International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 06 | June-2018 www.irjet.net p-ISSN: 2395-0072

Optimization of Wear Behaviour of Cryogenically Treated H13 Tool Steel Material under Dry Sliding Condition

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Abstract - Material H13 tool steel is chromium-molybdenum hot work steel which is normally used in cold and hot work tooling applications. H13 tool steel shows a better combination of larger toughness and resistance to thermal fatigue cracking therefore, it is mainly used for hot work tooling applications compared with other tool steel, also due to its better toughness and more stability in heat treatment, H13 tool steel material is used in various cold working applications. Deep cryogenic treatment was carried out on H13 tool steel material to improve its wear resistance by varying soaking period as 12hrs, 16hrs, and 20hrs.

This paper gives optimum value for wear behavior of cryogenically treated H13 tool steel. Wear test was conducted on the pin-on-disc machine under dry sliding condition. Untreated, cryogenically treated (12hr/16hr/20hr) samples were tested on the pin-on-disc machine, from which 16hrs treated sample gave the best result for wear resistance. Equations are developed to predict the wear resistance of H13 tool steel material. It is reported that the wear resistant properties of H13 tool material were improved by deep cryogenic treatment.

***Key Words*: H13 Tool Steel, Wear, Cryogenic, Pin on Disc, Tribology**

1. INTRODUCTION

According to AISI classification system, Chromium hot- work tool steels are mainly classified as group H steel. This series starts from H1 to H19 steels. H13 chromium hot work steel is normally used in cold and hot work tooling applications, in forging and casting industry due to its better combination of more toughness and fatigue resistance. Wear and corrosion are most affecting problems in industry, which results in material loss and maintenance expenditure. To reduce the wear of tool material, the life of the tool should be improved by improving its wear resistance which will lead to a reduction in equipment downtime and maintenance cost. Cryogenic treatment is used to improve physical and mechanical properties of the tool, by cooling a material to extremely low temperature due to the transformation of retained austenite phase into martensite phase. Cryogenic treatment is classified as cold treatment (0˚C to -80˚C), Shallow cryogenic treatment (-80˚C to -160˚C), deep cryogenic treatment (-160˚C to -196˚C). Deep cryogenic treatment is carried on H13 tool steel material at -196˚C by varying soaking time as 12hrs, 16hrs, 20hrs at Metallurgy Department, College of Engineering Pune Maharashtra.

1.1 Literature Review

A. Molinari *et. al.* [1] Carried the test on AISI M2 steel, the deep cryogenic test conducted on this material after two tempering cycles. Wear resistance of M2 Steel was increased due to increase in hardness. Also, it can be seen that for AISI H13 steel, toughness and wear resistance is improved.

R. Thornton *et al.*[3] performed cryogenic treatment on five materials named lamellar graphite cast iron (SAE J431 G10), pearlite carbon steel (EN10083 C50R), AISI A2, D6 and M2 tool steel. Fine perlite structure was observed in cryogenically treated samples of non-alloy steel which resulted in improvement of wear resistance. Due to deep cryogenic treatment, wear resistance of tool steel was improved in their annealed condition.

P. Sekhar Babu [4] in his experiment, he performed cryogenic treatment on H13 tool steel at different temperatures (-40˚C, -78˚C, -150˚C, -190˚C) and performed wear test on pin-the on-disc machine at 3 levels, it has been seen that wear resistance of the material was maximum at -150˚C.

S. A. Sonawane *et al.[*6] performed an experiment on pin-on-disc for untreated and cryogenically treated samples on M2 tool steel, it has been observed that hardness of M2 tool steel is not affected significantly by cryogenic treatment over the non-cryogenically treated sample. Sliding velocity was the most affecting parameter compared with sliding distance and pressure. Wear resistance was improved in cryogenically treated M2 tool steel compared with the non-cryogenically treated sample.

Blaze Stojanovic *et. al.* [7] did optimization of tribological behaviour of aluminium hybrid composites using Taguchi method. The experimentation was carried out on the block on disc tribometer under the dry sliding condition, parameters selected were load, sliding speed, sliding distance. From ANOVA analysis it has been seen that a most affecting parameter for wear rate is a load.

