# EFFECT OF HEAT TREATMENT AND IT'S BEHAVIOUR ON MECHANICAL PROPERTIES OF PURE TITANIUM

## Abstract

Titanium (Ti) is widely used in many applications due to its compatibility with different environmental conditions. However, pure Ti has low-to-moderate strength. Heat treatment of Ti is one option to improve its mechanical properties. The current study aims to investigate the effect of heat treatment on microhardness (Vickers) and wear properties of pure Titanium (Ti – Grade 2). The cylindrical shaped Ti was isothermally held in the tubular furnace at a temperature of 920˚C for about 30 mins and cooled in different modes such as quenching in water, ice, oil (Servo 4T 20W40), air (Normalizing), and furnace cooling (Annealing). Further samples were kept in a freezer for 20 days (–20). The results of each specimen were compared and the best cooling medium was determined in terms of hardness and worn-out surfaces. Specimen cooled in water exhibited intermediate (fair) wear and hardness properties compared to specimen cooled in other media.

**Keywords:** Pure Titanium, Heat treatment, Cooling Media, Wear, Hardness.

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## I. INTRODUCTION

Pure titanium (atomic number 22, atomic weight of 47.9) has a melting point of 1675 °C and a density of 4.5 g/cm³. Titanium metal and its alloy are essentially non–magnetic and offer good heat transfer capability. It occurs in two allotropic forms i.e., α–Ti and β–Ti. At room temperature α–Ti is in a hexagonal structure and at a temperature of 882.5°C it is converted to a β–Ti in the regular system [1–5]. Ti is characterized by a very low thermal conductivity of 11.4 W/mK, which is 3–4 times smaller than Fe and up to 16 times lower than Cu. In its soft state, Ti has a tensile strength of raw material 460 – 590 MPa. It is stated that Ti has a high ductility and excellent corrosion resistance to seawater, chlorides, organic acids, and air atmosphere; no oxidation at 200°C, and has a high creep resistance at high temperatures. Pure, unalloyed titanium is used mainly in construction, which is required to have high corrosion resistance. These include chemical equipment and rigs working in the surrounding seawater as well as elements used in medical technology and watchmaking [6–9]. Ti is widely used in the aerospace industry, both in airframes and engine components. Even non–aerospace applications take advantage of the excellent strength properties of Ti.

However, it is stated that commercially pure Ti (> 99%) is not well-suited for aircraft applications because of its low-to-moderate strength. Moreover, the yield strength of Pure Ti is within the range of 170–480 MPa, which is too low for heavily loaded aerostructures [10]. In this regard, many researchers are taking a keen interest in improving the mechanical properties of pure Ti by alloying, plastic deforming as well as heat treatment processes [1, 2, 8, 11].

The literature states that the majority of the research works focused on heat treatment on Ti alloys. However, only a few researchers carried out work on heat treatment on commercially pure Ti grade 2. Moreover, studies on tribological properties are scant. Commercially pure Ti is represented by four distinct, especially grade I, grade II, grade III, and grade IV. In the project, pure titanium of grade II was used. The current study is to investigate the effects of heat treatment on hardness (Rockwell) and tribological properties of pure Ti grade 2. An attempt was also study the microstructural changes after heat treatment.

## II. EXPERIMENTAL METHODOLOGY

The pure titanium grade 2 (carbon 0.08, max, Nitrogen 0.03max, Iron 0.30 max) round bar was procured from OZAIR trade link Ahmadabad, Gujarat of 12mm diameter. The received titanium rod specimen was in the dimension of 10mm in diameter and 1.5 meters in length. Later, it was cut with the help of a wire cutting machine for the required dimensions of length 30 mm and diameter 10mm for the heat treatment process.

The cylindrical specimen (ϕ 10mm × 30 mm L) as shown in Figure 1 is heated in the specially designed Tubular furnace (open at both ends) with a sensor-based temperature controller to maintain the required isothermal temperature to facilitate rapid quenching. In this apparatus, the specimen to be heat treated was hooked from the top of the furnace and it led into the cylindrical coiled furnace (Figure 2). The temperature attained value was indicated in the digital reading equipment connected to the furnace. The specimens were heated to 920°C temperature inside the furnace for half an hour (30 mins) and experiments were repeated for different cooling/quenching media such as Ice quenching, water quenching, oil quenching (Servo 4T 20w40 engine oil), freezing (–$20^0$ C), annealing (furnace cooling) and normalizing.

