Ultra Scientist Vol. 25(1)B, 51-60 (2013).

Study of Effects of Cryogenic Treatment and Heat Treatment on the Friction and Wear Behavior of AISI A2 Tool Steel Under Dry Sliding Condition

VANDANA JHA[1] and PRABHASH JAIN[2],

(Acceptance Date 25th January, 2013)

Abstract

The wear and friction may cause failure of industrial component which in turn may increase the production cost. It is important for a tool material to possess good wear resistance, toughness and other mechanical properties so as to reduce the failure. In this work, the effect of cryogenic treatment on the mechanical properties of AISI A2 tool steel is analyzed as cryogenic treatment enhances the mechanical properties of steel. The present investigation covers the study of friction and wear behavior of cryogenic treated and heated treated samples of AISI A2 tool steel under dry sliding condition. This study is the comparative study which shows the enhancement of mechanical properties by cryogenic treatment on samples versus untreated (heat treated) samples. The friction and wear results of the sliding test on heat treated and cryogenic treated specimens using pin on roller configuration showed that the cryogenic treatment increases the wear resistance and reduces the coefficient of friction of AISI A2 tool steel in comparison to heat treatment.

Key words: Heat Treatment, Cryogenics, AISI A2 Tool Steel, Wear, Friction.

Introduction

AISI A2 tool steel is the most commonly used variety of air-hardening steel. It is commonly used for blanking and forming punches, trimming dies, thread rolling dies, and injection molding dies. A 5% Chromium steel which provides high hardness after heat treatment with good dimensional stability. Used in many applications which require good wear resistance as well as good toughness. Wear is the unintentional removal of solid material from rubbing. The basic type of wear, which is always present to varying degreeswhen any rubbing action between solid surfaces occurs, is that of adhesive nature. Wear resistance is defined as the ability to resist wear and abrasion. Cryogenics is the study and use of materials at extremely low temperatures. cryogenic processing makes changes to the structure of materials being treated and is dependent on the composition of the material, it performs three things; viz. retained austenite turned to martensite, carbide structure is refined and stress is relieved.[1]

A brief literaturere view about the effect of wear and friction on heat treated specimens and cryogenic treatment of specimens under dry sliding condition are presented as follows: cryogenics is a one-time permanent process and it affects the entire cross section of the material, usually done after the conventional heat treatment process but before tempering. The effect of cryotreatment is not favorable on TiN coating. Cryogenic treatment imparts better wear resistance and is superior to any coating if it is made for few microns only[2]. The wear resistance increases with increasing implantation dose and decrease in coefficient of friction was observed for all loads[3]. The mode of wear and the operative wear mechanism are identical for all of the cryotreated specimens at the selected test conditions .The wear resistance of the AISI D2 steel gets considerably enhanced by cryotreatment, compared to that of the conventionally treated one, irrespective of the time of holding. The extent of improvement of wear resistance, however, is dependent on the wear test conditions, which control the active mechanisms and mode of wear[4]. Friction decreased with increasing temperature whereas wear of the tool steel increased with temperature for Al–Si-coated high-strength steel. The principal material removal mechanism appeared to be adhesive wear, abrasion and oxidized wear initially, but the mechanisms of these changes and their influence on the tribological process are unclear and further studies are necessary to fully explain these mechanisms[5]. After deep cryogenic treatment the peaks of austenite have a low intensity due to the transformation of retained austenite in martensite[6]. The maximum bulk hardness can be obtained either by increasing the soaking time or tempering duration[7]. The literature review shows that least work has been done on AISI A2 TOOL STEEL and on medium load condition.

2. Experimental method

This section describes the materials, specimen geometries, test equipment and experimental procedure employed in this work.

2.1 Test equipments :

The major equipments used for carrying out the experimental investigations are: multi-tribo tester and a precision weighing machine.

Multi Tribo-Tester (Ducom Instruments Pvt. Ltd., Bangalore, India) with software (Winducom 2008) for measurements of frictional force, wear, coefficient of friction and temperature of lubricant oil on wide range of materials such as metals, ceramics, polymers, composites and coatings and also used to study pure sliding, partial sliding and pure rolling, dry or lubricated contacts is shown in Fig. 1 and its major specification are listed in Table 1.