Ajith Arun Daniel *et. al.* [10] investigated the wear resistance and friction coefficient on Aluminium 5059/Sic/MoS2 on the pin-on-disk machine under dry sliding condition. Applied load and sliding distance were most affecting factors for friction coefficient, Load and percentage of SiC were most affecting factors for wear rate.

Sanjeev Katoch *et al.* [12] in their research studied the tribological behavior of H11 hot die steel after cryogenic treatment at -154˚C and -184˚C for the specific time period (6, 21, 36hrs). It has been seen that cryogenic treatment reduced the retained austenite content near to zero, which resulted in improvement of hardness and wear resistance. Optimization was carried out by using full factorial response surface methodology, which showed that 21hr at -184˚C for H11 steel is optimum soak timing to get lower wear rate. Sliding Speed affected more compared with the load.

2. METHODS AND MATERIAL

Material Selection:

In this experiment, H13 tool steel material with hardness 44HRc was used. Specimen dimensions are diameter 12mm, height 25mm. The chemical composition of H13 tool steel is given in Table I.

Table -1: Chemical Composition

Material	H13
C	0.39
Mn	0.35
Cr	5.17
Ni	0.10
Mo	1.38
S	0.005
P	0.011
Si	1.05
V	0.87

Cryogenic Treatment:

Cryogenic treatment is normally used to give better dimensional stability of parts, removal of residual stresses, and enhancement of mechanical and physical properties. Cryogenic process is carried out in 3 phases: gradual cooling to cryogenic temperature, holding for a particular time, gradually warmed to room temperature.

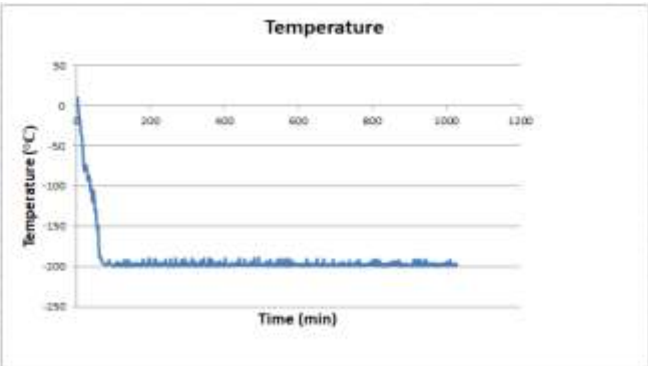

Fig -1: Cryotreatment Cycle for 16hrs Soaking period

Types of Cryogenic Treatment:

a) Shallow Cryogenic Treatment: In shallow cryogenic treatment, the material is soaked between temperature range -50˚C to -100˚C then hold at that temperature for a particular period.

b) Deep Cryogenic Treatment: In Deep cryogenic treatment, the material is soaked at temperature -150˚C to -198˚C then hold at that temperature for a particular period.

Deep cryogenic treatment is carried out on H13 tool steel material at -197˚C for a different soaking period of 12hrs, 16hrs and 20hrs at Metallurgy Department, College of Engineering Pune. From these samples hardness of 16hrs soaking period was more hence it was selected for wear optimisation.

Fig -2: Cryogenic Process Setup

Procedure for Wear Experiment:

The samples were tested on the pin-on-disc machine in dry sliding conditions at surrounding temperature in reference with ASTM G99 standards using pin-on-disc machine with friction and wear monitor of TR20, Ducom makes, Bangalore. EN31 steel disc of diameter 215mm was used as counter disc. Pin type samples of H13 tool material are tested for wear.

Wear rate calculations:

Wear rate in mm3/N-m
ρ: Density of H13 Tool Steel in gm/cc
L: Sliding distance in the meter.
F: Load in Newton

Wear rate = (Δm*(10ˆ3))/ρLF

Fig -3: Pin-on-disc setup

Design of Experiment by Taguchi Method:

Taguchi method was used for the DOE which minimizes the no of experiment by recording data. The experiment was carried out for 3 factors each one at 3 levels, the L9 orthogonal array is selected to conduct the experiments.