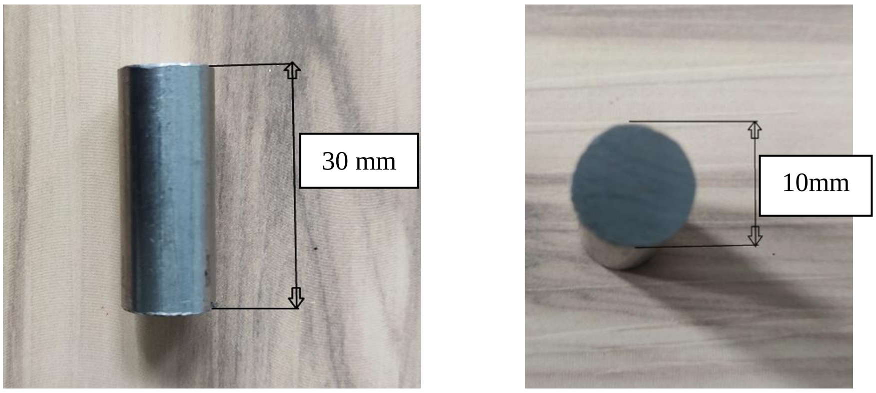

**Figure 1:** Standard specimen for heattreament

**Figure 2:** Rapid Quenching Experimental Setup (Tubular Furnace)

The first set of samples were heated at 920°C respectively for 30 minutes followed by rapid quenching in ice flakes. The same trend was followed for water quenching, salt bath, and oil quenching. However, for annealing samples were treated at 920°C respectively for half an hour followed by a long cooling in the furnace itself (annealing) to reach room temperature. For normalizing, after 30 minutes the samples were cooled down to room temperature in the open air itself. Later heat-treated samples were kept in the freezing chamber at containing temperature -20℃ for 20 days. Sectioned Heat-treated samples are shown in Figure 3.

Salt Oil

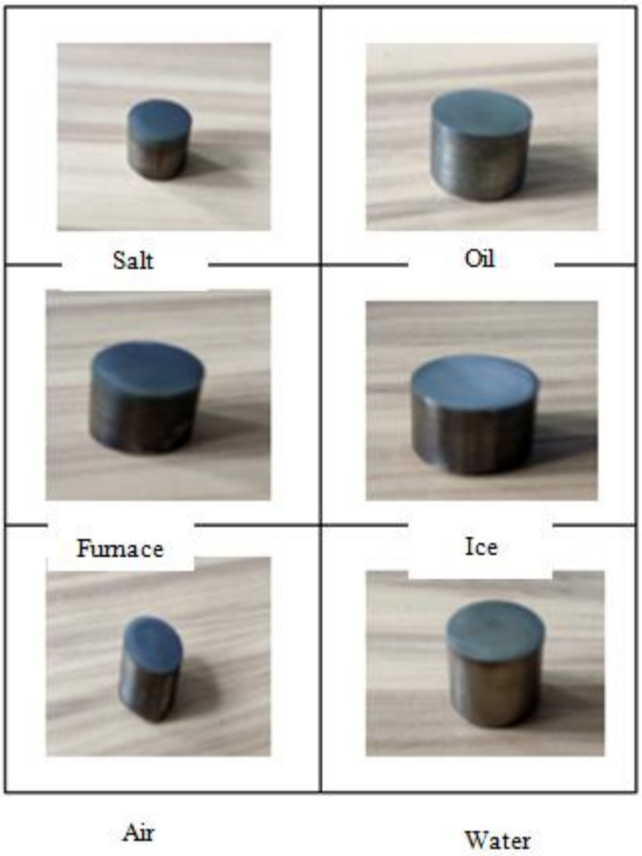

**Figure 3:** Specimens after heat treatment for 30 min at 920℃

The Micro-hardness test was conducted for all the heat-treated specimens. The hardness was conducted using the HVS 1000B Model. The determination of the Micro-hardness of a material involves the application of a minor load followed by a major load. The minor load establishes the zero position. The major load was applied and then removed while still maintaining the minor load. For the study, diamond indenter at a minor load of 10Kgf and a major Load of 100Kgf was used for a dwell time of 16.4 seconds. The load was chosen after multiple trials of indentations. Heat-treated specimens were also subjected to wear tests using Pin on Disc type wear testing machine at RYMEC was Bellary for tribological characterization. A metallurgical microscope (Leica model at AIET), used for microstructural studies.