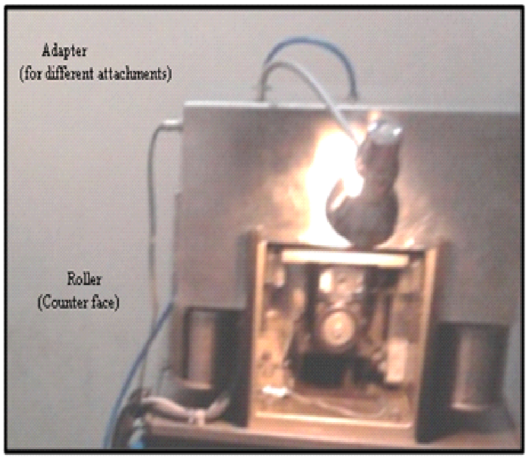

Figure 1. Experimental setup showing Tribo-Tester

Table 1. Specifications of Multi Tribo Tester

Parameter	Unit	Max.	Min.	Remarks
load	N	0	1000	
Speed	RPM	0	1200	
Temperature	^{o}C	Ambient	120	
Wear	µm	0	2	Least count 1µm

Weighing Machine: The Digital Analytical Balance of A&D Company Ltd. has auto self-calibration with internal weights, percentage weighing, counting and 12 units of measurement, plus an under-hook for density measurement. Capacity x precision: 210 g x 0.1 mg.The HM Series laboratory scales economically provide high-end features and performance. This digital laboratory scale provides advanced resolution, are easy to use and calibrate, and adjust their settings based on environmental changes.

2.2 Test material and specimens:

In this work AISI A2 tool steel was used to investigate the friction and wear characteristics under dry sliding condition. The composition is given in table 2. As per the requirement of adaptor of multi-tribo tester, sample blanks (6.35 mm × 6.35 mm × 9 mm) for examinations were cut by using electro-discharge machining. The size and shape of counter face material (EN-31 steel) were Ø50 (major dia) x Ø25(minor dia) x 20mm (thickness), and disc (flat roller) .Chemical composition of EN31 steel (counter face) is given in Table 3. It is hardened to 51 HRc and has a tensile strength of 1600 MPa and an elongation of 1-2%.

Table 2. Chemical composition of AISI A2 Tool Steel

C %	Mn %	Cr %	Ni %	Mo %	V %
1.00	0.1	5.0	0.3	1.0	0.15-0.5

Table 3. Chemical Composition of EN-31 Steel

C %	Mn%	Si %	S%	P %	Cr %	Ni%	Mo%
1.03	0.45	0.328	<0.005	<0.008	1.05	<0.005	0.59

2.3 Test procedure :

AISI A2 tool steel was chosen for investigation based on its wide applications in industries. The pin on roller configuration was employed for experimentation. The tests were performed in two set, first set consist of 25 samples which were heat treated (austenized to 940ºC, soaked for one and half hour, oil quenched and tempered for two and half hour at 550°C) and second test consist of 25 cryogenic treated (at -140ºC for 48 hour, tempered for 3 hours at 250ºC) sample. The tests were conducted at room temperature to measure the frictional force and wear under different operating parameters(load, speed). The test samples, prepared by EDM were polished with 200 and 1800 grit Si-carbide sand paper to achieve the final surface finish, subjected to5 min bath with acetone solution and then dried with sample dryer. The pin was pressed against the roller through a pneumatic system with different load values (30N, 40N, 50N, 60N, 70N). The gap of 2mm was maintained between block samples of size 6.35 mm×6.35 mm×9 mm and counterface roller before executing each experiment. The mass of the steel blocks were measured by means of weighing machine before and after each test to evaluate the wear rate. The Multi Tribo Tester was equipped with a computerized data acquisition and control system for controlling and monitoring various parameters. The test duration was kept 5min for each sample. The friction coefficient was calculated as the ratio between friction force and normal load. The wear rate was measured as a ratio of the weight loss and sliding distance. The wear rate, coefficient of friction was measured by performing sliding test for each sample by changing the load and speed value. The various combinations of different parameters used in the experiments for both heat treated and cryogenic treated samples are given in Table 5. The schematic layout and photograph of the experimental setup is shown in Figure. 1

