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Investigation on the wear behaviour of Aluminium alloys at cryogenic temperature and subjected to cryo -treatment

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Investigation on the wear behaviour of Aluminium alloys at cryogenic temperature and subjected to cryo -treatment

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Abstract: The published information on ferrous and nonferrous metals especially Aluminium alloys subjected to deep cryogenic treatment (DCT) have yielded much improved mechanical, tribological and thermal properties resulting in improved properties in the field. Keeping the above aspects in view, tribological studies have been taken up in this work with the main objective of evaluating the wear resistance of the most used Aluminium alloys viz: Al 2024, 6082 and 7075 samples at cryogenic temperature and subjected them to deep cryogenic treatment for 64 hrs. The novelty of the work lies in conducting the wear test in cryogenic atmosphere which is the first of its kind as meagre report is available. It is observed from the wear data that the slide wear resistance and coefficient of friction evaluated in the laboratory conditions show superior wear resistance for the load application of 40N and 50N and lower friction levels for the samples subjected to sliding at cryogenic temperature as well as for the samples deeply cryo treated compared to the untreated ones. The data have been substantiated by Scanning Electron Microscopic features (SEM).

Keywords: *Aluminium Alloy, Wear, Cryogenic Temperature, Cryogenic Treatment, SEM*

1. Introduction

The demand for the use of Aluminium alloys in automotive and aerospace sectors still exists in view of possessing low density, good stiffness and other mechanical properties. However in recent years, the composites especially Aluminium MMC's have taken the lead over its base alloy. But the critical parts in specific applications calls for good ductility, strength, wear resistance for which the Aluminium alloys are most suitable ones. The improvement in the characteristics of Aluminium alloys are possible either by incorporating some of the elements such as silicon, zinc, copper, silicon carbide, zirconium or by subjecting them to deep cryogenic treatment.

The work carried out by Volker Francis et al [1] on the effect of deep cryogenic treatment on wear resistance and microstructure of Aluminium 6061 alloys shows that the cryogenic treatment is very effective in improving the wear resistance in CrN surface coated Aluminium 6061 alloy samples. The main reason for the improvement in wear resistance has been attributed to the GP zones generated during cryogenic treatment and the same has been detected using differential scanning calorimeter. In another work carried out by K.E.Lulay et al [2] have reported on mechanical properties viz., tensile strength, percentage elongation, Charpy impact and hardness and it is observed that with increase in cryogenic soaking time from 2 hours to 48 hours, the impact properties improve to a higher level. It is also reported in the paper that increasing the soaking time to judge its effect on the properties, needs further study. The investigation on the behaviour of cryogenically treated Aluminium 6063 and 8011 materials conducted by K K Padmanabhan et al [3] very clearly indicates that the cryogenic treatment of these alloys has influence on the hardness and wear resistance. Further, it is stated that increase in soaking time may result in better properties. The reasoning is attributed to the changes in microstructure that takes place during the treatment. R.Thornton et al [4] has reported on the beneficial aspects of cryogenic treatment on wear resistance in grey cast iron which is used in brake discs. The Pin on Disc tests of grey cast iron samples were carried out on brake disc materials before and after cryogenic treatment and an improvement in the wear rate was reported.

Keeping the above literature points in view, the tribological performance has been taken up in this work at both room temperature and cryogenic temperature for the cryogenic treated and untreated samples, as hardly any literature could be cited on the tribological data conducted at cryogenic temperature and also the information on cryo-treated Aluminum alloy samples (Series 2024, 6082 and 7075) for 64 hours is less reported. A specially designed and developed cryo-tribometer set up has been employed to conduct the slide wear and coefficient of friction tests at cryogenic temperature and hence the present investigation gets the credence of carrying out the measurements for the first time. These wear data have been corroborated with the scanning electron microscopic features.

2. Materials and Methods

2.1Materials

The Aluminium alloys of three series viz; 2024, 6082 and 7075 were made available in the form of rods. Subsequently, they were machined to the required dimensions to carry out different tests. The test samples were analysed for chemical composition using optical emission spectrometry and the results are shown in the Table 1.

