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Residual Stress and Wear Studies of Deep Cryogenically Treated SAE 52100 Bearing steel

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ABSTRACT

In this work mainly used to study the diffraction phases and residual stress on SAE 52100 bearing steel in which applying the effect of cryogenic treatment at various operating conditions. The tensile residual stress behavior is assessed by X-Ray diffractometer as per the ASTM standard E2860-12. Refinement of carbide particle by deep cryogenic treatment (DCT) is often proposed in literature as the improvement for the residual stress in the bearing steel. X-Ray diffractometer technique includes the identification of phases and quantitative analysis of crystalline chemical compounds, residual macro and micro stress analyses. The tensile residual stress increased by +30Mpa owing to deep cryogenic treatment when compared with that of conventional heat treatment (CHT). Moreover, the DCT process improves the hardness of SAE 52100 bearing steel by 15% compared to CHT process.

Keywords: *Cryogenic treatment, Residual Stress, Wear, Micro-hardness, Corrosion*

Introduction

Bearing is one of the machine elements which is constrained the relative motion between moving parts to allow movement in the desired motion. Bearings are the important components for all forms of rotating and

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reciprocating machinery. SAE 52100 bearing steel is normally used in all dynamic condition of components which employed with use of bearings. Most of the industry has consumer of bearing to help to apply the general engineering and railways. Since the bearing is subjected to high stress, these parts must be strong enough to withstand high stress, including fatigue and impact stresses. At the same time, they have to maintain tensile strength, resist corrosion and wear. The following SAE 52100 chromium-alloy and high-carbon bearing steel used made all bearings presently which is suitable for dynamic applications. Moreover, observed the temperatures nearing $125_{o}C$ for all rotary satisfactory operation with adverse effect on load capacity.

The present work being understood the causes of failure in SAE 52100 steel materials and same analysis of resisdual stresses identified from the materials which use of X – ray diffraction techniques. The failure may be occured in the bearing is mainly due to the high friction in the bearing balls. Some rolling bearings failures are due to rolling contact fatigue (RCF) and are defined as the mechanism of crack propagation (Stewart and Ahmed, 2002). Cryogenic treatment is a permanent treatment and it imparts changes in the entire cross-section in the component. It seems the cryogenic treatment initially provide slow cooling to the steel components until given respective temperatures and further drastically heating back based on ambient temperature conditions. Authors reported that cryogenic treatment has improved the mechanical and tribological properties in all ferrous and non-ferrous materials likely has improved the performance of durability in the machined components. Cajner et al. (2009), Podgornik et al. (2009), Arockia Jaswin et al. (2011) and Liu et al. (2006) determined the effects of deep cryogenic treatment of 3Cr13Mo1V1.5 alloy improved the performance both wear and mechanical properties based on present high chromium cast iron. Authors showed due to the percentage of retained austenite was resulted an increase in hardness and abrasion resistance. The structure revealed better properties seen over a material owing to transforming into martensite and secondary carbides precipitation. Huang et al. (2003) studied the micro structural changes of M2 tool steel and concluded that the cryogenic treatment has facilitated the formation of carbon clustering and increase the packed carbide density which is the process of cryogenic heat treatment and further improving the wear resistance of steels. Pellizzari et al. (2001) authors reported that heat treatment improves the mechanical properties of material homogenity in all surfaces is based on closed packed molecules structure may be given better life of dynamic components.

According to Alexandru Ailincai and Baciu (1999), author determined the microstructure seems that cryogenic cooled materials has produced dense and hard micrstructure than no crogenically trated samples. They also observed that the cryogenic cooling induced the formation of very fine carbides smaller than 1micrometer, which occupy micro voids and contribute to an increase of the density. Barron (1974) authors can be tested on various lathe tools, drilling tools and zone punches which the process of cryognic treatment with soaked in liquid nitrogen for 12 hrs and further investigated the tool life has been increased from 50% 200%. Wilson (1971) concluded that cryogenically treating slitter knives in paper mills increases the lifetime by more than 500% due to complete transformation of the retained austenite to martensite**.** Mohan Lal et al. (2001) investigated a study of wear resistance with use of treatment parameters in various D3, M2 and T1 tool and die steel materials.

