Effect of Heat Treatment and It's Behaviour on Mechanical Properties of Pure Titanium

SATYANARAYAN
Dept. of Mechanical Engineering
Alva's Institute of Engineering and Technology
Shobhavana Campus, Mijar - 574 225 Moodbidri Mangalore, D.K District, Karnataka, India
satyan.nitk@gmail.com, satyaa.aiet@aiet.org.in

VEERABHADRAPPA ALGUR
Department of Mechanical Engineering,
RYM Engineering college, Ballari, India – 583104
veereshalgur@rymec.in

KUSAMMANAVAR BASAVARAJ
Department of Mechanical Engineering,
RYM Engineering college, Ballari, India □ 583104
veereshalgur@rymec.in
kusammanavarb@gmail.com

ABSTRACT

In present days due to the growing demand for Pure Titanium (Ti) with enhanced physical and chemical properties, many researchers are taking a keen interest regarding improvement in heat treatment processes to meet the present demands. The present study aims to investigate the effect of heat treatment on Wear and Micro – hardness (Vickers) properties of pure Titanium (Ti – Grade 2). The cylindrical shaped 10 mm × 30 mm Titanium was isothermally held in the tubular furnace (a device consists of a cylindrical cavity surrounded by heating coils that are embedded in a thermally insulating matrix.) 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 freezer for 20 days (-20). To know the effect of hardness property of the specimens cooled under different media, specimens were subjected to Vickers Hardness and Wear Test. The results of each specimen were compared and the best cooling medium was determined in terms hardness and wear values. Specimen cooled in water exhibited intermediate (fair) wear and hardness property in compared specimen cooled in other media. However, freezed specimen in indicated less weight loss and higher frictional force..

Keywords—***Pure Titanium, Heat treatment, Cooling Media, Wear, Hardness***

I. INTRODUCTION

Titanium has many attributes that are useful in today's modern society. Titanium is an element of atomic number 22. Pure titanium metal has a melting point of 1675 °C and an atomic weight of 47.9. The density of pure titanium metal is 4.5 g/cm³. Furthermore, pure titanium metal and its alloy counterparts are essentially non-magnetic and offer good heat transfer capability. It occurs in two allotropic forms: Ti α and Ti β. Variation α is crystallized at room temperature in hexagonal configuration and at a temperature 882.5ºC is converted to a high temperature Ti β crystalizing in the regular system. Ti is characterized by a very low thermal conductivity of 11.4 W m-1 K-1, which is 3-4 times smaller than for iron and up to 16 times lower than for copper. In soft state. Ti has a tensile strength raw material 460- 590 MPa. Titanium has a high ductility and excellent corrosion resistance to sea water, chlorides, organic acids, and air atmosphere; no oxidation at 200ºC and has a high creep resistance at high temperature. Pure, unalloyed titanium is used mainly in the 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 watch making.

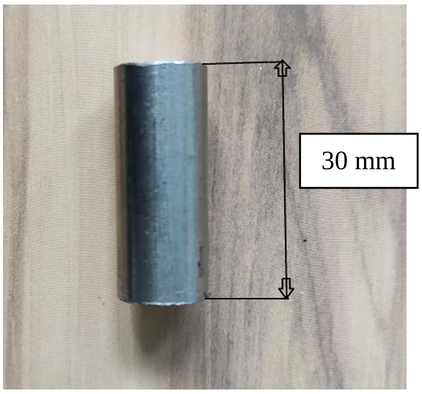
Titanium is a metal showing a high strength-weight ratio which is maintained at elevated temperatures and it has exceptional corrosion resistance. These characteristics were the main cause of the rapid growth of the titanium industry over the last 40 years. The major application of the material in the aerospace industry, both in air frames and engine components. Non aerospace applications take advantage mainly of their excellent strength properties. It is a relatively lightweight, corrosion-resistant structural material that can be strengthened dramatically through alloying and, in some cases, by heat treatment. Titanium metals have very high tensile strength and toughness (even at extreme temperatures). They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. It is planned to make this project because no one has ever tried to use pure titanium and done heat treating it i.e., using a rod specimen.

The heat treating of titanium sheet has been carried out earlier but heat treating a pure titanium rod is the first attempt done by our project team. Titanium is seen as a good material for application in many fields due to its compatibility with different environments. However, it remains unclear whether what happens when this material is exposed to certain high temperatures for longer periods of time. The primary objective of this study was to investigate the effect of heat on a 3cmlength and diameter of 1cm commercially pure titanium grade 2 at a constant temperature of 920°C at different heating times. Then specimens are heated 30 min in each specimen. Further Pure Titanium was cooled in Air, Furnace. In order to Know the Transition, pure Titanium was kept in -20ºC in Freezer for 20 days. Titanium specimen quenched in oil, water, salt bath and Ice.