Table 4. Parameters for friction and wear experimentation Multi-Tribo Tester

Workpiece Material	**AISI A2 alloy Steel**
Counterface (roller) Material	EN 31 high carbon alloy steel.
Load (N)	30,40 ,50, 60,70.
Speed (rpm)	400,600,800,1000,1200.
Test Duration (minutes)	5

Table 5. Parameter combinations for friction and wear experiments

Exp No.	Load (N)	Speed (rpm)	Contact Pressure (MPa)	Sliding Velocity (m/s)	Sliding Distance (m)
1.	30	400	0.744	1.05	315
2.	30	600	0.744	1.575	471
3.	30	800	0.744	2.095	627
4.	30	1000	0.744	2.62	786
5.	30	1200	0.744	3.14	942
6.	40	400	0.992	1.05	315
7.	40	600	0.992	1.575	471
8.	40	800	0.992	2.095	627
9.	40	1000	0.992	2.62	786
10.	40	1200	0.992	3.14	942
11.	50	400	1.24	1.05	315
12.	50	600	1.24	1.575	471
13.	50	800	1.24	2.095	627
14.	50	1000	1.24	2.62	786
15.	50	1200	1.24	3.14	942
16.	60	400	1.49	1.05	315
17.	60	600	1.49	1.575	471
18.	60	800	1.49	2.095	627
19.	60	1000	1.49	2.62	786
20.	60	1200	1.49	3.14	942
21.	70	400	1.74	1.05	315
22.	70	600	1.74	1.575	471
23.	70	800	1.74	2.095	627
24.	70	1000	1.74	2.62	786
25.	70	1200	1.74	3.14	942

3. Results and Discussion

In this section the friction and wear results for heat treated and cryogenic treated AISI A2 tool steel specimens in dry sliding contact with EN31 steel exposed to different load and speed values at room temperature are presented and discussed. The parameters considered while performing the experiments for both heat treated and cryogenic treated samples are summarized in the table. The results are graphically summarized.

3.1Friction and wear behavior of heat treatment samples :

Fig. 2 Exhibits a graph of wear rate as a function of the sliding velocity obtained for each sample at different load values and at 400, 600, 800, 1000, 1200 rpm value. The wear rate gives the idea about the amount of weight loss at different sliding velocity with time. The wear rate is calculated by the ratio between the weight loss and the sliding distance. The temperature below the worn surface is also measured. It is observed that with increasing the load and sliding velocity, the wear rate also increases with some exceptions. At low load (30N) the increase in wear rate is slow. At 70N load value, the wear rate increases with increase in sliding velocity and then decreases after 2.62m/s sliding velocity. So decrease in wear rate can be attributed to the formation of thin oxide layer on the surface due to the increase in temperature or localized pressure. This type of trend has been reported by some earlier investigators[7].

Fig. 3 shows the curve of the average coefficient of friction against sliding velocity at different load and rpm values considered in this work. It is observed that there is a distinct change in the general shapes of the curves from 1.05m/s to 3.14m/s sliding velocity for all load values. The fluctuation of curve at 30N follows a severe wear regime. At starting the value of average coefficient of friction at 30N load is very low in comparison to other load values then it follows an increasing and decreasing curve with increase in speed from 400rpm to 1200 rpm and sliding velocity from 1.05m/s to 3.14m/s. After 2.62m/s sliding velocity the friction start decreasing up to 3.14m/s sliding velocity at 30N, 50N and 60N load value. Between 2.095m/s and 2.62m/s sliding velocity the increase in friction value is observed at all load values with an exception at 40N. At 70N the highest value of coefficient of friction is observed at temperature and speed. For all loads the value of average coefficient of friction is fluctuating and this type of behavior may be attributed to the different operating parameters like load, temperature, speed.