Finally has reported the life of materials around 110% which may be imparted cryogenic treatment process. Ioan Alexandru and Vasile Bulancea (2002) have concluded the retained austenite has low mechanical properties through this heat treatment process due to the internal residual stresses increased in the closed packed structure. Authors find the techniques of heat treatment process which has improved the stability of steel materials at the conditions of retained austenite would transform to martensite condition when quenched steel as cryogenically treated. Mack Alder and Olsson (2000) reported that depends upon the condition of materials with residual stress would be decided the materials maintaining the endurance limit after case hardening. The objective of the present work is to examine the distribution of tensile residual stress in SAE 52100 bearing steels due to cryogenic treatment, with respect to cryogenic treatment time, temperature, pre and post treatment condition of the bearing material.

Experimental Invesigation

The composition of the SAE 52100 was confirmed using optical emission spectroscope (OES). The spark analyzer software is used in estimating the compositions of the individual elements investigate from the sample. The following dimension of specimen were involved for the various testing are cylindrical, 18 mm in diameter and 10 mm in height. Moreover, the chemical composition was carried out which is help of optical spectrometer is to help for identifying the quantitative element for all tested samples and further composition of the SAE 52100 bearing steel was tabulated in Table 1.

Table-1 Chemical Composition of SAE 52100 Bearing Steel

Material	C	Cr	Mn	Si	S	P	Iron
SAE 52100 Wt.%	0.90	1.469	0.31	0.23	0.001	0.003	Bal.

Thermal Treatment

As per the procedure ASM standards (1995) the few samples were heat-treated to involve various testing process. The machined specimens were formed in to two groups, Group 1 (CHT) and Group 2 (DCT) and subjected to two different treatment processes. The following thermal treatment was given to the SAE 52100 bearing steel specimens: The Group 1 samples were subjected to hardening at 850°C for one hour, followed by an oil quench, and tempered immediately after quenching at 200°C for two hours. The Group 2 samples, which underwent hardening, were slowly cooled from room temperature to −185°C in 3.5 hours at 1°C/min, soaked at −185°C for 24 hours, and then heated back to the room temperature. Finally, the samples were tempered immediately at 200°C temperature for two hours. The cryogenic processor uses a liquid to cool the samples. A PID temperature controller regulates the liquid nitrogen flow. The temperature controller is used to set the deep cryogenic treatment parameters, which in turn, control the process parameters. The values of the deep cryogenic treatment processes are recorded and stored using a data acquisition system.

Residual Stress Analysis

The test samples for the residual stress analysis were machined as per the ASTM standard E2860–12 (2013). The samples were taken from each group and subjected to the residual stress analysis using X-Ray diffractometer and the samples, machined for X-ray diffraction test, were fine polished with silicon carbide sheets and also cleaned by using electroplating process. Residual stress present in the SAE 52100 bearing steel subjected to CHT and DCT were compared in this study. The residual stress can be determined by passing high intensity chromium rays to the samples with the help of ceramic X-ray tubes. Residual stress analysis was determined by room temperature and it was calculated with the help of PROTO software. The residual stress was calculated as to given two input parameters namely Bragg angle and ½S2, based on the ASTM standard and directly giving the input parameter to the XRD.

Vicker’s Hardness Test

Test specimens for the Vickers hardness test were machined as per ASTM standard E92-82 (2004). For hardness test the few samples were taken from each group at various loading conditions. Hardness measurement was made with a 30kgf load with a dwell time of 15 seconds. Various samples were prepared for testing the hardness on each sample at normal ambient conditions. The different results have been carried out of various levels at which applying the indentation were made.

