

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 6, Issue 10, October 2017

Usage and Scope of Cryogenics in Field of Machine Tool Treatment and in Tribology of Space Engine

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ABSTRACT: Advanced use of cryogenic treatment also known as sub zero heat treatment of cutting tool along with the double tempering action for enhancement of performance in machining which eliminates the very major drawback of wear and tear at the molecular level of HSS and improves wear resistance, abrasion resistance, tool life and dimension integrity along with it it provides a good surface finishing to the workforce. Provides strength due to change of lattice from austenite to martensite structure. Effect of rapid cryogenic treatment over slow cryogenic treatment. And the inner tribology of the high speed shaft bearing, which operates at cryogenic conditions of rocket fuel in turbopumps of space engine in absence of proper lubrication Between pump section and combustion zone at different thermal condition and advancement of cryogenics in improving the shelf life and operation life duration. And this paper briefly summarize the recent advancements and possible scope of the above mentioned topic in other branches of mechanics and mechatronics.

KEYWORDS : cryogenic tribology -scope of cryogenics in mechanics -cutting tool efficiency -molecular lattice of cutting tool -cryogenic engine -space engine -high speed shaft bearing.

I. INTRODUCTION

The word cryogenics come from the Greek word 'kroys' means cold that is cryogenics is a branch of thermodynamics which deals with the process and treatment at a sub zero temperatures. Cryogenic temperature is practically made possible due to cryogenic liquids.

Cryogenic has a wide range of applications in almost every field. In this paper we briefly review and discuss its use in machining tool treatment and high speed cryogenic engine.

The main drawback of machine tool is its low life time due to wear and tear during machining hence this process require regular replacement or regular sharpening but due to the cryogenic treatment of the machine tools which is known to enhance the properties such as wear resistance, abrasion resistance, dimension integrity and also the tool life. These properties are enhanced due to change in the microstructure of the HSS or any cutting tool metal the cryogenic treatment is always followed either by tempering or double tempering for good results. Cryogenic treatment can also be applied to ferrous, non-ferrous, composites, plastics etc.

The improvement in the reliability of cryogenic liquid propellant became a international technical problem which require high pressure turbopumps to transfer liquid propellant to the engine. In this process the tribology of the high speed shaft seal and bearing plays a important role in cryogenic engine of space vehicle where the proper lubrication is not possible due to the small viscosity at cryogenic temperature and the shaft seal and bearing must also overcome the high speed operation that has various critical speeds during different stages of space travel.

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II. PROCEDURE OF MACHINE TOOL TREATMENT

The cryogenic treatment of metal tool treatment can be classified into two types based on the temperature of treatment they are shallow treatment and deep treatment

In shallow cryogenics the temperature between -80° to -140° is the operating temperature and in deep cryogenics temperature between -140° to -196° is applied. The cryogenic treatment mainly depends on variables such as soaking temperature, soaking time, cooling speed. During the process of treatment the microstructure of the metal changes from austenite to martensite which give the toughness to machine tool.

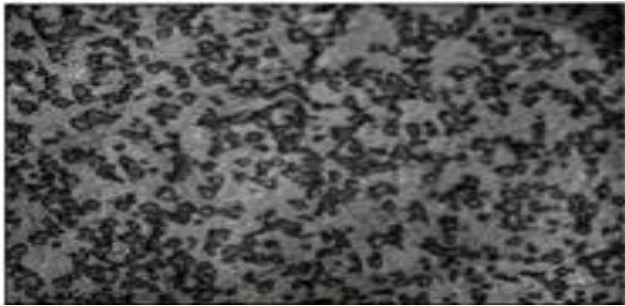


Fig 2.1(a): Austenite micro structure

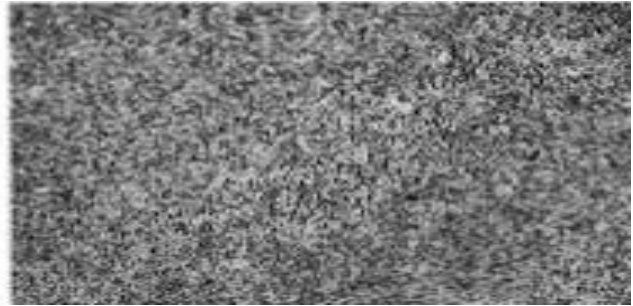


Fig 2.1(b): Martensite micro structure

The soaking period is an important parameter in the conversion of material from austenite to martensite, the formation of new carbides and for carbide distribution . The optimization of the soaking period is important for achieving maximum efficiency and reducing costs in cryogenic treatment. . A review of the literature on cutting tools and materials showed that the samples were subjected to cryogenic treatment soaking periods of between 1 and 40 h (Table 2.1).

