Experimental Investigation of Thermal Conductivity, Wear Behavior and Hardness of Cryogenically Treated H13 Tool Steel Material

Vivek Ahire[1], Sameer Sayyad[2], Dr. S. A. Patil[3], Puja More[4]

[1]PG Student, Mechanical Engineering Department, Government College of Engineering, Aurangabad (M. S.), India
[2]PG Student, Mechanical Engineering Department, Government College of Engineering, Aurangabad (M. S.), India
[3]Associate Professor, Mechanical Engineering Department, Government College of Engineering, Aurangabad (M. S.), India
[4]PG Student, Mechanical Engineering Department, Government College of Engineering, Aurangabad (M. S.), India

---***---

Abstract - *H13 material is used in extrusion, forging and casting industry. H13 has low thermal conductivity amongst all the tool materials used in the industry. For increasing the thermal conductivity of H13 cryogenic treatment is used. In this paper we studied the changes in thermal conductivity, wear resistance and hardness due to the various holding time of the cryogenic temperature at -196⁰ C like 12 hours, 16 hours and 20 hours. Test samples were subjected to wear tests on the pin-on-disc machine in dry sliding condition and also the thermal conductivity of the samples is determined. Hardness and X-ray diffraction are also studied. From the test results, it is found that cryogenically treated samples at 16 hours give the best result amongst all the treated and untreated samples for hardness, wear resistance and thermal conductivity.*

Key Words: H13 Tool, Cryogenic treatment, Thermal conductivity, Hardness, Wear rate

1. INTRODUCTION

In cryogenic treatment, microstructure changes occur. Retained austenite is converted to the martensitic phase. Cryogenic treatment is conducted at a negative temperature.

Cryogenic treatment is mainly classified into two types;
1. Shallow cryogenic treatment,
2. Deep cryogenic treatment.

In shallow cryogenic treatment, the samples are soaked at a temperature between -50⁰C to -100⁰C and then held at this temperature for a particular time. Similarly, for deep cryogenic treatment, the soaking temperature is between -150⁰C to -198⁰C and then held at this temperature for a particular time.

H13 tool material is mainly used in extrusion and forging industries but temperature transfer due to heating of tool material is less. Due to this crack occurs at tool i.e. on die and punches. Hence, continuous cooling is required for die and punches.

2. MATERIALS AND METHODS

The material selected is H13 tool steel. H13 is chromium hot worked steel. This material is mainly used in extrusion and forging industries. The chemical composition of the material is in Table

Table -1: Chemical Composition

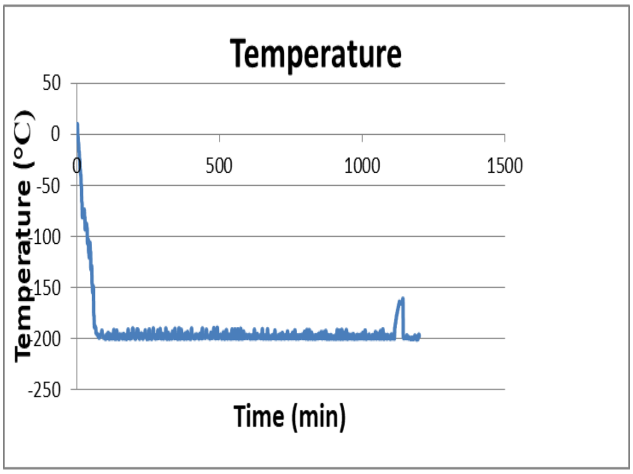
Material	H13
C	0.39
Mn	0.35
Cr	5.17
Ni	0.10
Mo	1.38
S	0.005
P	0.011
Si	1.05
V	0.87

2.1 Cryogenic Treatment

The cryogenic treatment is conducted on samples at -196⁰C for 12 hours, 16 hours and 20 hours. Cryogenically treated samples are used for the measurement of thermal conductivity, wear resistance. The cryogenic set up is shown in Fig 1.

Fig -1: Cryogenic set up

Cryogenic treatment is mainly used to give more dimensional stability of the material, removal of residual stresses and improvement of mechanical, physical and thermal properties. Cryogenic process is carried out in 3 phases: gradual cooling to cryogenic temperature, holding for a particular time, gradually warmed to room temperature. The cryogenic treatment cycle is as shown in Graph 1



Graph -1: Cryogenic Treatment Cycle

2.2 Thermal Conductivity Test

Thermal conductivity is the property of a material to transfer heat from 1 point to another. Thermal conductivity is carried out to find the effect of cryogenic treatment on the H13 material. For this samples are prepared as per ASTM E1225 i.e. 36mm round rod 457 mm lengths.