Table 1 Chemical composition of the three Aluminium alloy samples in (wt %).

Material	Cu	Mg	Si	Fe	Mn	Cr	Zn	Ti	Al
Al 2024	4.302	1.376	0.042	0.121	0.520	0.002	0.016	0.052	Balance
Al 6082	0.070	0.673	0.974	0.248	0.773	0.011	0.015	0.017	Balance
Al 7075	1.257	2.300	0.052	0.189	0.039	0.198	5.915	0.074	Balance

2.2Methods

2.2.1Hardness

The Brinell Hardness Measurements were done according to standards at an imposed load of 62.5 Kgf with a ball diameter of 2.5 mm.The test samples were subjected for hardness measurements with a dwell time of 10 s for one reading. An average of three readings were noted and averaged to get the final value.

2.2.2Wear

The Pin on disc tests were performed both at room temperature and cryogenic temperature for untreated as well as cryogenic treated samples soaked for 64hours. The cryo-tribometer set up, to carry out the slide wear and friction measurements at cryogenic temperature, has a pin on disc set up with liquid nitrogen purging unit in it. The equipment has been specially designed and developed in accordance with the ASTM standards and is given in detail in reference [5]. The schematic representation of the cryo-tribometer is shown in the Fig. 1 with the inset showing the geometry of the sample. The tests were conducted on three representative samples and the average value has been reported. The co-efficient of variation has been calculated for each measurement, which is reported to be less than 15% as per the ASTM standard.

The displacement of the worn samples is measured by a Linear Variable Differential Transducer (LVDT). The entire setup was insulated within a double walled chamber made of Stainless Steel 304L. The test samples were kept in a cryogenic chamber, which was partially filled with liquid nitrogen. Continuous supply of Liquid Nitrogen into the chamber was maintained by pressurized flow over the Pin on Disk interface to maintain the cryogenic temperature. Scavenging has been done to remove air and relieve the specimen from frost and frozen moisture.

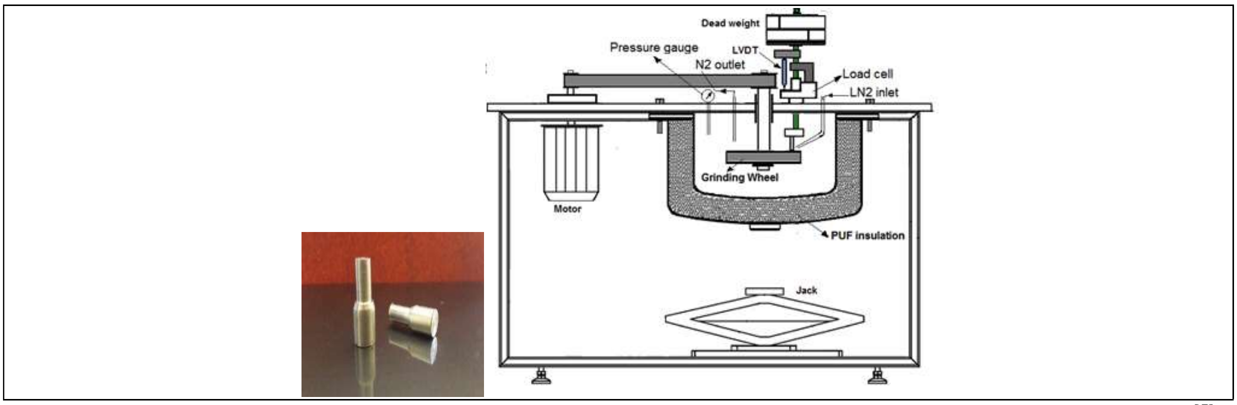

Fig: 1 Schematic diagram of the cryo-tribometer with the inset showing the sample geometry[5]