Baldissera et al-exposed test samples to cryogenic heat for 9- and 24-h soaking periods for cryogenic treatment in order to investigate the wear and corrosion resistance, hardness, and soluble material conditions of AISI 302 austenitic stainless steel. They concluded that a 9-h soaking period was adequate for wear behaviour. Darwin et al. subjected samples to 12-, 24-, and 36-h soaking periods to give maximum wear.

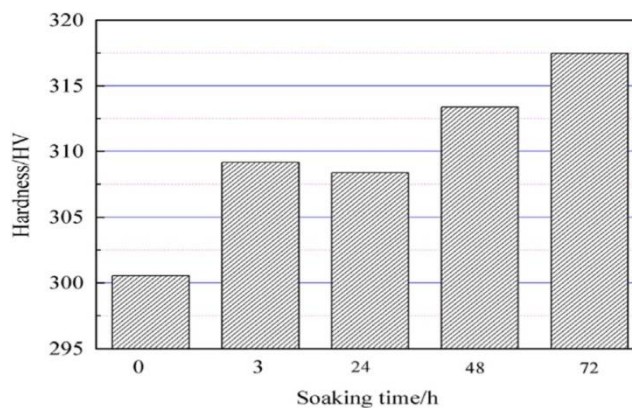


Fig 2.2: Variations of hardness for different cryogenic treatment soaking periods

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Temperature (°C) Rockwell hardness (HRA)

	P-40 untreated	P-40 deep cryogenic treated
Room Temp.	84	83.5
100	83	83.2
200	81.5	82
300	78	80
400	76	77.8
500	71	74.6

Table 2.1: Red hardness of P-40 tool.

Resistance to martensite stainless steel (SR34, containing 18 % Cr) commercial segments. The researchers reported that they had obtained the best wear resistance with a soaking period of 36 h. Moreover, they determined a 24 % increase in the wear resistance of samples with the 36-h soaking period

Shirbhate et al. applied cryogenic treatment to HSS (M2) cutting tools by holding them for 8, 16, and 24 h. They reported that in drilling experiments, a 24-h holding time had yielded a better performance in cutting tool cutting torque, surface roughness, and wear resistance. The researchers determined a 35 % improvement in work piece material surface roughness after cryogenic treatment. Baldissera et al. examined the effect of cryogenic treatment on the mechanical properties of 18NiCrMo5 carbide steel. The researchers compared cryogenic treatment soaking periods of 1 h (M1) and 24 h (M24) and concluded that hardness and stresses were higher in samples held for a 24-h soaking period than in those held for a 1-h soaking period.

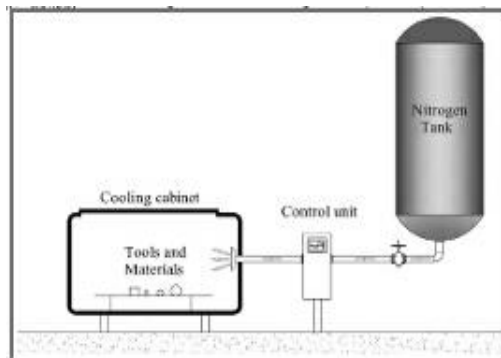


Fig 2.3: Block diagram of cryogenic treatment.

Gu et al. analysed the effect of cryogenic treatment parameters on Ti-6Al-4V alloy and compared the effects of different cryogenic treatment periods on the hardness of samples

According to the literature, in general, similar improvements have been achieved in cryogenic treatment applied to cutting tools and in cryogenic treatment applied to steel. In this framework, it is important to examine studies on steel in order to analyse the effect of cryogenic treatment on cutting tools. A great majority of studies on cryo-treated tools are observed to focus on a 24-h soaking period (Table 2.1). However, some studies have obtained better results at lower or higher holding times. The results obtained for different soaking periods varied according to the material of the cryo-treated tool and the machining type of the tool.