## III. RESULTS AND DISCUSSION

The determined Tribological properties of heat-treated specimens are mentioned in Table 1. An effect of heat treatment on tribological properties of specimens at different loading conditions is shown in Figures 4, 5, 6, and 7.

| NAME | RUN | S | L | TIME | Initial Wt. | Final wt. | Wt. loss | FF | Ra | Micro Hard |
|---|---|---|---|---|---|---|---|---|---|---|
| FREEZER - 20 | 1 | 954 | 10 | 16.4 | 15.96 | 15.88 | 0.082 | 3.82 | 2.91 | 25.77 |
|  | 2 | 954 | 30 | 16.4 | 15.88 | 15.63 | 0.248 | 11.77 | 3.61 | 23.55 |
| AIR | 3 | 954 | 10 | 16.4 | 16.01 | 15.96 | 0.055 | 3.58 | 2.33 | 21.9 |
|  | 4 | 954 | 30 | 16.4 | 15.96 | 15.74 | 0.220 | 11.97 | 4.33 | 27.17 |
| WATER | 5 | 954 | 10 | 16.4 | 15.81 | 15.76 | 0.057 | 3.58 | 3.95 | 29.64 |
|  | 6 | 954 | 30 | 16.4 | 15.76 | 15.56 | 0.200 | 11.62 | 4.09 | 28.82 |
| ICE | 7 | 954 | 10 | 16.4 | 15.84 | 15.78 | 0.052 | 3.55 | 2.68 | 23.23 |
|  | 8 | 954 | 30 | 16.4 | 15.78 | 15.59 | 0.193 | 12.3 | 2.95 | 24.99 |
| FURNACE | 9 | 954 | 10 | 16.4 | 15.66 | 15.61 | 0.049 | 3.5 | 2.40 | 20.44 |
|  | 10 | 954 | 30 | 16.4 | 15.61 | 15.41 | 0.196 | 12.08 | 4.58 | 23.5 |
| OIL | 11 | 954 | 10 | 16.4 | 15.73 | 15.68 | 0.054 | 3.41 | 2.09 | 23.02 |
|  | 12 | 954 | 30 | 16.4 | 15.68 | 15.48 | 0.197 | 13.01 | 3.25 | 22.03 |
| SALT | 13 | 954 | 10 | 16.4 | 14.99 | 14.93 | 0.054 | 3.43 | 2.29 | 28.78 |
|  | 14 | 954 | 30 | 16.4 | 14.93 | 14.78 | 0.153 | 11.76 | 3.62 | 20.64 |

It was observed that at 10N and 30 N loading conditions maximum weight loss was observed for the specimen kept in the freezer and minimum weight loss for the specimen cooled within the furnace as shown in Figure 4. Maximum heat loss was due to the transition from ductile to brittle behavior and minimum weight loss was due to reliving stresses and making the material optimum hardness.