Reciprocatory Wear Test

The wear resistance was measured using a reciprocatory equipment and further wear monitor (DUCOM TR- 281M-M4) on heat treated and deep cryogenically treated bearing steel. Further investigation of wear scar, wear debris and wear loss also be investigated as per the ASTM standard; G-133. Photograph of the Reciprocatory Friction and Wear Monitor (RFWM) as shown in Figure 1.

Figure1: Photographic view of the Reciprocatory Friction and Wear Monitor

Corrosion Test

The salt spray corrosion test was carried out as per the ASTM B117 [17], to investigate the corrosion properties on CHT and optimized DCT samples. Sample was taken from each group for conducting the test. Salt spray test was applying the samples being tested with prescribed environmental temperature is controlled the chamber for 24 hrs. Normally, the test was carried out from the steel samples to testing of corrosion resistance at which very fine fog mist conditions.

Characterisation Study Using Optical Microscope

The samples for the given test are prepared as per the ASTM standard E3-01 [19]. The specimens were examined using the optical microscope (Nikon EPIPHOT 200) at 1000 X magnification. The bearing steel specimens are prepared / machined for the testing and micro-structural studies to a length of 10 mm and 10 mm. Further, few samples were prepared and polished at which various SiC water proof abrasive papers of different grid sizes followed by fine polishing using diamond paste of 1µm submicron size, with the help of an automatic polishing machine. Finally, the polished surface was etched with 2% Nital solution and slowly drying help of hot air for exhibiting microstructure.

Results and Discussion

Residual Stress Analysis

In this result was shown from the residual stress analysis of bearing steel both CHT and DCT samples at various temperature conditions. At present the conditions of environment drastically cool down process which a cryogenic treatment process like deep cryogenic treatment would produce quantitatively the value of residual stress normally +84.6 MPa for CHT samples and for DCT samples resulted +113.8 MPa so on. From the condition of cool down process may produced transformation of retained austenite to martensite in the bearing steel has improving the stress due to the precipitation of fine carbides to improve the mechanical properties has revealed in the DCT samples. The CHT samples is improved the residual stresses, ductility and toughness due to the fine carbides during the cryogenic treatment process.

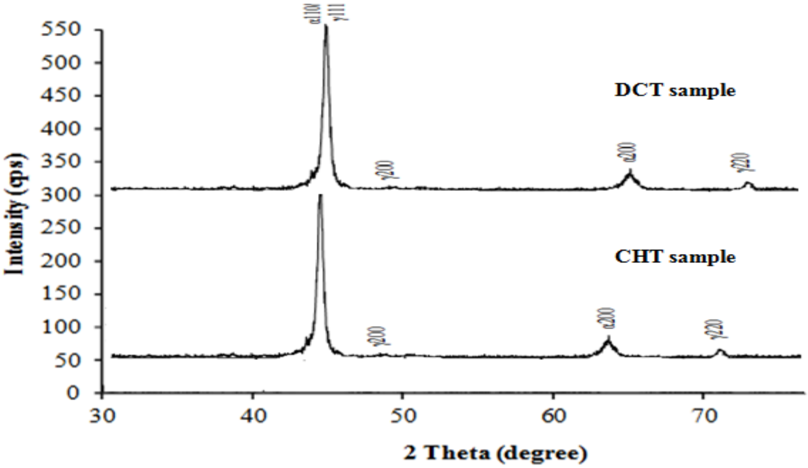

Figure 2: X-Ray Diffraction Pattern

The Figure 2 showed X-ray diffractograms profile peaks revealed the condition of bearing steel of the optimized DCT and CHT samples. X-ray techniques is the process in which determine the residual conditions and moreover seen the phases of retained austenite (200) and (220) during the case of CHT and DCT optimised samples. The peaks only show the exact phases present in the samples which applied the cryogenic treatment from the plane of martensite situation and present in the percentage of carbide particles.