The cryogenic tests were performed as per the same procedure followed at room temperature tests. The test samples were in the form of a pin of total length 27 mm having a shoulder at 14 mm and diameter of 6 mm. The loads selected were 40 N and 50 N with a track radius of 30 mm. The wear tests were carried for duration of 10 minutes at a constant speed of 400 rpm. The counter-surface used is an alloy steel disc (EN32) with surface roughness of 1µm and hardness 62 HRC. The Aluminum samples was soaked in liquid nitrogen in a cryostat unit having the features like various rates of cooling, soaking and warming periods without causing thermal shocks and were 2 hours,64 hours and 9 hours respectively. The cryo-treatment followed is described in Fig. 2 in the form of a graph. The details of the cryostat unit is described under the reference [6]

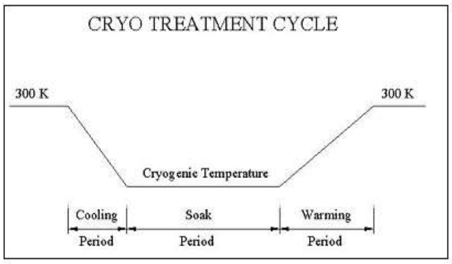

Fig : 2 Cryo treatment cycle[6]

The plan of action followed to perform the tests is shown in the Fig 3 which consists of two phases (Phase I and Phase II).

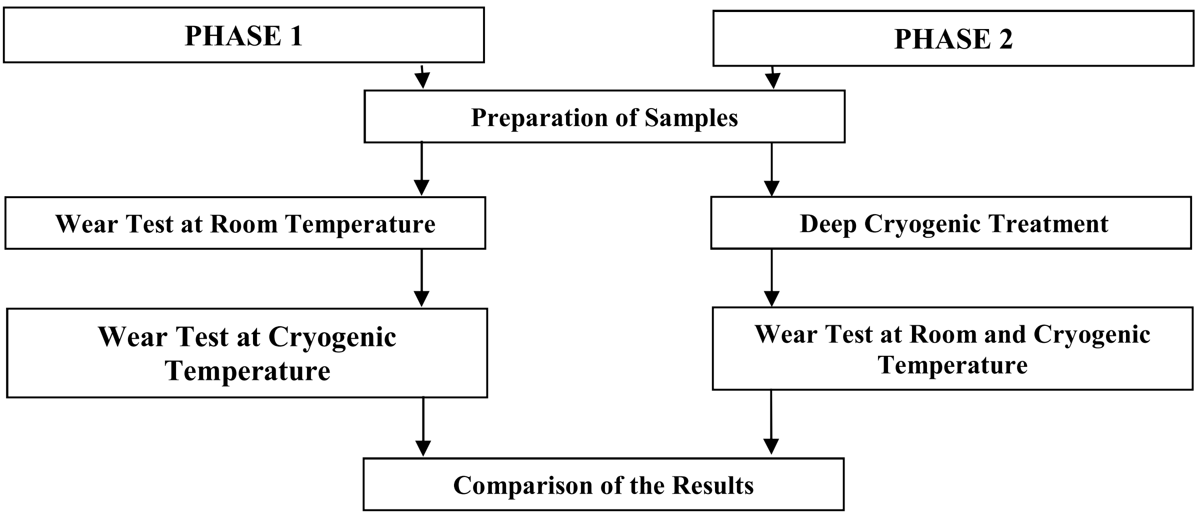

Fig: 3 Plan of action for the study

Table 2: The sample details and designations

Sl. No	Sample Details	Sample Designation
1.	Untreated raw sample subjected to POD at Room Temperature	UT
2.	Untreated raw sample subjected to POD at Cryogenic Temperature	CT
3.	Sample subjected to Deep Cryogenic treatment and POD performed at Room Temperature	DCT
4.	Sample subjected to Deep Cryogenic treatment and POD performed at Cryogenic Temperature	DCT- CT

3. Results and Discussion

The test samples have been designated and the details are provided in the Table 2. The test results in respect of hardness for Aluminum alloy samples for the untreated and cryogenic treated samples are shown in the form of bar graph in Fig 4. It is seen from the figure that the hardness is marginally higher for the deep cryogenic treated samples, compared to the untreated ones. The higher hardness obtained for the deep cryogenic treated samples seems likely to be due to finer grain structure formed as compared to the untreated samples. No attempt has been made in this work to measure the grain size of the samples.