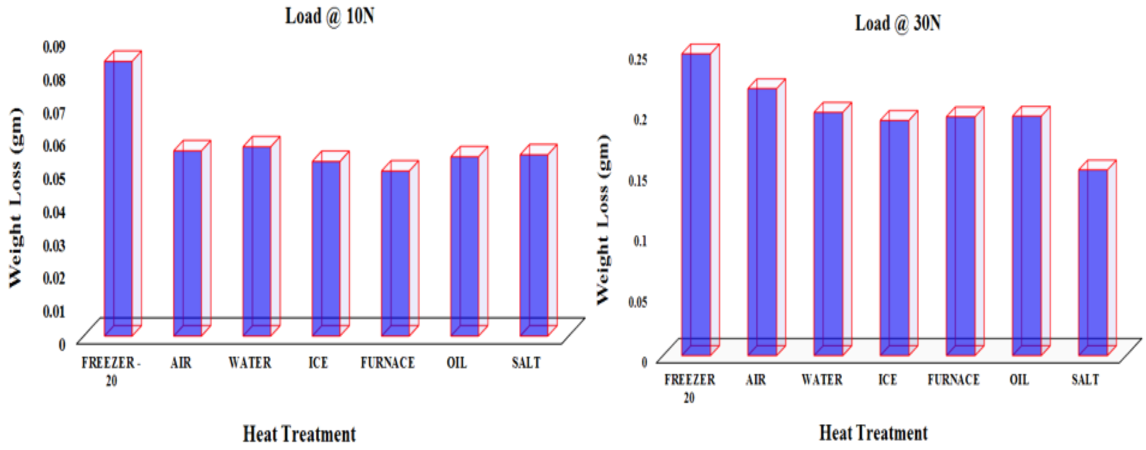

**Figure 4:** (a) Heat Treatment V/S Weight Loss (10 N) and (b): Heat Treatment vs.Weight Loss (30 N)

At 10N loading conditions, the frictional force was highest for the Ti cooled in the freezer and the least for the specimen cooled in water at the 30N loading process (Figure 5). The reason could be due to Ti grains became hard enough under rapid cooling leading to improvement in the hardness.

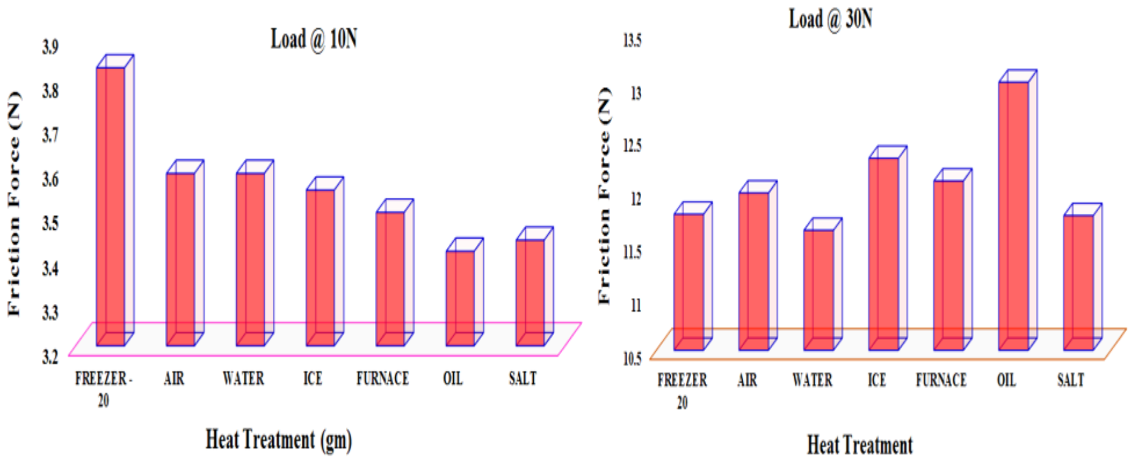

**Figure 5:** (a): Heat Treatment vs. Friction Force (10 N) and (b): Heat Treatment vs. Friction Force (30 N)

Ti Specimen quenched in cold water exhibited the highest microhardness under both loading conditions (10N and 30N), and furnace furnace-cooled samples showed the least microhardness. The hardness signifies the resistance of the metal/alloy to plastic deformation.