X-ray diffractogram estimated the percentage of carbide particles at various conditions of temperature in which the cryogenic treatment process. After estimated the carbides from the retained austenite samples is 14% and continued deep cryogenic treatment samples is resulted in 3%. Finally determined the retained austenite percentage decreases owing to cryogenic treatment conditions.

SEM analysis of wear morphology on treated samples

The present investigated of surface morphology on treated samples at which various operating conditions. Both DCT and CHT samples was revealed the morphology conditions at which on the process of cryogenic treatment shown the Figure 3. As per ASTM standard has applied in which the reciprocating wear test on both samples to exhibit the surface characterization during ambient conditions. The worn surfaces show that a strong deep groove and wear track present in the samples DCT and CHT images at various loading conditions. Moreover, the small debris particles also act as the abrasion has produced surface track in the samples due to loading conditions. Figure 3 the SEM images showed the delamination pits and groove at the following load conditions such as 25N, 50N and 75 N respectively.

Sometimes the conditions of surface morphology of deep cryogenically treated samples significantly to resist the wear resistance at varying loads due to the carbides particles. The wear behaviour has showed sever grooving abrasion at maximum load 75 N and corresponding frequency 5 Hz, it revealed the samples experience wear loss of 5.398 mg in the CHT and DCT samples respectively. SEM micrographs (Fig.4) showed that worn surface and wear debris morphology revealed on surfaces at ambient conditions and significant loading conditions. The SEM micrograph images found the wear debris of the CHT samples as shown in Figure 4 has large platelets and flake shaped particles worn out and further determined the particle size which is comparatively smaller than the optimised DCT samples. The SEM micrographs were seen the worn morphology DCT samples considerably smoother than that of the CHT samples at significant loading conditions. Further it shows the SEM images more delamination lips and small considerably cracks could be seen in the CHT samples than the DCT samples.

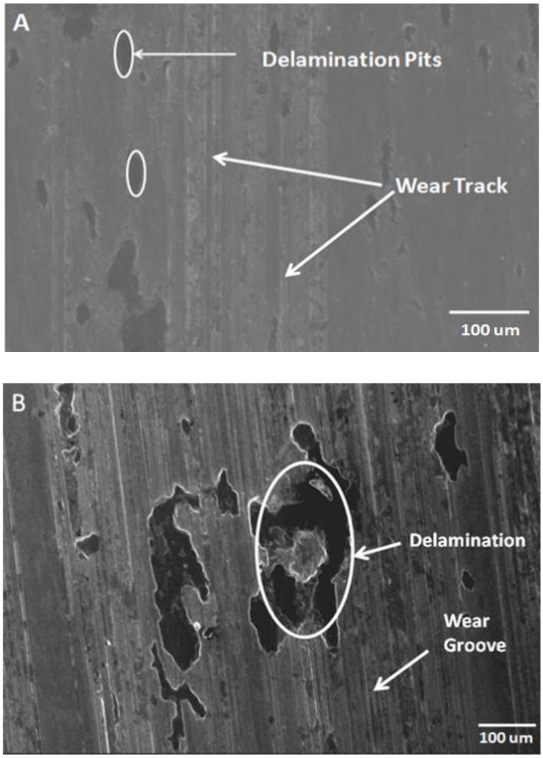

Figure 3: SEM images of wear track morphology (A) DCT samples (B) CHT samples at the loads of 25N and 50N

The worn surfaces of the CHT samples has more damage and large delamination of lips due to the gap voids during treatment process at which subjected to load of 25 N, 50 N and 75 N respectively. Moreover, it would be found some observation from the SEM micrographs in the condition of wear mechanism for CHT samples induced as sever plastic deformation due to fine carbides not present in the specimen. Therefore, the deep cryogenically treated specimen has given better wear resistance than the conventionally heat-treated process significantly. Due to the hard phase structure may be revealed at cryogenic process treatment would resist the wear at different loading condition. The SEM images is revealed the evident of better surface morphology due to fine carbides when they continue cryogenic heat treatment process.