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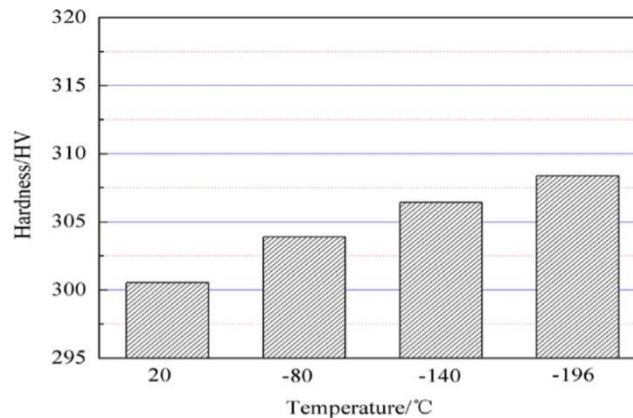


Fig 2.3: Variations of hardness at different cryogenic treatment soaking temperatures

Soaking temperature

Cryogenic treatment applied at low temperatures shows variations according to the type of tool. Cryogenic treatment temperatures applied to cutting tools range between -80 and -196 °C . In order to enhance mechanical properties such as wear resistance, hardness, and toughness, the appropriate soaking temperature should be determined for the tool that will undergo cryogenic treatment. Various studies carried out for this purpose have attempted to achieve optimization by using different soaking temperatures to find the best one for cryogenic treatment. It has been reported that, among cryogenic treatment parameters, soaking temperature is the most effective parameter in enhancing the wear resistance of the samples. Researchers have determined the optimum cryogenic treatment temperature as -184 °C.

Firouzdor et al. investigated the effect of deep cryogenic treatment (-196 °C) on the tool life and wear resistance performance of HSS drills in the drilling of CK40 carbon steel under dry conditions. They found that cryogenic treatment applied to HSS tools increased tool life by 77 %. Gu et al carried out similar studies. They conducted a study to investigate the effect of cryogenic treatment temperature on the hardness of Ti- 6Al-4V alloy and found that deep cryogenic treatment (-196 °C) was the most effective parameter on the hardness of the alloy (Fig 2.3).

Previous studies have shown that the effects of different cryogenic treatment temperatures vary according to the type of material . Therefore, it is important to determine the most suitable cryogenic treatment temperature according to the material properties of the tools that will undergo cryogenic treatment.

Tempering process

Cutting tools are generally tempered after cryogenic treatment .The tempering process is performed to eliminate internal stresses on the cutting tool that occur due to excessive cooling. Generally, the tempering process is applied to cutting tools by holding them at $150-200$ °C for 1.5–2 h . In some previous studies, more than one tempering process was applied consecutively after cryogenic treatment The primary aim of the cryogenic treatment and tempering cycle is to convert materials from austenite to martensite and to increase hardness. Another aim is to enhance wear resistance by improving the carbide distribution in the microstructure .

Rate of cooling

There are two principle approaches regarding the rate of cooling in cryogenic heat treatment. The first approach is termed thermal shock, in which the samples are rapidly brought to a cryogenic application temperature. In the other approach, the samples are gradually brought to cryogenic temperature

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Number	Cryogenic treatment soaking period (h)
1	1
2	3
3	5-6
4	8
5	9
6	12
7	16
8	18
9	20
10	22

Table 2.2: cryogenic treatment soaking periods.