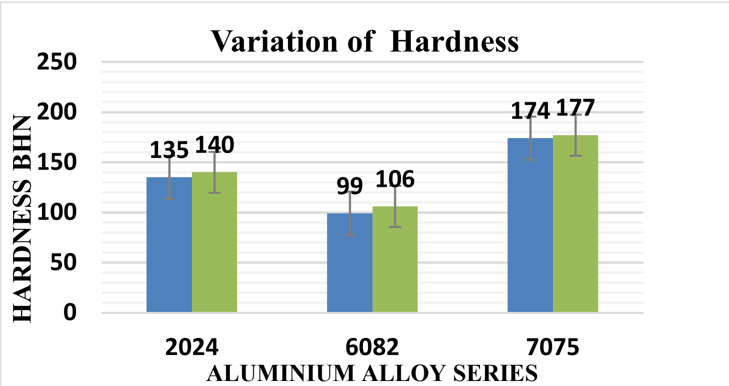

Fig: 4 Variation in the hardness level for the treated and untreated samples.

The slide wear data for the Aluminium test samples 2024, 6082 and 7075 in respect to UT, CT, DCT and DCT-UT are shown in the Figs. 5, 6 and 7 respectively for both 40 N and 50 N load applications with red colour for 40N and blue colour indicating the results for 50 N. Similarly the coefficient of friction for the corresponding Aluminium samples are displayed in the Figs. 8, 9 and 10 respectively for the application of 40 N and 50 N load, with the same colour designation chosen. The Scanning Electron Microscopic features of CT and DCT-CT of 2024, 6082 and 7075 alloy samples subjected to slide wear test are shown in the Figs. 11 & 12 a and b, Figs. 13 & 14 a and b and Figs. 15 & 16 a and b respectively for the treated & un-treated aluminium samples.

It is observed from the Figs. 5, 6 and 7 that irrespective of the load application (40 N and 50 N) UT is showing the highest wear loss and DCT-CT is exhibiting the least. It is quite logical and in line with the theoretical prediction that the slide wear resistance is superior in DCT-CT followed by DCT, CT and UT and the reason for this trend is attributed to the hardness obtained for DCT-CT samples in the same order. The deep cryogenic treated samples subjected to cryogenic slide wear test has shown the best resistance to wear as well as the lowest coefficient of friction compared to UT,CT and DCT samples for the application of both 40 N and 50 N load. This trend is noticed for 2024, 6082 and 7075 Aluminium samples. The slide wear data gets very good support from the worn surface features obtained from the SEM examination.

It is seen from the Figs. 12 a and b when compared with the Figs. 11a and b, that the surface topographies like the material flow (micro cutting action) is higher in CT and lesser in DCT-CT for 50 N load application. In the Figs. 12a and b, the matrix cracks, more debris formation along the sliding direction are noticed. In the Figs. 11 a and b, less debris formation and few cracks are visible. Thus the SEM pictures when examined, gives good support to the sliding wear results. For Aluminum 6082 samples, for 50 N load application, CT samples in the Figs. 14a and b reveals more matrix distortion material flow, cracking tendencies compared to DCT-CT in the Figs. 13a and b. The SEM features of Aluminium 7075 shown in Figs. 15a, b and 16a, b in respect of DCT-CT and CT samples, CT is exhibiting higher level of delamination together with the debris formation. The wear data shown in the Figs. 5 to 7 are substantiated from the worn surface features shown in Figs. 11 to 16.