One end of the rod which is heated by the electric heater of 2A, 230 V, and the other end is cooled by a water circulated heat sink. The middle portion, i.e. test section of the bar is covered by a shell containing insulation of lower thermally conductive material. The temperature of the rod is measured at 5 different sections, while 2 thermocouples measure the temperatures at the shell. Two thermometers are provided to measure the inlet and outlet temperatures of the water. A dimmer is provided to the heater to control its input. Constant water flow is circulated through the heat sink. A gate valve provided to control the water flow.

First, start the electric supply due to which heating the bar by adjusting the heater input around 120 volt. Then start cooling water supply through the heat sink and adjust it to around 100-200 cc per minute. After that bar temperature will start rising. Check the temperatures at time intervals of 5 minutes each. When all the temperatures remain steady, note down its values

According to Fourier's law of heat conduction,

$$Q = -KA\frac{dt}{dx}$$

Where,
Q = Heat carried out by water (Watt),
K = thermal conductivity of the material (W/mK),
A = Cross section area (m^2),
DT/dx = temperature gradient.

The rate of heat transfer, Q is calculated as

$$Q = m \times Cp \times dt$$

m = mass flow rate of water,
Cp = specific heat of water and
it is a temperature change of water supplied.

2.3 Wear Test

Wear test is carried out to find the effect of cryogenic treatment on the H13 material. The wear test is performed on a pin on disc machine make of DUCOM. The cylindrical pin is prepared of 12 mm and height 28 mm. Also, the surface of the material is polished and surface roughness is about 0.1µm. All samples and disc are clean with help of sand paper. Selected parameters are normal load 50N and 60N, sliding velocity 3.14 m/s and 3.76 m/s.

Wear rate calculations:
Wear rate in mm^3/N-m
ρ: Density of H13 Tool Steel in gm/cc
L: Sliding distance in the meter.
F: Load in Newton.

$$Wear\ rate = \frac{\Delta m * (10^{\wedge}3)}{\rho LF}$$

2.4 Hardness

Hardness test was performed on microhardness tester of Future test make FM-700. Test load was 980 µN and dwell time was 10 second. Rockwell C hardness values are obtained. For this samples are polished with help of Mirror polishing machine of Mentation technology make.

2.5 X-Ray Diffraction (XRD)

This analysis is used to find crystal structure, crystallinity, and orientation of phases. XRD test was performed on Bruker make D8 Advance diffractometer, using Cu-Kα radiation. A scan between 5° to 70° with step size 0.02 and scan speed 2°/minute. The peaks are identified by origin and compared with standard data.

3. RESULTS AND DISCUSSION

3.1 Thermal conductivity

The observed and calculated data is as shown in Table 2.

Table -2: Thermal Conductivity of samples

Sr. No.	Samples	Thermal Conductivity, K (W/mK)
1	Untreated	25.3743
2	12 Hours	26.3395
3	16 Hours	28.2029
4	20 hours	27.2319

3.2 Wear

The weight loss values are shown in Table 3

Table 3: Weight loss of samples

Sr. no.	Load (N)	Sliding Velocity (m/s)	Wear time (minutes)	Weight loss in grams			
				Untreated	12hrs	16 hrs	20 hrs
1	50	3.1416	90	0.1016	0.0925	0.0743	0.0748
2	50	3.7699		0.1559	0.1498	0.1228	0.1195
3	60	3.1416		0.1216	0.1028	0.0844	0.0842
4	60	3.7699		0.2123	0.1897	0.1635	0.1614

Wear rate and improvement in wear as shown in Table 4

Table 4: Wear rate of all samples

Sr. No.	Wear rate				Improvement wear rate to Untreated, %		
	Untreated	12 hrs	16 hrs	20 hrs	12 hrs	16 hrs	20 hrs
1	1.5455	1.40711	1.13025	1.1074336	13.829	26.87	28.35
2	1.9643	1.88748	1.5472	1.5057	3.91	21.23	23.34
3	1.5365	1.2989	1.0669	1.0639	15.46	30.56	30.75
4	2.2432	2.0041	1.7272	1.7052	11.93	25.74	26.84

Hardness

The hardness of the material is finding out by microhardness tester is as shown in Table 5

Table 5: Hardness of all samples

Sr. No.	Sample	Hardness (HRC)
1	Untreated	45
2	12 Hours	51
3	16 Hours	54
4	20 hours	55

XRD

XRD test was performed on all samples. Only martensitic phase is detected in all treated samples and austenite phase is found to be less as compared to untreated samples. Also, the crystallinity of all samples was observed shown in Table 6

Table 6: Crystallinity from XRD

Sr. No.	Sample	Crystallinity
1	Untreated	24.2%
2	12 Hours	25.4%
3	16 Hours	25.6%
4	20 hours	24%

4. CONCLUSIONS

1. The thermal conductivity of treated samples of 12 hours, 16 hours and 20hours is increased by 3.8%, 11.15%, 7.32% respectively with respect to untreated samples.
2. Wear rate of treated samples of 12 hours, 16 hours and 20hours decreases as compared to that of the treated samples.
3. The hardness of the cryogenically treated samples is also increased as compared to that of untreated.
4. From XRD test it is clear that due to cryogenic treatment crystallinity increases and also the percentage of martensitic phase increases as compared to the untreated samples.
5. From the above discussion, it is concluded that cryogenic treatment at 16 hours gives the best result for thermal conductivity, wear resistance, hardness.