Tribological (wear) study was carried out on all heat-treated specimens at 10N and 30NLoads. The wear Behavior of Ti was carried for 16.4 minutes. and scanning electrode microscope (SEM). Microstructure and Tensile strength were performed. All the results were analyzed and compared with the parent sample. It was observed that the heating period influenced microstructural arrangement of the material and microstructural changes affected negatively the ultimate tensile strength while percentage elongation was improved. Titanium alloys are heat treated to achieve Stress relieving, to reduce residual stresses developed during fabrication. Annealing, to achieve an optimum combination of ductility, machinability, dimensional stability and structural stability. Solution treating and aging to increase strength. In the present investigation, effect of heat treatment and it's behaviour on mechanical properties of pure titanium is assessed.

II. EXPERIMENTAL METHODOLOGY

The pure titanium round bar specimen was procured from OZAIR trade link Ahmadabad, Gujarat of circular cross section rod of 12mm diameter. As received titanium rod specimen was in dimension of 10mm diameter and 1.5 meters in length. Later, it was cut with the help of wire cutting machine for the required dimensions of length 30 mm and diameter 10mm. Now the specimen prepared is ready for the heat treatment process.



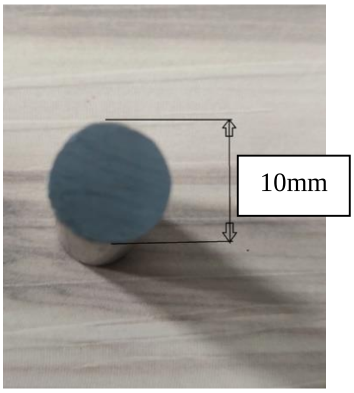


Fig 1: Specimen

The prepared specimen (L 30 mm and ϕ 10mm) is heated in the specially designed Tubular furnace (open at both the ends) with sensor-based temperature controller maintained required isothermal temperature to facilitate for rapid quenching. In this apparatus the specimen to be heat treated is hooked from top of the furnace and it is led into the cylindrical coiled furnace. The temperature attained value is indicated in the digital reading equipment connected to the furnace. The specimens are 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, annealing (furnace cooling) and normalizing.

Fig 3: Rapid Quenching Experimental Setup (Tubular Furnace)

Ice Quenching: The first set of samples is heated at 920°C respectively for 30mins followed by rapid cooling (ice quenching), this treatment was chosen in order to follow the influence of the titanium structure β on the corrosion resistance.
Water Quenching: The second set of samples is heat treated at 920°C respectively for half an hour followed by rapid cooling in water (water quenching).

Oil Quenching: The third set of samples is heat treated at 920°C respectively for half an hour followed by rapid cooling (oil quenching). Oil used was Servo 4T 20w40 engine oil. Quenching in engine oil is done to check what might the temperature, viscosity and other chemical property of the oil does to the specimen. It also controls distortion and reduces the risk of cracking.
Annealing: The fourth set of samples are treated at 920°C respectively for half an hour followed by a long cooling in the furnace itself (annealing). This process is done to increase the ductility of the specimen.
Normalizing: The fifth set of samples are treated at 920°C respectively for half an hour and then cooled down to room temperature in air (normalizing). This process is done in order to relieve stresses in the specimen.
Freezing : The fifth set of samples are treated at 920°C respectively for half an hour and then cooled down under -20℃ freezer.
Salt Bath: The fifth set of samples are treated at 920°C respectively for half an hour and then a hardening technique that ensures the material is highly wear resistant.