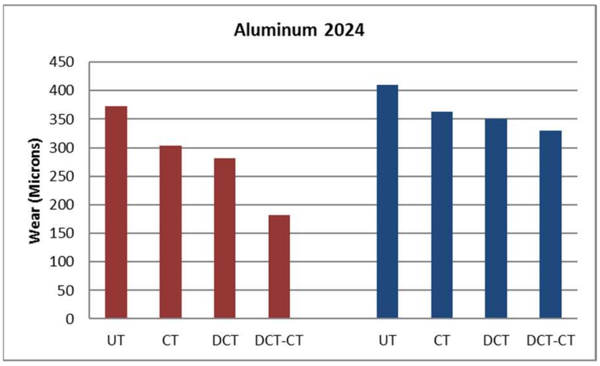

Fig .5 Wear in microns for Al 2024 untreated and treated samples for 40N and 50N load applications.

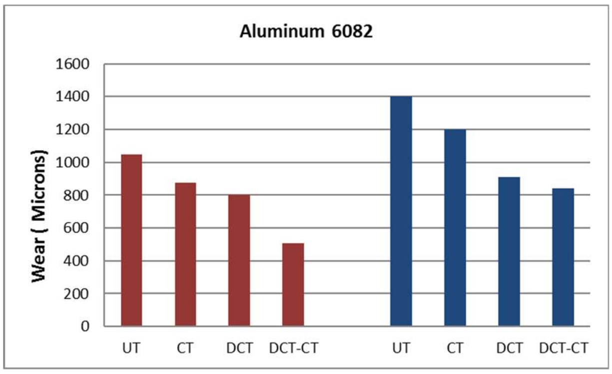

Fig. 6 Wear in microns for Al 6082 untreated and treated Samples for 40N and 50N load applications.

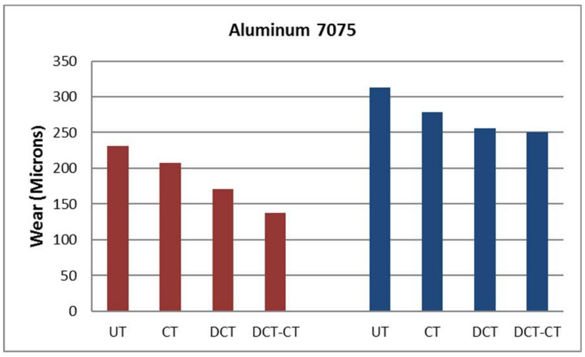

Fig. 7 Wear in microns for Al 7075 untreated and treated samples for 40N and 50N load applications.

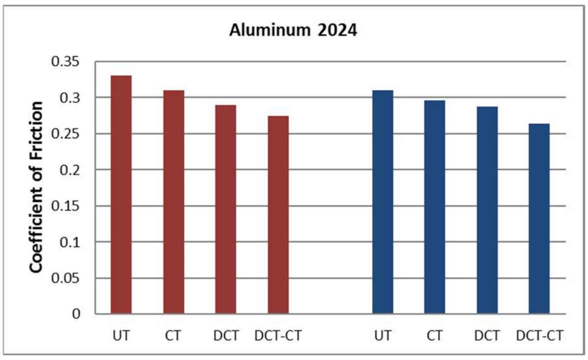

Fig. 8 Coefficient of friction for Al 2024 untreated and treated samples for 40N and 50N load applications.

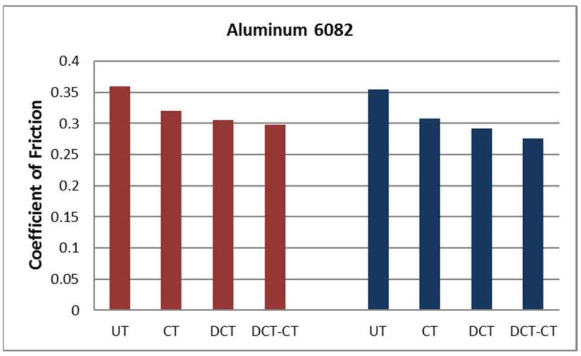

Fig. 9 Coefficient of friction for Al 6082 untreated and treated samples for 40N and 50N load applications

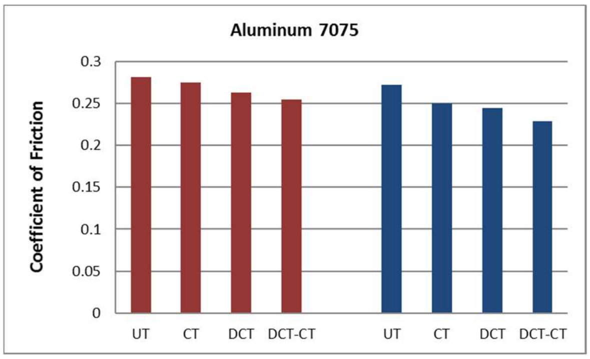

Fig. 10 Coefficient of friction for Al 7075 untreated and treated samples for 40N and 50N load applications.