Fig. 4 shows the curves of average wear with respect to sliding distance. Wear is cumulative result of the wear measured for each sample during experiment in selected time duration. It is observed that the wear increases

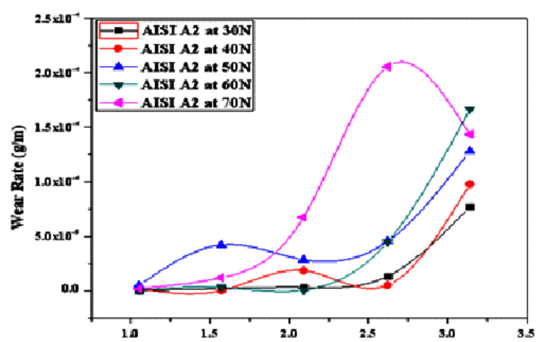

Fig.2 Wear rate as a function of sliding velocity for heat treated samples

with increase in sliding distance for all load values. In starting there is large variation in the value of average wear for each load. The highest value of average wear is given by the intermediate load value *i.e.* 50N. After 746m sliding distance the linear variation is observed between average wear and sliding distance for all loads. At 3.14m sliding distance the value of average wear at 70N is higher than 30N, 40N but lower than 50N, 60N. One of the possibilities for this type of behavior may be the plastic deformation due to increased load and sliding distance.

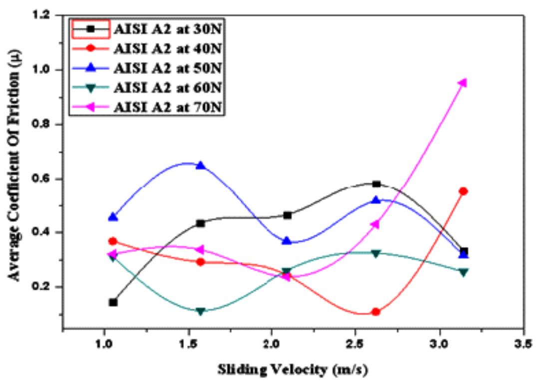

Fig. 3. Average Coefficient of friction as a function of slidingvelocity for heat treated samples.

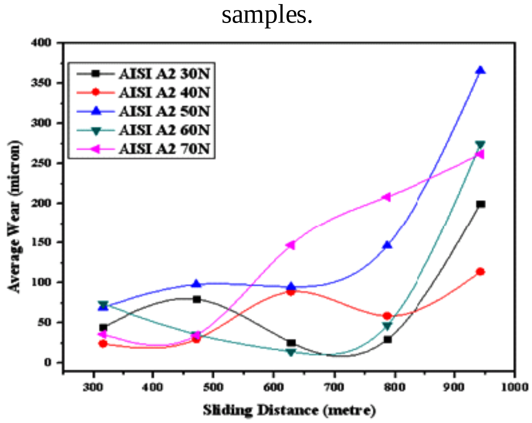

Fig. 4. Average wear as a function of sliding distance for heat treated specimens

3.2 Wear and frictional behavior of cryogenic treated samples :

Typical curve of weight loss versus sliding velocity is shown in fig. 5. It is depicted from the figure that at lowest load and at highest load value the wear rate decreases after 2.62m/s whereas the increase in wear rate is observed at intermediate load values. At the starting or low values of sliding velocity fluctuating curve behavior is observed for all load values. At 3.14m/s the wear rate value of 50N load is higher than other load values. The wear rate behavior of cryogenic treated samples depicted from the figure may due to refinement of grain size or phase transformation. In general as the load increases the improvement in wear resistance due to cryogenic treatment also increases and it is phenomenal at higher speed and at higher velocities .So it can be attributed that wear resistance depend upon load, sliding velocity, temperature and soaking time. It is estimated earlier by other authors also[2].