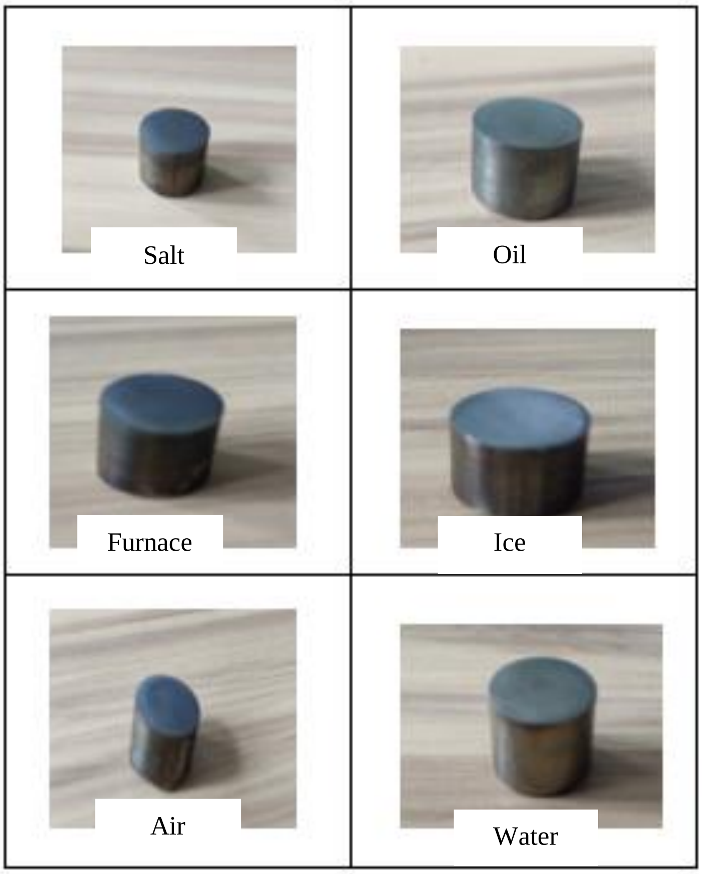


Fig 4: Specimens after heat treatment for 30 min at 920℃

The Micro-hardness test was conducted for all specimens once the heat treatment job is done. The hardness was conducted using HVS 1000B Model (with load-range from 10gm up to 1000gm) with camera and image analysis software. The determination of the Micro-hardness of a material involves the application of a minor load followed by major load. The minor load establishes the zero position. The major load is applied, then removed while still maintaining the minor load. The depth of penetration from zero datum is measured from a dial, on which a harder material gives a higher number. That is, the penetration depth and hardness are inversely proportional. The chief advantage of hardness is its ability to display hardness values directly, thus obviating tedious calculation involved in other harness measurement techniques. For correct research project for hardness testing, diamond indenter at minor load of 10Kgf and major Load of 100Kgf was used for dwell period of time 16.4 seconds.

Fig 5: Microhardness Tester

Commercially pure Titanium is represented by four distinct, specially grade I, grade II, grade III and grade IV. Pure Titanium ranges from grade I, which has highest corrosion, resistance, format ability and lowest strength to grade IV, which offer the highest strength and moderate formability. In the project pure titanium of grade II [carbon 0.08, max, Nitrogen 0.03max, Iron 0.30 max] was used. Initially pure Titanium metal was in the form of long rod. Later it was made into 7 pieces of 3 cm length and 1 cm diameter. Each pure Titanium metal piece was heated in a furnace and kept in a different type of medium for 30 minutes, heated Iso−thermally up to 920℃ temperatures in a furnace.

To investigate the effect of heat treatment on micro-hardness and tribological property of pure Ti, metal was quenched in water, salt bath, Oil and Ice after heating from 920℃ (30 mins). Further Pure Titanium was cooled in Air and Furnace. In order to know the Transition, pure Titanium was kept in -20ºC in a Freezer for 20 days. After heat–treatment specimens were subjected to wear testing (Pin on Disc type) at RYMEC Bellary for tribological characterization technique to estimate the tribological properties (co-efficient of friction and wear mechanism).

Scanning Electron Microscopy is a test process that scans and electron with an electron beam to produce a magnified image for analysis. This method is also known as SEM analysis and SEM microscopy and is used very effectively in micro analysis and failure analysis of solid inorganic materials.

RESULTS AND DISCUSSION

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

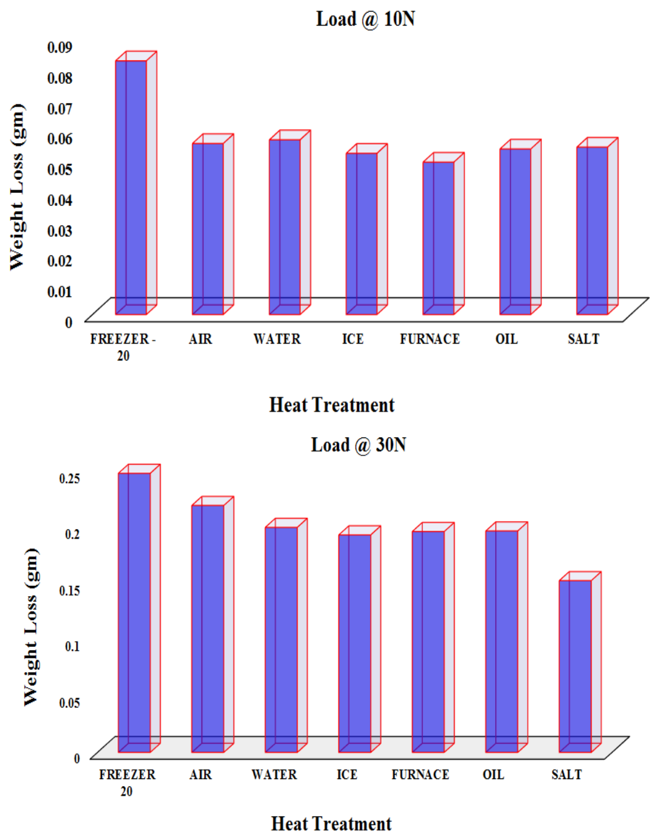


Fig 6(a): Heat Treatment V/S Weight Loss (10 N) and Fig 6(b): Heat Treatment V/S Weight Loss (30 N)