Investigations reported by various researchers regarding improvement in wear resistance due to deep cryogenic treatment in Aluminium alloy samples have been attributed to the GP zone formation which has been examined using TEM. It has been reported by the studies of K. Mohan [7] et al on the topic "Microstructure and Mechanical Behaviour of Al 7075-T6 subjected to Shallow Cryogenic Treatment" that the formation of second phase particles in Al 7075 due to cryogenic treatment results in microstructure variation which in turn has improved the fatigue strength**,**

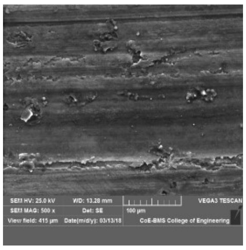
Fig 11a

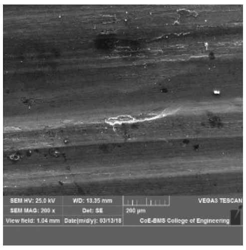
Fig 11b

Fig 11a, b SEM images of Al 2024 samples at 500x and 800x for treated samples.

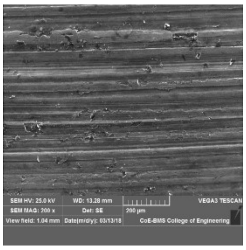
Fig 12a

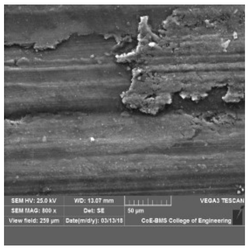
Fig 12b

Fig 12a, b SEM images of Al 2024 samples at 500x and 800x for untreated samples.

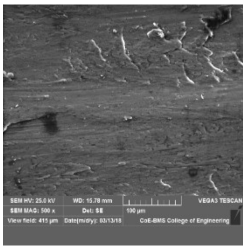
Fig 13a

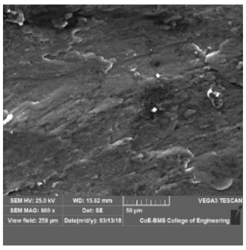
Fig 13b

Fig 13a, b SEM images of Al 6082 samples at 500x and 800x for treated samples.

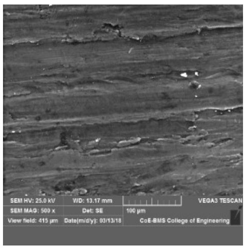
Fig 14a

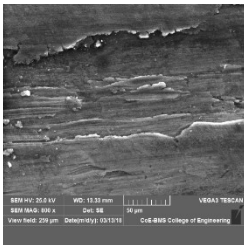
Fig 14b

Fig 14a,b SEM images of Al 6082 samples at 500x and 800x for untreated samples.

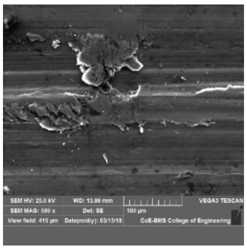
Fig 15a

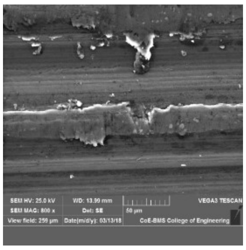
Fig 15b

Fig 15a, b SEM images of Al 7075 samples at 500x and 800x for treated samples.