Fig. 6 shows the curve between the average coefficient of friction and sliding velocity for cryogenic treatment. The figure shows that low load values shows large variation in the value of average coefficient of friction. Large increase and decrease is observed at 30N, 40N load with increase in sliding velocity. It is observed that 30N load shows highest value of average coefficient of friction with increase in sliding velocity. With increase in load values the large fluctuation in the value of average coefficient of friction decreases with increase in sliding velocity. At 3.14m/s sliding velocity the average coefficient of friction for 60N, 70N is lower than 30N, 40N and 50N shows the lowest value. In general, the average coefficient of friction decreases with increasing load value and sliding velocity with some exceptions. Fig.7 displays the average wear with respect to the sliding distance and it is observed that at 70N the average wear first decreases and then there is continuous increase in average wear value with increasing sliding distance. After 786 m sliding distance, the value of average wear decreases and this type of decrease in value is also observed at 30N, 40N. At starting the figure shows that with increase in load the average wear decreases with increase in sliding distance but this type of behavior is observed up to 471m sliding distance only. At 942m, 30N gives the lowest value of average wear and value of averagewear for 70N lies between the value of average wear for 30N,40N and 50N, 60N.

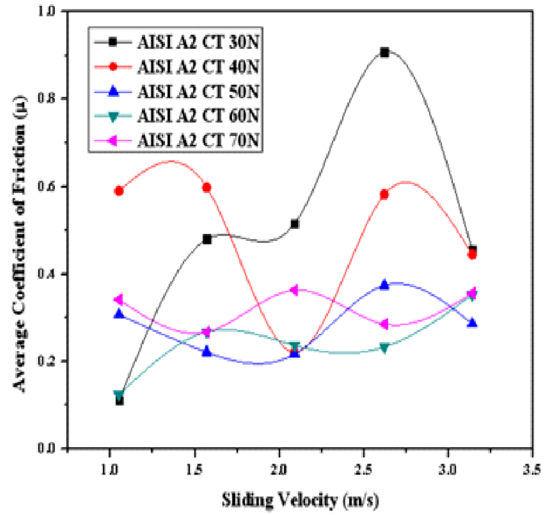

Fig. 6. Average coefficient of friction as a function of sliding velocity for cryogenic treated samples

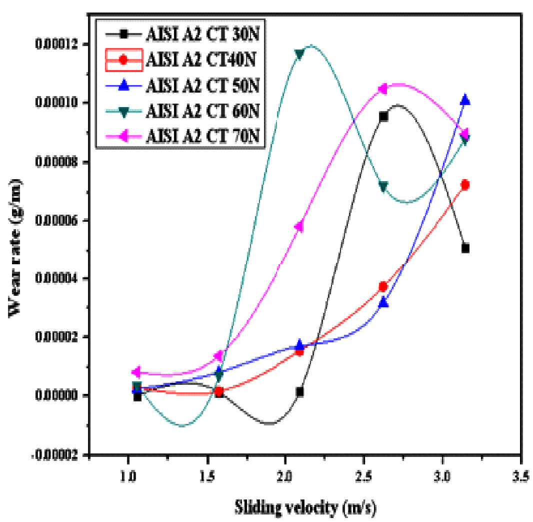

Fig. 5. Wear rate as a function of the sliding velocity for cryogenic treated samples

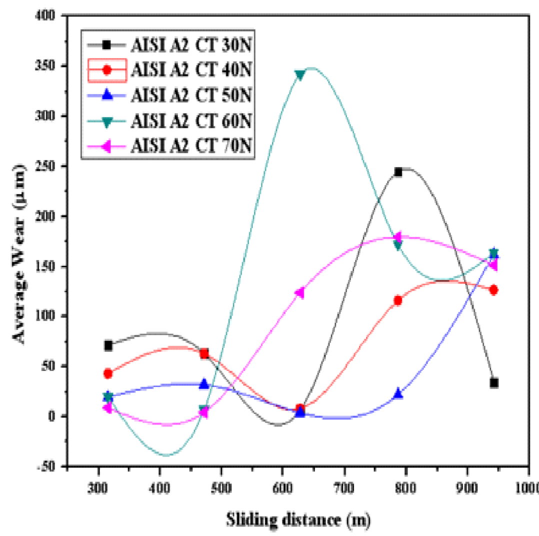

Fig. 7. Average wear as a function of sliding distance for cryogenic treated samples