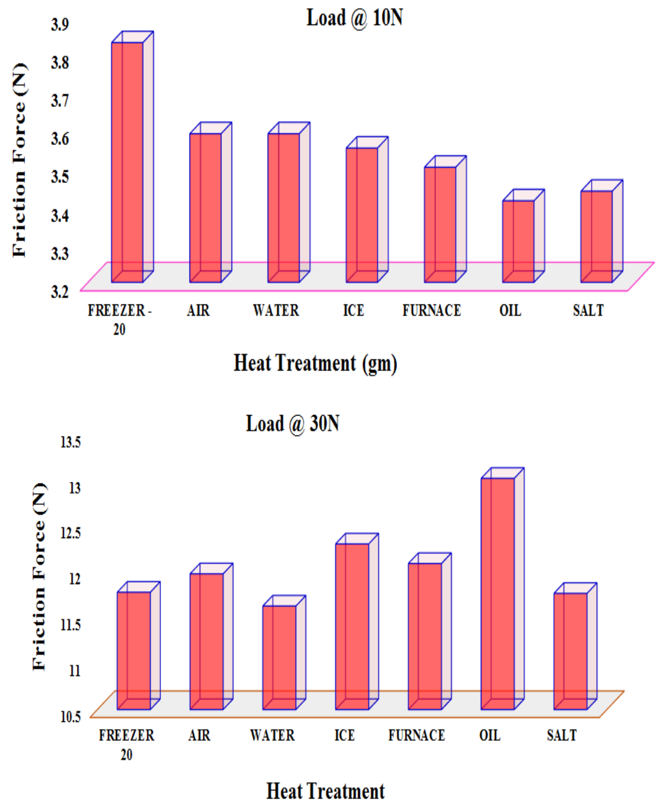
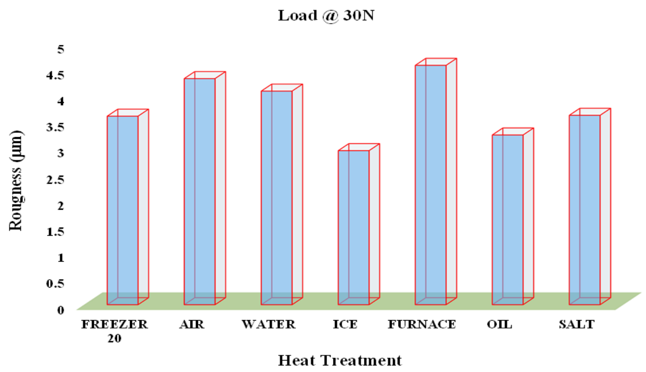


Fig 7(a): Heat Treatment V/S Friction Force (10 N) and Fig 7(b): Heat Treatment V/S Friction Force (30 N)



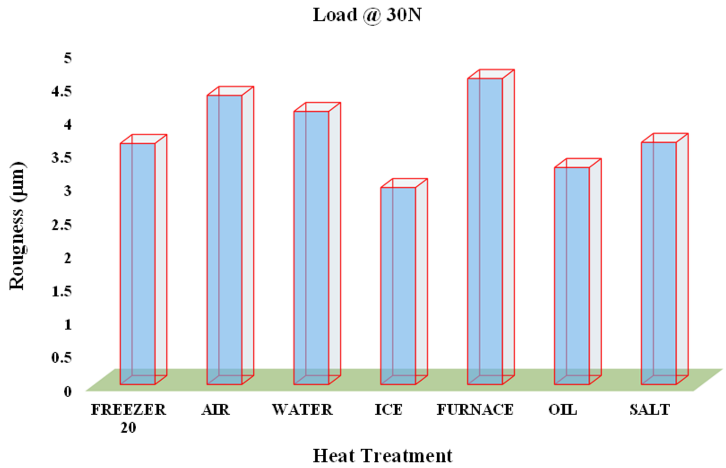
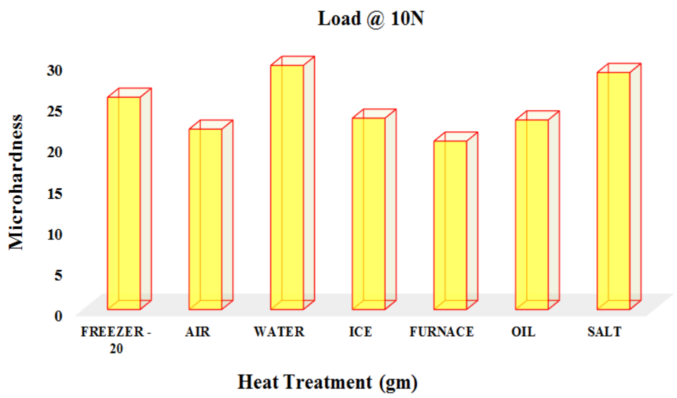