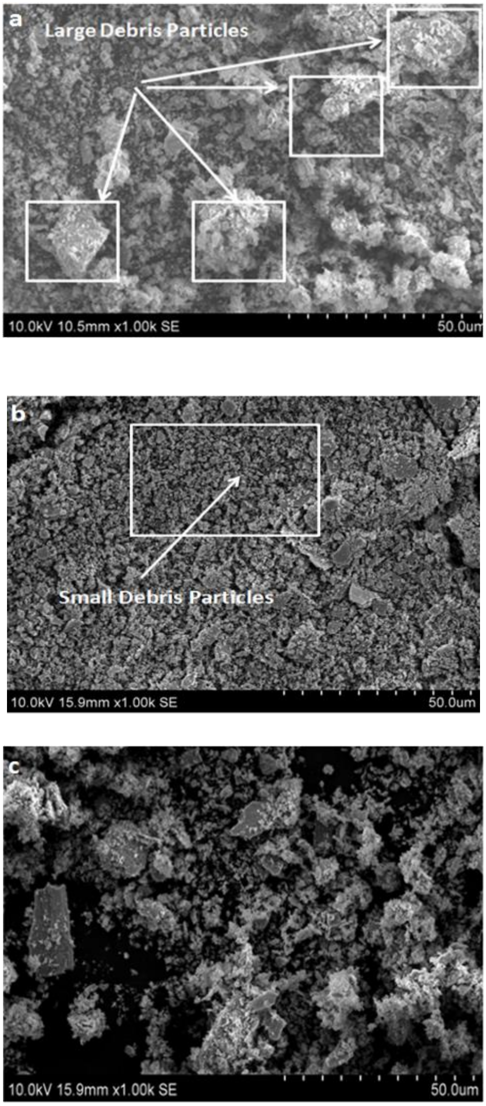

Figure 4: Wear debris particles extracted by wear test at loading conditions (a) 25N, (b) 50N and (C) 75N

Vicker’s Hardness Test

The hardness of the SAE 52100 bearing steel shows a significant hardness of 725 HV for the CHT samples and for the DCT samples it has improved to

838 HV. The hardness of the DCT samples shows an improvement of 15% than the CHT samples. Improvement in the hardness is owing to the transformation of retained austenite to the martensite. Table 2 shows the hardness value of SAE 52100 bearing steel. From the table has reported the hardness been tested at room conditions CHT and DCT samples. It was observed the maximum hardness value of DCT is higher than CHT samples at cryogenic treatment. Due to precipitation of carbon consists in the samples DCT has shown better hardness than CHT samples at room conditions. The trails (I, II and III) were carried out in all the samples were revealed same value of hardness reported in the table 2.

The salt spray test of the THT and DCT samples shows how much time to take the metal become rust. The DCT samples shows very less time to take corrode the given material compared to THT samples. The main reason is the precipitation of fine carbides due to deep cryogenic treatment. Carbides reduce corrosive nature and improve strength. The results are tabulated in the Table 3. The conventionally salt spray test was carried out against the both specimen resulted DCT samples is better than CHT samples was shown in the table 3. May be DCT samples micrographs showed the amount of carbides present in the CHT samples than DCT samples. Due to the carbides present in the samples has more attack corrosive in the CHT surface significantly.

Table 2 Hardness Value of the SAE 52100 Bearing Steel

Sl.No	**Condition**	**Vicker's Hardness, HV**			**Mean**
		Trial I	Trial II	Trial III	
1	CHT	724	726	724	725
2	DCT	842	836	836	838

Corrosion Test

Table 3 Corrosion Test Result of the SAE 52100 Bearing Steel

Sl. No	**Condition**	**Time(Hrs)**	**Percentage of Rusted(%)**	**Time(Hrs)**	**Percentage of Rusted (%)**
1	CHT	14	70	24	100
2	DCT	14	35	24	80