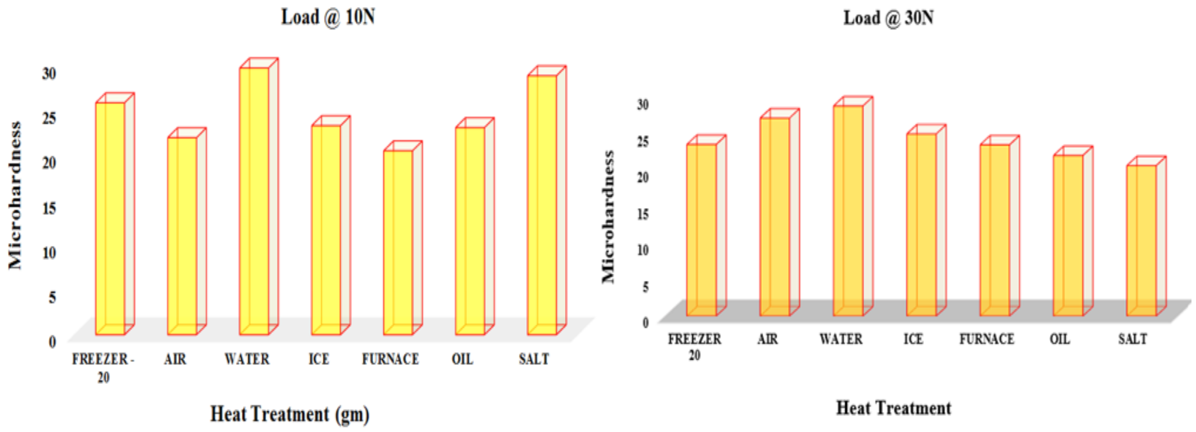

**Figure 6:** Heat Treatment vs. Microhardness at (a) 10 N and (b) at 30 N loading conditions

Improvements in the properties were attributed to sudden temperature differences and reduction in the sizes of Ti grains. The finer distribution of Ti grains leads to the improvement in microhardness. Moreover, due to rapid cooling/solidification, Ti grains became optimally hard enough leading to improvement in the microhardness. Thus, heat-treated Ti grade 2 quenched in normal water revealed a controlled and optimum cooling rate due to which alloy showed higher hardness.

The microstructures of heat-treated Ti specimens cooled in different cooling media are shown in Figures 7, 8, 9, 10, 11, 12, 13.

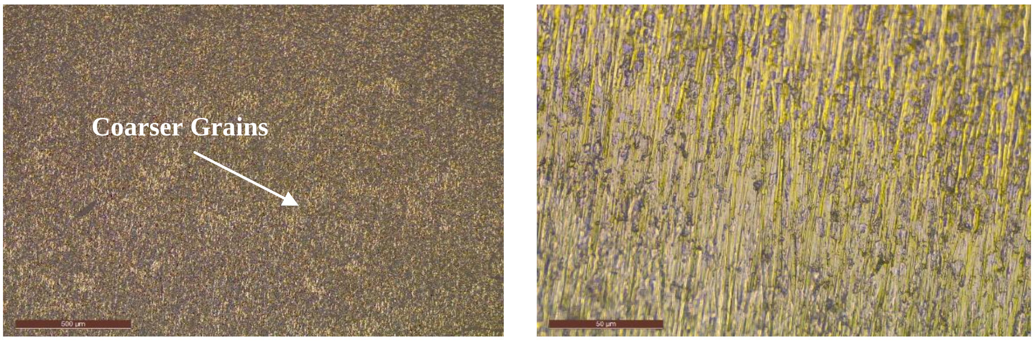

**Figure 7:** Microstructure images of the worn surfaces at 5x and 20x of specimen cooled in Air

The Ti grains cooled in air exhibited coarser grains (Figure 7), however, the specimen allowed to cool rapidly in the freezer showed small grains under stressed conditions (Figure 8) due to this freezer specimens transformed to brittle nature by exhibiting higher weight loss. Brittle behavior is due to a higher cooling rate.

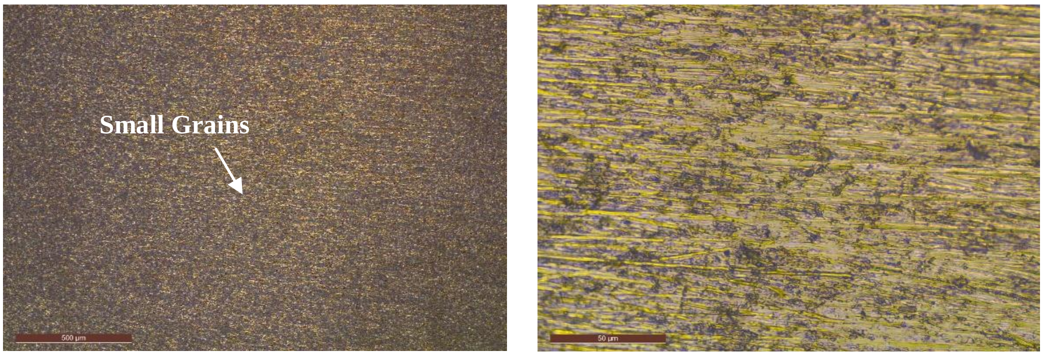

**Figure 8:** Microstructure images of the worn surface at 5x and 20x of the specimen kept in the freezer

Figure 9 shows the Ti relaxed grains. These grains are regarded as stress-relieved grains with improved mechanical properties, especially ductility with yield. Due to again higher cooling rate for the specimen quenched in ice, Ti showed intermediate stressed grains as shown in Figure 10.