Fig 8(a): Heat Treatment V/S Roughness (30 N) and Fig 8(b): Heat Treatment V/S Roughness (10 N)



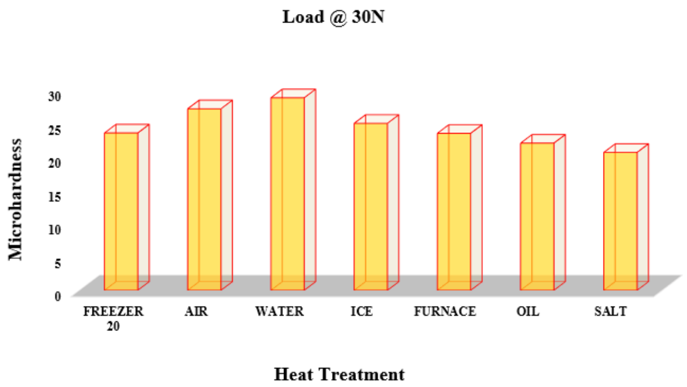


Fig 9(a): Heat Treatment V/S Microhardness (10 N) and Fig 9(b): Heat Treatment V/S Microhardness (30 N)

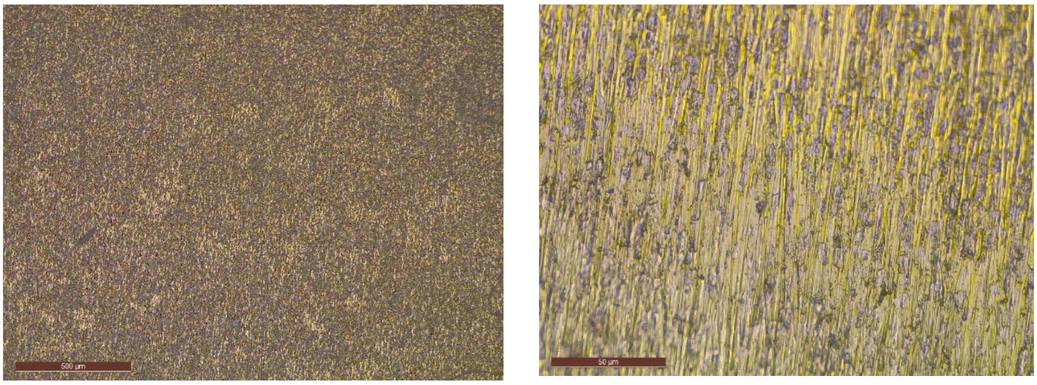


Fig: Microstructure images of worn surface at 5x and 20x of specimen cooled in Air

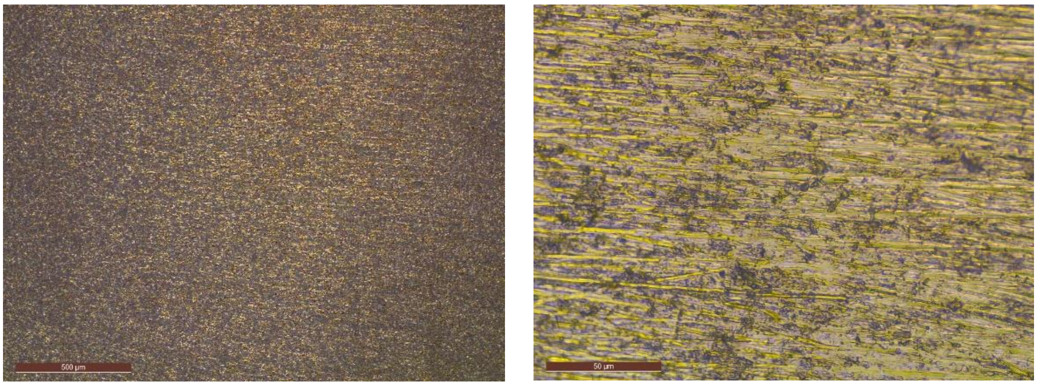


Fig: Microstructure images of worn surface at 5x and 20x of specimen cooled in freezer in -20℃

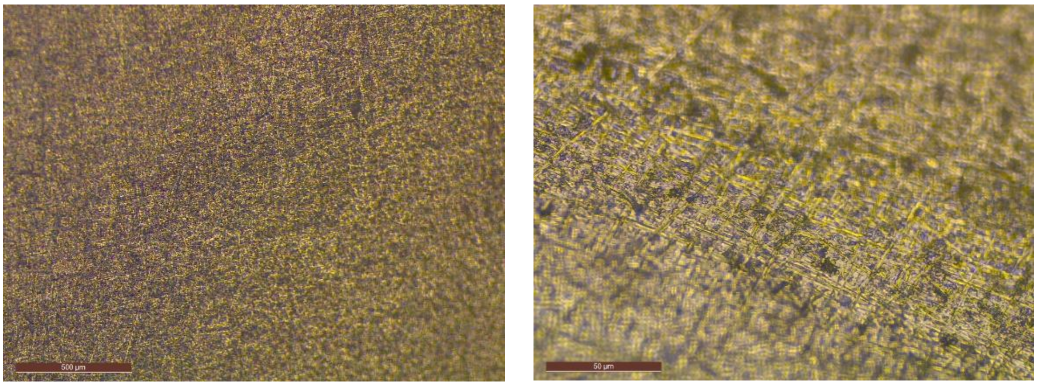


Fig: Microstructure images of worn surface at 5x and 20x of specimen cooled in furnace