Acknowledgment

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

REFERENCES

1. Corey J. Isaak & Wayne Reitz, “The Effects of Cryogenic Treatment on the Thermal Conductivity of GRCop-84”, Materials and Manufacturing Processes, 23:1, 82-91, 2007.
2. D. S. Nadig, V. Ramakrishnan, P. Sampathkumaran, and C. S. Prashanth, “Effect of cryogenic treatment on thermal conductivity properties of copper”, Advances in Cryogenic Engineering, 133-139, 2012.
3. M. E Mehtedi, P. Ricci, L. Drudi, S. El Mohtadi, M. Cabibbo, S. Spigarelli, “Analysis of the effect of Deep Cryogenic Treatment on the hardness and microstructure of X30 CrMoN 15 1 steel”, Materials and Design 33, 136–144, 2012.
4. R.H.Naravade, S.B.Belkar, R.R.Kharde, “Effects of Cryogenic Treatment, Hardening and Multiple Tempering On Wear Behavior of D6 Tool Steel”, The International Journal Of Engineering And Science, Volume 2 Issue 5, Pages 01-15, 2013.
5. R. Thornton, T. Slatter, H. Ghadbeigi, “Effects of deep cryogenic treatment on the dry sliding wear performance of ferrous alloys”, Wear305,177–191, 2013.
6. S.N. Aqida · D. Brabazon · S. Naher, “An investigation of phase transformation and crystallinity in laser surface modified H13 steel”, Applied Physics A Material science and processing 110, 673-678, 2013.
7. Idayana, A.Gnanavelbabub*and K. Rajkumarc, “Influence of Deep Cryogenic Treatment on the Mechanical Properties of AISI 440C Bearing Steel”, Elsevier, 97 1683 – 169, 2014.
8. K.-H. Shi, K.-C. Zhou, Z.-Y. Li, X.-H. Liu & X.-Q. Zan, “Effect of Cryogenic Treatment on Thermal Behavior of WC-9Ni-xCeO2 Cemented Carbides”, Materials and Manufacturing Processes, 30:12, 1425-1430, 2015.

9. Adem C¸ ic¸ neck, Fuat Kara, Turgay Kıvak, Ergu¨ n Ekici, and _Ilyas Uygur, “Effects of Deep Cryogenic Treatment on the Wear Resistance and Mechanical Properties of AISI H13 Hot-Work Tool Steel”, Journal of Materials Engineering and Performance Volume 24(11) 4431, November 2015.
10. S. A. Sonawane, V. K. Tripathi, S. D. Ambekar, “Wear Behaviour of Cryogenic Treated M2Tool Steel under Dry Sliding Condition”, Applied Mechanics and Materials, Volume 798, 395-401, 2015.
11. Chen-hui XIE1, Ji-wu HUANG2,3, Yun-Feng TANG2, Li-ning GU, “Effects of deep cryogenic treatment on microstructure and properties of WC−11Co cemented carbides with various carbon contents”, Transactions of Nonferrous metals society of China 25,3023-3028, 2015.
12. Sanjeev Katoch, Rakesh Sehgal & Vishal Singh, “Effect of cryogenic treatment on the tribological behavior of H11 hot die steel dry sliding against D3 steel”, Tribology - Materials, Surfaces & Interfaces, 2016.
13. B. Podgornik, I. Paulin, B. Zajec, S. Jacobson, V. Leskovsek, “Deep cryogenic treatment of tool steels”, Journal of Materials Processing Technology 229 398–406, 2016.
14. Valmik Bhawar, Shreyans Khot, Prakash Kattire, Mohan Mehta, Rajkumar Singh, “Influence of Deep Cryogenic Treatment (DCT) on Thermo Mechanical Performance of AISI H13 Tool Steel”, Journal of Materials Science and Chemical Engineering, 5, 91-101, 2017.
15. Ajith Arul Daniel, Sakthivel Murugesan, Manojkumar, Sudhagar Sukkasam, “Dry Sliding Wear Behaviour of Aluminum 5059/Sic/MoS2 Hybrid Metal Matrix Composites”, Volume 20, 1697-1706, 2017.
16. Prudente W. R., Jefferson Fabrício C. Lins, Siqueira R. P., Priscila S. N. Mendes, Rodrigo E. Pereira, “Microstructural evolution under tempering heat treatment in AISI H13 hot-work tool steel”, International Journal of Engineering Research and Application, Vol. 7, Issue 4, pp.67-71, April 2017.