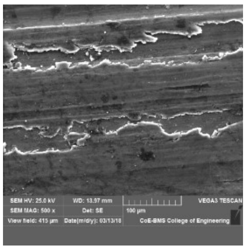
Fig 16a

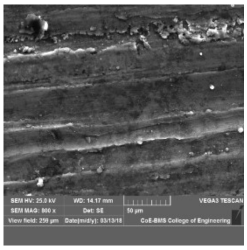
Fig 16b

Fig 16a, b SEM images of Al 7075 samples at 500x and 800x for untreated samples.

hardness and tensile properties. The work reported by Shahsavari etal [8] on the cryogenic rolling of Aluminum 2024 alloys, reveals an improvement in the ultimate tensile strength and hardness. The work reported by F. Bouzada etal [9] on the effect of deep cryogenic treatment on the microstructure of Aluminum alloy revealed marginal improvement on the static mechanical properties and residual stress. A slight increase in the precipitation at and near the grain boundaries have been observed which is expected to improve the stress corrosion cracking resistance of the alloy. Similar works have been reported by Chun-mei Li et al [10] that the deep cryogenic treatment performed, induces the second precipitation of GP zones in the Aluminum matrix while simultaneously maintaining the favourable discontinuous distribution along the grain boundaries, which improves the properties of the alloy. In the work reported by K K Padmanabhan [3] on Aluminum 6061 and 8011 alloys, for every eight hours cryogenic treatment, the wear resistance has shown improvement due to dislocation in atoms and increase in the density due to cooling effect. Longer soaking times improves the hardness and wear properties. Thus Aluminium alloys have shown improved hardness, wear and frictional properties following cryogenic treatment. Thus the present work gets credence from the published work in respect of improved tribological behaviour. The work may be summarised that the slide wear resistance and friction coefficient have improved for the samples tested at cryogenic temperature after subjecting it to deep cryogenic treatment.

The cryogenic treatment is an add-on process to heat treatment cycle, which can be practiced before or after the heat treatment. However, the cryogenic procedure does not substitute the regular heat treatment procedures. The advantage of cryogenic treatment is that it is a complete, irreversible process, which distinguishes itself from the other heat treatment processes of hardening like normalizing, annealing, quenching & tempering, pack carburising etc., in the form of phase change, grain refinement etc.

4. Conclusion

The following are the important findings drawn from this work.

- The effect of deep cryogenic treatment on the hardness and wear characteristics of Aluminum 2024, 6082 and 7075 alloys at room temperature as well as at cryogenic temperature show a slight improvement in the hardness and the improvement was found to be 3.6%, 7% and 1.2% respectively.
- As regarding the slide wear data of Alumium 2024 samples, DCT-CT is showing the highest wear resistance with DCT, CT and UT in the decreasing order. The percentage improvement is found to be 24% between the untreated and cryogenic treated samples at room temperature and 40% between them at the cryogenic temperature at a load of 40N and 15% and 25% respectively at a load of 50N.
- The above trend holds good for the Aluminium 6082 samples. The percentage improvement is found to be 25% between the untreated and cryogenic treated samples at room temperature and 42% between them at the cryogenic temperature at a load of 40N and 40% and 30% respectively at a load of 50N.
- Although Aluminium 7075 samples exhibit the same trend, the percentage improvement is lesser than the other two Aluminium alloys selected for study. The percentage improvement is found to be 22% between the untreated and cryogenic treated samples at room temperature and 30% between them at the cryogenic temperature at a load of 40N and 15% and 5% respectively at a load of 50N.
- It is evident from the coefficient of friction data that the DCT-CT is exhibiting lowest value for 40N load as well as for 50N load applications compared to DCT, CT and UT samples.
- The SEM features support the slide wear data. The worn surface features give credence to the wear data. Increase in the volume fraction of the secondary phases, precipitation hardening and high dislocation density may be the reasons for the improvement in wear resistance for the cryo treated samples as reported by others.
- Evaluation conducted at cryogenic temperature for deep cryogenic treated samples for 64hours has revealed the best results. Thus, for the application involving liquid nitrogen temperature, it is preferred to use Aluminium samples subjected to deep cryogenic treatment for improved tribological performance.

5. Acknowledgment

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