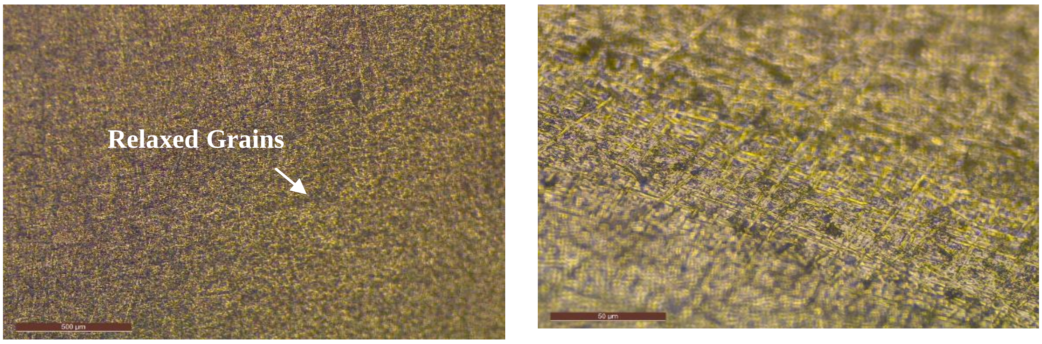

**Figure 9:** Microstructure images of the worn surface at 5x and 20x of specimen cooled in the furnace

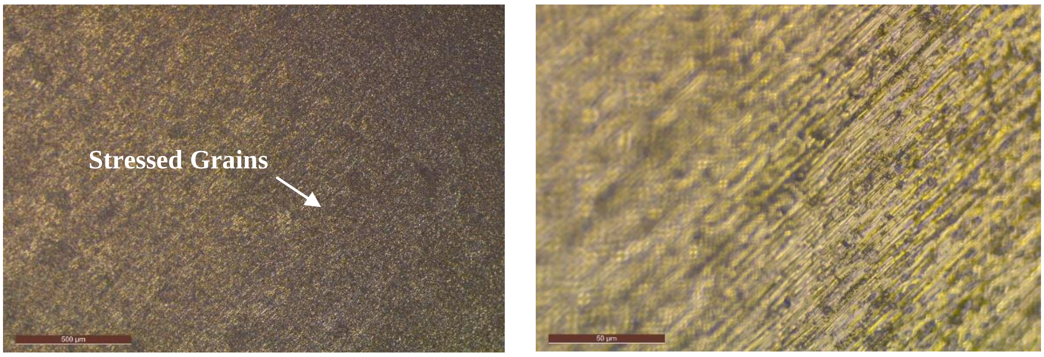

**Figure 10:** Microstructure images of the worn surface at 5x and 20x of specimen Quenched in Ice

Specimens cooled in oil, salt, and water are regarded as moderate cooling techniques to improve most of the mechanical properties. The microstructure of the specimen cooled in oil indicated nearly nodular (spherical) grains as shown in Figure 11, whereas the specimen cooled in a salt bath revealed uniformly elongated grains (Figure 12). The Ti specimen allowed to quench in water exhibited a moderate cooling rate due to which it showed equiaxed grains as shown in Figure 13.