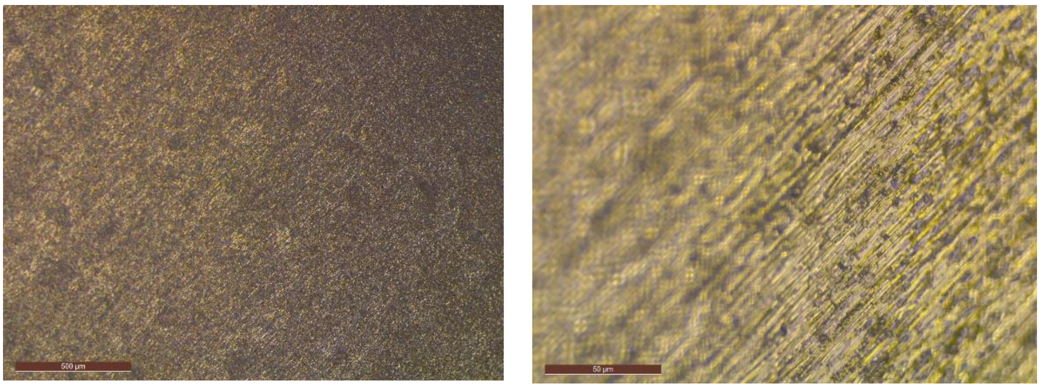


Fig: Microstructure images of worn surface at 5x and 20x of specimen Quenched in Ice

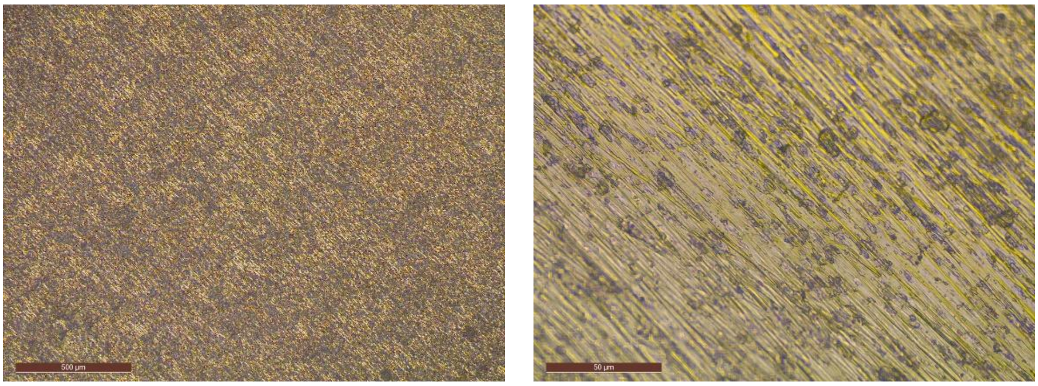


Fig: Microstructure images of worn surface at 5x and 20x of specimen Quenched in Oil

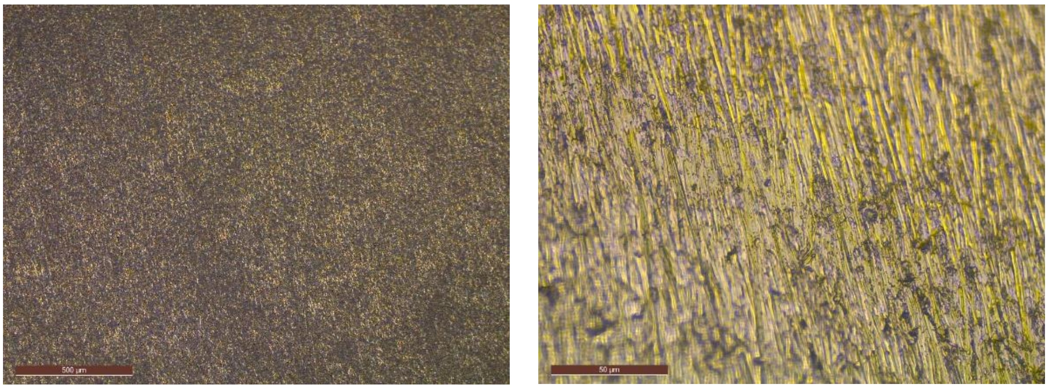


Fig: Microstructure images of worn surface at 5x and 20x of specimen Quenched in Salt

