set of strain-free grains, so wear resistance decreases [5].

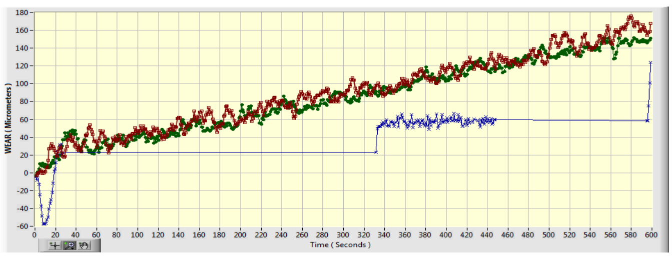

Figure 5: Wear rate vs Time for Untreated; Shallow cryogenically treatment; Deep cryogenically treated samples

3.4. Frictional force analysis

The frictional force of shallow cryogenically treated sample is high as presented in Figure 6. This is due to the initial slow starting speed of the disc which is in a direct contact with the pin. So, initially there is more frictional force due to the formation of debris at the tip of the sample. But as the time goes the disc achieves its optimum speed, it will throughout the debris away from the pin and the frictional force decreases.

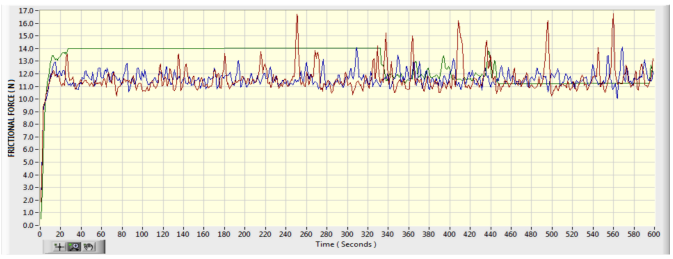

Figure 6: Frictional force of Untreated; Shallow cryogenically treatment; Deep cryogenically treated samples

4. Conclusions

1. The microstructure of the cryogenically treated samples became fine, stable, and stress free.
2. The microhardness of cryogenically treated samples was also quite high as compared to the untreated samples which could be because of the transformation of residual austenite into martensite with hard body-centred-tetragonal microstructure.
3. The wear resistance of shallow cryogenically treated samples was found maximum followed by deep cryogenically treated samples. However, the wear resistance of untreated samples was minimum. The maximum wear resistance of cryogenically treated samples could be attributed to the precipitation of fine carbides after such treatments.
4. The frictional force in cryogenically treated samples was found less as compared to untreated samples. The possible reason could be the refined microstructure of the cryogenically treated samples.

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