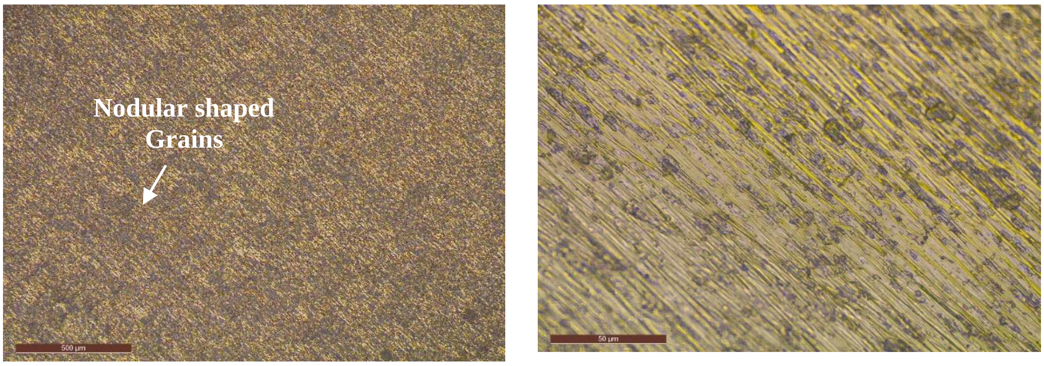

**Figure 11:** Microstructure images of the worn surface at 5x and 20x of specimen Quenched in Oil

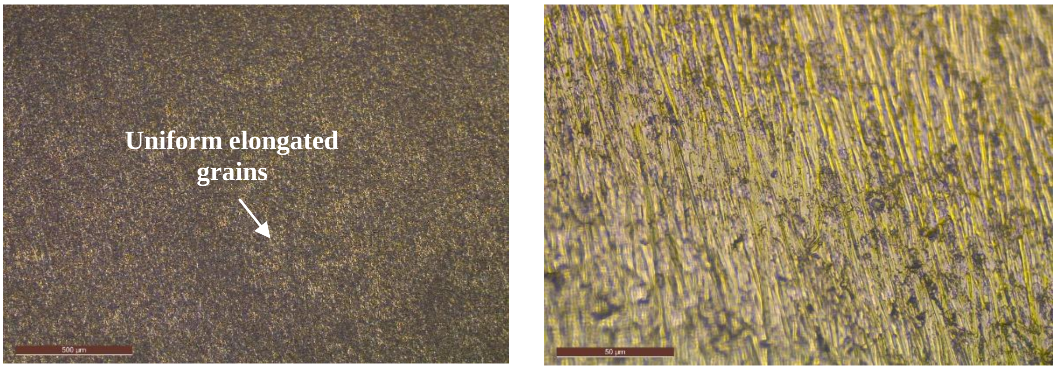

**Figure 12:** Microstructure images of worn surface at 5x and 20x of specimen Quenched in Salt

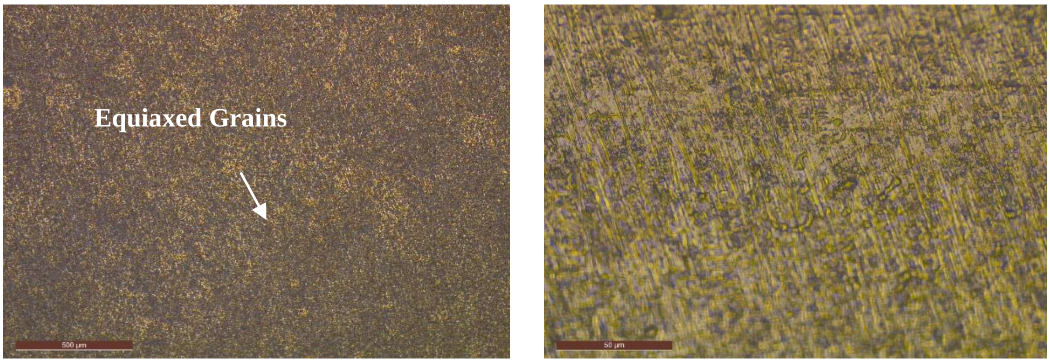

**Figure 13:** Microstructure images of the worn surface at 5x and 20x of specimen Quenched in Water

Among all the media, the equiaxed grain material exhibited the highest hardness or strength i.e. specimen cooled in water. Compared to the results of Jayaram and Satyanarayan [12] and Prabhu et al. [13], based on cooling media, it was presumed that the cooling rate decreased with cooling media in the order Freezer>ice-quenched >quenched in water>quenched in oil >quenched in salt bath>cooled in air>cooled in the furnace. Based on the results, it can be regarded as specimen quenched in water, oil and salt bath are moderate and good. Among all the water is an optimum method to improve the microhardness and tribological properties.

## IV. CONCLUSIONS

Based on the results and discussions the following conclusions are drawn:

- Specimen cooled in water exhibited intermediate (fair) wear and hardness properties compared to specimen cooled in other media. However, the frozen specimen in indicated less weight loss and higher frictional force.
- Specimen cooled furnace exhibited the least micro-hardness hardness of the Normalized specimen is greater than the Annealed specimen.

## V. ACKNOWLEDGMENT

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