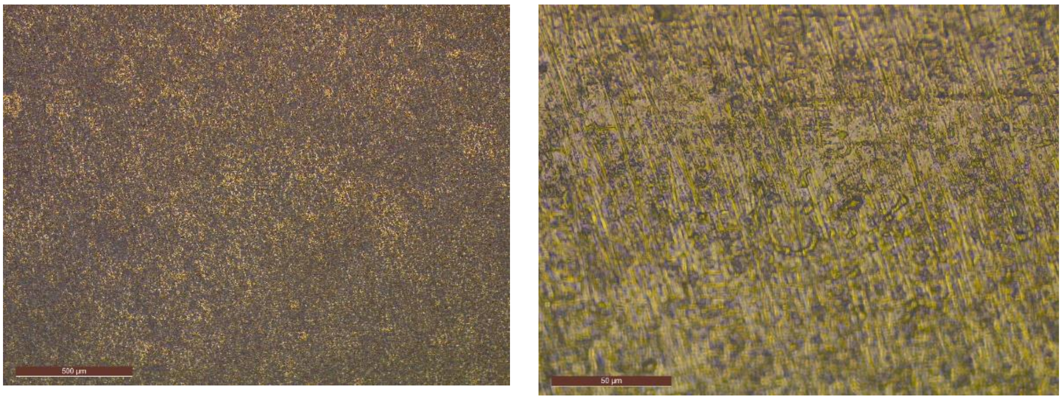


Fig: Microstructure images of worn surface at 5x and 20x of specimen Quenched in Water

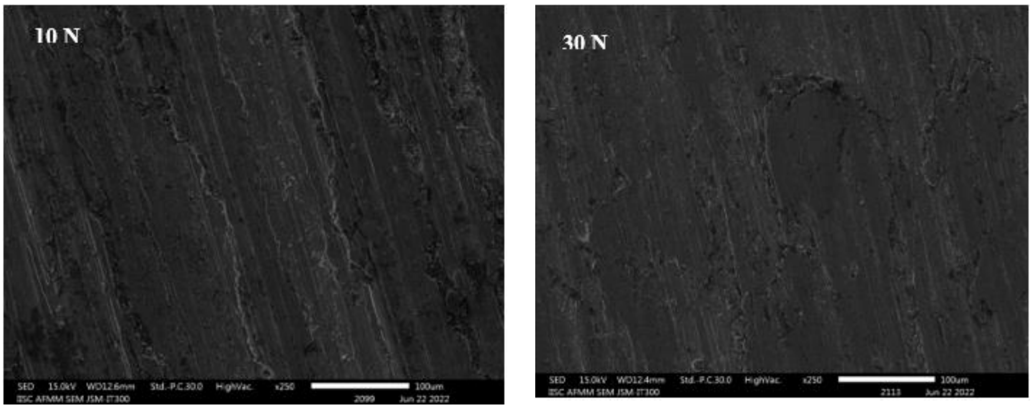


Fig: Isothermal heated (30mins) Ti grade 2 Specimen cooled in Air from 920°C

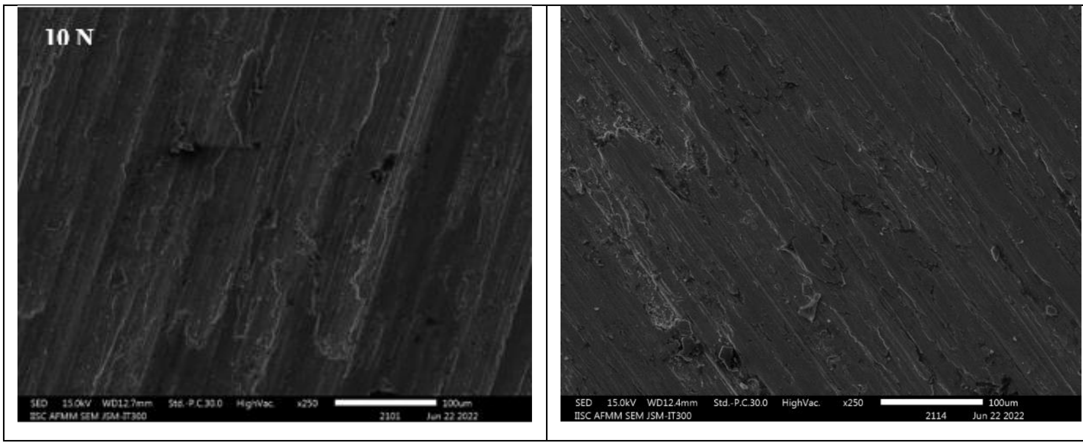


Fig: Isothermal heated (30mins) Ti Specimen quenched in Salt Bath (Ankur Salt) from 920°C