3.3 Comparison of friction and wear behavior of heat treatment and cryogenic treatment of AISI A2 steel :

The comparative graph is shown in fig.8.The wear rate of heat treated samples and cryogenic treated samples at 30N, 50N, 70N load value is shown in the figure with different sliding velocities. It is observed that at low load 30N, cryogenic treated sample show a fluctuating curve in comparison to heat treated sample but at highest sliding velocity 3.14m/s the wear rate of cryogenic treated sample is less than heat treated sample. At 70N the wear rate of cryogenic treated sample is lower than the heat treated sample with increase in sliding velocity. At 50N also the value of wear rate for heat treated sample is higher than the cryogenic treated sample. So it is observed that cryogenic treatment increases the wear resistance of AISI A2.

The average coefficient of friction of heat treated and cryotreated samples with respect to sliding velocity for different load values (30N, 50N, and 70N) are shown in fig.9.The figure shows that highest value of average coefficient of friction is obtained at 30N for cryogenic treated sample. At 70N the fluctuant curve is obtained for both cryogenic treated and untreated sample with increase in sliding velocity but after 2.62m/s increase in the value of average coefficient of friction is noticed up to 3.14m/s. The increase in the value of average coefficient of friction for cryogenic treated samples is very low in comparison to heat treated samples. At 50N the decrease in value of average coefficient of friction is observed after 2.62m/s for both type of samples, but in at this load also the value of average coefficient of friction for cryotreated sample is lower than the heat treated sample.

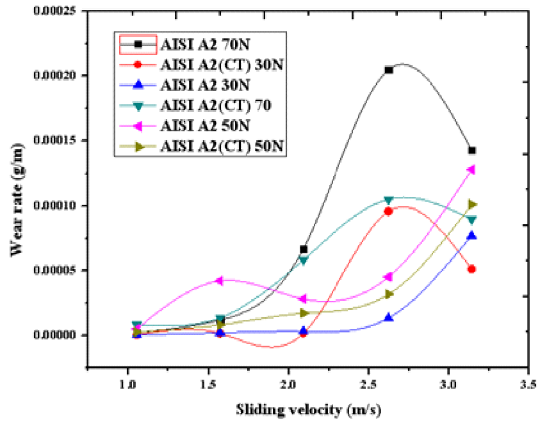

Fig. 8. Comparison of wear rate for cryogenic treated and heat treated samples of AISIA2 steel

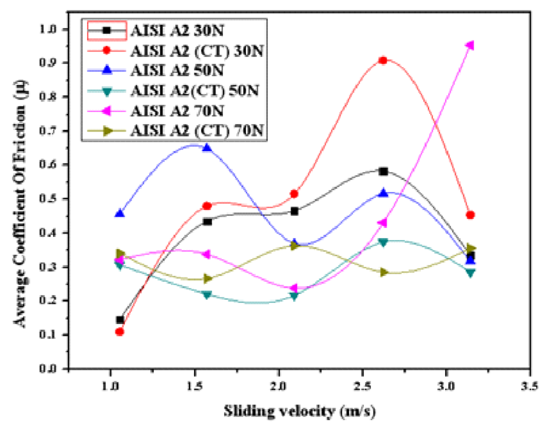

Fig. 9. Comparative graph of average coefficient of friction as a function of sliding velocity

In fig.10 the average wear as a function of sliding distance for heat treated and cryotreated samples at different load values is shown. For all loads the value of average wear is fluctuant. 30N cryotreated sample shows the most fluctuant curve, but it decreases sharply after 786m sliding distance. The decrease in value of average wear rate is also observed at 70N after 786m sliding distance. From the given figure it is clearly estimated that cryogenics treatment increases the wear resistance of the AISI A2 steel because of the transformation of retainedaustenite into martensite and finer or uniform distribution or martensite laths as described in earlier experiments[2,7].