Table -2: Levels for DOE

Factors \Levels	Low (1)	Medium (2)	High (3)
Load (Kg)	3	5	7
Sliding Velocity (m/sec)	3.141	3.769	4.398
Sliding Time (min.)	60	90	120

Table -3: L9 Orthogonal Array

No. of Experiments	1 Load	2 Sliding Velocity	3 Sliding Time
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	1
9	3	3	2

Table -4: Experimental Data

Load (Kg)	Sliding Velocity (m/sec)	Sliding Time (min)	Wear Rate (mm^3/N-m)
3	3.141	60	$0.0189140 * 10^{-3}$
3	3.769	90	$0.0173040 * 10^{-3}$
3	4.398	120	$0.0278440 * 10^{-3}$
5	3.141	90	$0.0129790 * 10^{-3}$
5	3.769	120	$0.0111047 * 10^{-3}$
5	4.398	60	$0.0130200 * 10^{-3}$
7	3.141	120	$0.0175320 * 10^{-3}$
7	3.769	60	$0.0135440 * 10^{-3}$
7	4.398	90	$0.0269250 * 10^{-3}$

Generalized wear equation in terms of load, sliding velocity, a sliding time obtained from regression analysis is

Wear Rate = -0.0037 - 0.00051 Load + 0.00487 Sliding Velocity + 0.000061 Sliding Time

3. RESULTS AND DISCUSSION

Each experiment has a combination of various factor levels, it is necessary to differentiate the individual effect of all variables, which may be done by adding performance parameter values for respective levels ANOVA of H13 tool steel material data for wear rate is shown in Table IV.

Fig.4 shows that effect of the load is more on wear rate followed by Sliding velocity then sliding time.

Table -4: ANOVA for wear rate of h13 tool steel material

Factors	D. O. F.	SS	MSS	F_{ratio}	% Contribution
Load	2	0.000133	0.000067	9.12	45.08
Sliding Velocity	2	0.000118	0.000059	8.06	40.00
Sliding Time	2	0.000029	0.000014	1.97	9.83
Error	2	0.000015	0.000007		
Total	8	0.000295			

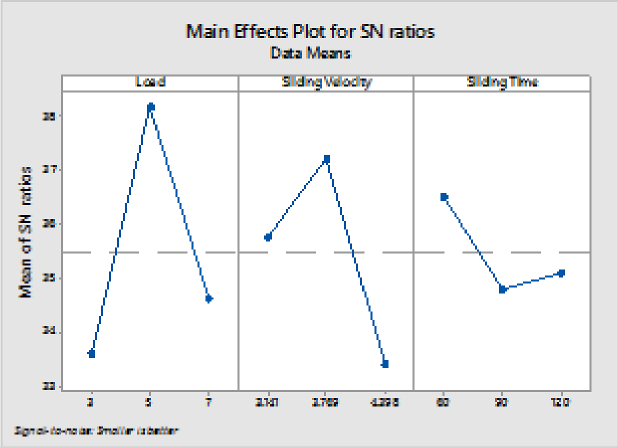

Fig -4: Effect of various parameters on S/N ratio for Wear Rate

To obtain the optimum value of wear rate, the values of variables taken from the graph are load=5kg, sliding velocity=3.769 m/sec, sliding time=60 min and the optimum value for wear rate is 0.01576 * 10^{-3}.

Table -5: Optimum values of wear rate

Response	Optimum value				Actual Value
	Load (Kg)	Sliding Velocity (m/sec)	Sliding Time (minutes)	Optimum Value for response	
Wear Rate (mm^3/N-m)	5	3.769	60	0.01576 * 10^{-3}	0.01246 * 10^{-3}

4. CONCLUSIONS

1. Cryogenically treated H13 tool steel material at the 16hrs soaking time showed the best result for wear resistance amongst 12hrs, 20hrs, and untreated sample.
2. The effect of load is more on the wear rate compared with sliding velocity and sliding distance.
3. The optimum conditions for wear rate are 5kg, 3.769m/sec and 60min.

ACKNOWLEDGEMENT

This study was supported by Government College of Engineering Aurangabad and Metallurgy Department of College of Engineering Pune.

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