III. TURBOPUMP BEARING IN THE SPACE ENGINE

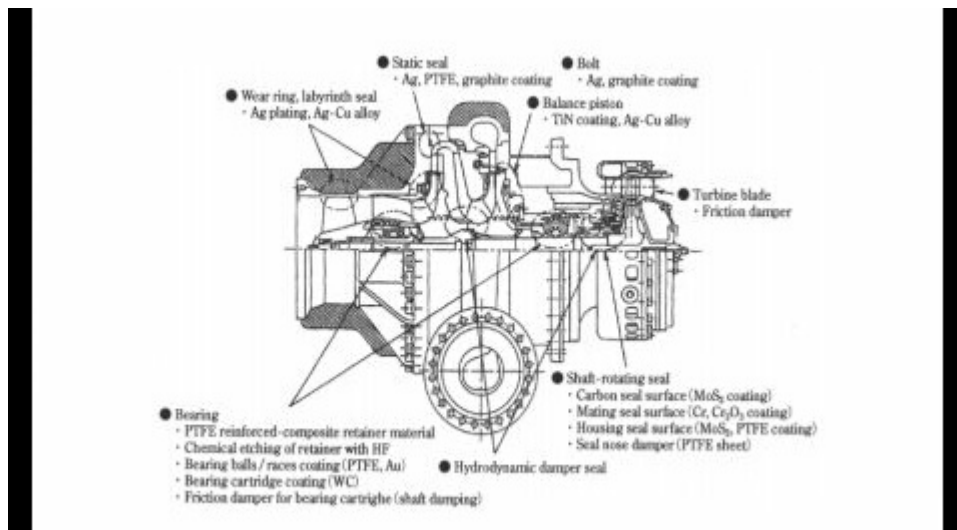


Fig 3.1: Typical tribology components and solid lubricants of a turbopumps

The turbopump bearings are all-steel (AISI 440C) bearings that are self-lubricated by the PTFE transfer film as a lubricant from the reinforced PTFE (poly tetrafluoroethylene) retainer. AISI 440C is martensitic stainless steel (with 16-18%Cr) and is one of the most widely used bearing materials in space systems because such high-Cr steel has a high corrosion resistance due to a superficial surface layer of Cr₂O₃. The resin PTFE retainer is reinforced with glass fibre, carbon fibre and laminated glass cloth to reduce wear as well as thermal contraction of the retainer. Although PTFE material has poor mechanical strength at room temperature, it has the best lubricant for use at cryogenic temperature because its mechanical tensile stress drastically increases and reaches to 80 MPa in LO₂ and 130 MPa in LH₂,

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respectively. In order to reduce wear of the PTFE composite retainer with poor thermal conductivity, sufficient cooling of the retainer is need to eliminate heat generation detrimental to successful bearing operation at high speeds.

Self-lubrication of retainer

Since LH_2 and LO_2 are particularly poor as lubricants because of their low viscosity under conditions of reduction or oxidation, hydrodynamic fluid lubrication is less effective. It is noted that the cryogenic pump fluids works to remove severe frictional heat and to prevent the temperature rise in the bearing. At low temperatures, the PTFE transfer film as a lubricant is kept to be hard and to sustain the bearing load, so that softening and rupturing of the transfer film due to a rise in temperature have to be eliminated. Under poor cooling conditions, it appears that the blackened transfer film due to thermal decomposition of PTFE should occur at a high temperature above about 500 K, and the degraded transfer film was not able to sustain the bearing load. Therefore, sufficient cooling by cryogenic fluids, as well as reduction of frictional heat generation, is very important to produce a durable lubricant film transferred from the retainer even in cryogenic fluid.

Cryogenic tribological problems

LH_2 is a particularly poor lubricant due to its extremely low viscosity (approximately equal to that of room-temperature air) and chemical reducing effect to remove native oxide film and to make fresh frictional surface, resulting in a severe lubricating condition at the frictional interfaces. Furthermore, at extremely low temperatures in LH_2 , the specific heats and thermal conductivities of tribo-materials drop off rapidly rather than those at the liquid nitrogen (LN_2 , boiling point 77 K) temperature. At a high temperature in LN_2 , the specific heats and thermal conductivities are less changed and same as those at a room temperature. In addition with vaporization of LH_2 , it is easy to produce local hot spots at frictional interfaces, so that frictional condition resulted in severe adhesive (welding) wear in LH_2 .

LO_2 has high oxidization power and forms oxide film at frictional surfaces, so that oxide film produces lower friction compared with that in LH_2 ; however, in boiling of LO_2 , oxide wear should increase due to high oxidization power. Active cooling is important to prohibit boiling of LO_2 at frictional interfaces. Furthermore, violent frictional heating in LO_2 can lead to the ignition of tribo-elements due to burn-out phenomenon occurring in nucleate boiling, that is defined by engineering heat transfer. Under burn-out phenomenon in boiling, an extreme rise in surface temperature was experienced because a marked reduction occurred in heat transfer. For example, in boiling of LN_2 , the sliding surface of Ag-10%Cu alloy (melting point 1,155 K) against Ti alloy (Ti-5Al-2.5Sn) melted due to burn-out wear during friction test [24]. The surface coating of TiN or TiO_2 had a high resistance to adhesive welding to the Ti alloy disk was able to protect from burn-out wear. The results were applied to the balance-piston system in the LH_2 turbopump of the LE-7.

IV. SCOPE OF CRYOGENICS

Cryogenic has wide application in recent days it is a intimate process of every industry not only for tool treatment but also in fields such as food processing, textiles, sewage treatment, and also in laboratory even now a days the automated cnc lathes even use cryogenic liquid while operating. The cryogenic tribology of space engine can also be applied to the road vehicle engines so that the efficiency increases in a leap and it paves a way for new models of engine like hydrogen engine, acetylene engine, if still advanced for maintaining the high speed bullet trains.

V. CONCLUSION

The bearing of the high speed space engine can be used in spindles of machine tools to get improved efficiency. And the engine parts of space engines can be cryo treated at specific portions so that the tribological errors can be easily corrected.

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