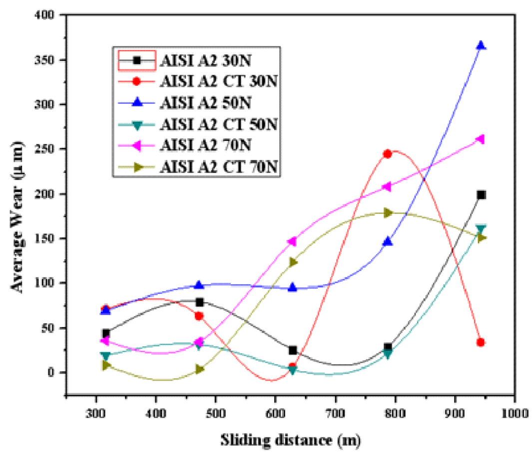

Fig.10. Comparative graph of average wear as a function of sliding distance for bothconditions (cryogenic or heat treatment)

4. Conclusion

This study is the comparative study in which the effect of cryogenic and heat treatment on friction and wear behavior of AISI A2 tool steel is analyzed at room temperature under dry sliding condition with changing load and speed. The pin on roller configuration is used for experimentation in which pin material is AISI A2 steel and EN31 steel is used as roller.Total 50 numbers of experiments were performed and various parameters like sliding velocity, frictional force, wear, sliding distance were analyzed during experimentation. From the results obtained under the experimental conditions of this study, the following conclusion can be drawn.

- For heat treatment samples, at low load value the wear rate is low because of low load and sliding velocity, the rise in temperature is not enough for wear. With increase in load or sliding velocity the wear rate increases with few exceptions. At 70N the decrease in wear rate is observed at high rpm and sliding velocity because of high temperature or may be because of oxide formation. The average coefficient of friction is fluctuant with increase in sliding velocity for heat treatment samples. At 70N increase in average coefficient of friction is observed at high speed and sliding velocity. In general average coefficient of friction decreases with increase in load and sliding velocity with few exceptions.
- For heat treatment samples, at high speed and sliding distance, increase in wear rate is observed. The intermediate load value shows the highest average wear at high speed.
- The cryogenic treatment increases the wear resistance of AISI A2 tool steel in comparison to heat treatment.
- The average coefficient of friction is cryogenic treated samples is low in comparison to heat treated samples.
- The fluctuating curve is obtained for all loads but the value of average wear of cryogenic treated samples is low in comparison to heat treated samples.

Acknowledgements

We would like to thank department of Mechanical Engineering, Barkatullah University, Institute of Technology,Bhopal for helping us

in our project**.**

References

1. Ajit Behera, S.C. Mishra and S.K. Swain, Cryogenic technique for processing steel treatment.
2. D. Mohan Lal, S. Renganarayanan, A. Kalanidhi, Cryogenic treatment to augment wear resistance of tool and die steels, *cryogenics 41* (2001).
3. N. Saklakoglu, I.E. Saklakoglu, V. Ceyhun, O.R. Monteiro, I.G. Brown, Sliding wear behavior of Zr-ion-implanted D3 tool steel, *tribology International 40,* 794-799 (2007).
4. D. Das, A.K. Dutta, K. K. Ray, Influence of varied cryogenic treatment on the wear behavior of AISI D2 steel, wear (2006).
5. J. Hardell, B. Prakash, Tribological performance of surface engineered tool steel at elevated temperature, *Int. Journal of Refractory Metals & Hard materials 28,* (2010).
6. Shaohong Li, Lihui Deng, Xiaochun Wu, Yong'an Hin, Hongbin Wang, Influence of deep cryogenic treatment on microstructure and evaluation by internal friction of a tool steel, cryogenics 50 (2010).
7. Mahdi Koneshlou, Kaveh Meshinchi Asl, Farzad Khomamizadeh, Effect of cryogenic treatment on microstructure, mechanical & wear behaviors of AISI H13 hot work tool steel, cryogenics 51(2001).