Microstructure characterization

The primary and secondary carbides was presented in the samples during cryogenic treatment process exhibited by which used in the optical microscope instrument. Optical micrographs are to help determine the top surface morphology characterization of both DCT and CHT samples at room temperatures. The Figure 5 and Figure 6 have exhibited that the retained austenite of DCT and CHT samples. The micrograph of the CHT samples shown in Figure 5 revealed non homogeneity distribution of primary carbides on the tempered martensite matrix. Few authors has resulted recently the cryogenic treatment on steel materials has reported low mechanical properties and wear properties due to retained austenite. Figure 5 percentages of fine carbide particles where resist in the wear properties of CHT samples at which show present the microstructure. Figure 6 revealed the microstructure of tempered martensite on DCT samples after cryogenic treatment process. The microstructure resulted has shows martensite nature present in the structure made after DCT treatment process. In this structure clearly identified where few percentage of dissolved and non- dissolved carbides were present in the structure at ambient conditions. The microstructure is evident from the surface some seen white patches of retained austenite have been detected from after CHT samples than in the micrograph of the DCT samples. At deep cryogenic temperature while the transformation of retained austenite in DCT samples resulted as following micro internal stresses, crystal defects and dislocation.

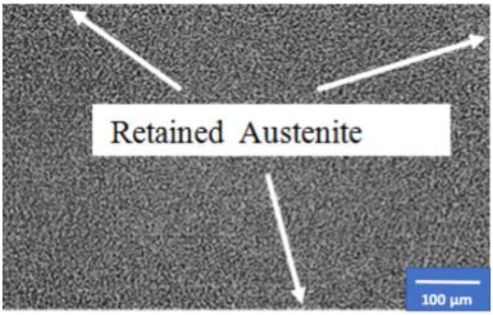

Figure 5: Microstructure of the Sample Subjected to CHT

Therefore, the microstructure of the sample of both DCT and CHT samples after the cryogenic treatment process has to significantly decrease due to the non dissolved carbides and retained austenite. Moreover, the retained austenite is normally the structure properties is under unstable condition at which the lower temperature and transforming the phases from retained austenite into martensite structure. Therefore, the paper was investigated the secondary carbides at which the condition of process of cryogenic heat treatment process.

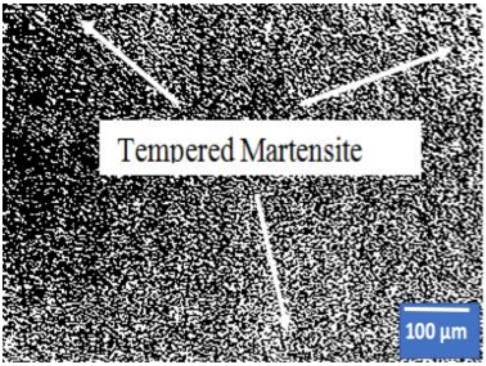

Figure 6: Microstructure of the Sample Subjected to DCT.

The application of deep cryogenic treatment would given better surface tempering to the steel materials due to increase the secondary carbides. In this cryogenic treatment specifically to improve the properties of steel materials based on the carbides present homogeneity in all areas both DCT and CHT samples. The improvements of mechanical and wear properties would be controlled at the variation of surface treatment and experimentally that the microstructure is decided the properties in the steel materials.

Conclusions

Tensile residual stress of the deep cryogenic treated SAE 52100 bearing steel shows an improvement of 36% compared to conventional heat treatment. Improvement in tensile residual stress is mainly due to the precipitation of fine carbides in the specimens subjected to deep cryogenic treatment with tempering. Hardness of the deep cryogenic treated samples shows an improvement of 15% compared to conventional heat treated samples. The improvement in hardness is mainly due to the transformation of retained austenite to martensite. Cryogenic treatment reduces the corrosive nature of the bearing material compared to the conventional heat treated samples. This study shows that the cryogenic treatment improves the tensile residual stress and life of the components.

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