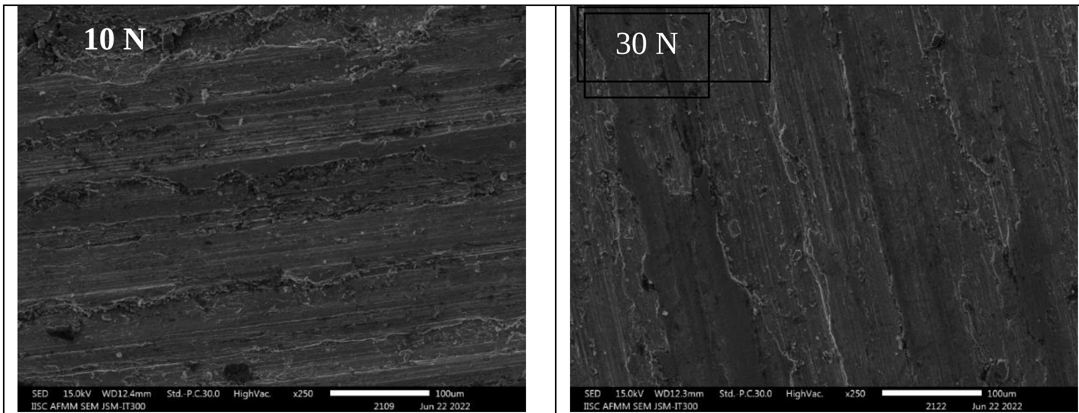


Fig: Isothermal heated (30mins) Ti Specimen quenched in Water from 920°C

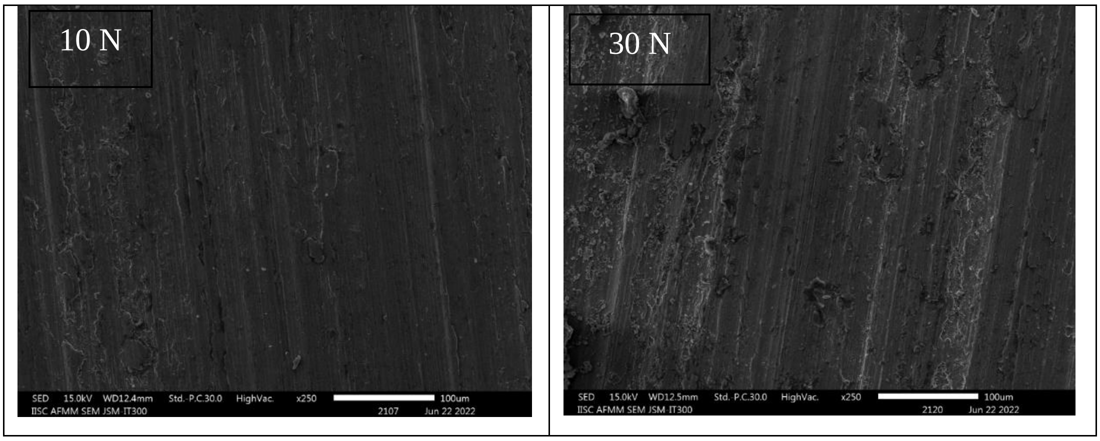


Fig:Isothermal heated (30mins) Ti Specimen freezed in -20C for 20 days from 920°C

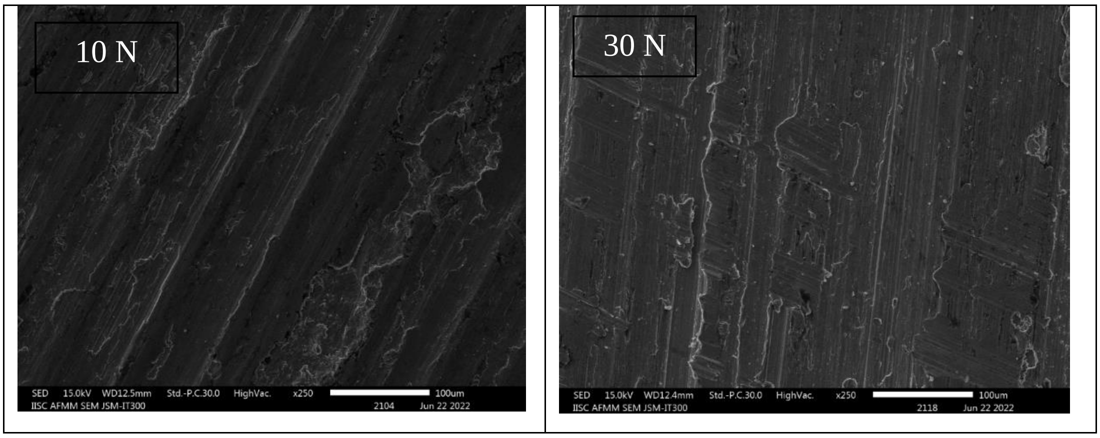


Fig: Isothermal heated (30mins) Pure Ti grade 2 Specimen Quenched in Ice from 920°C

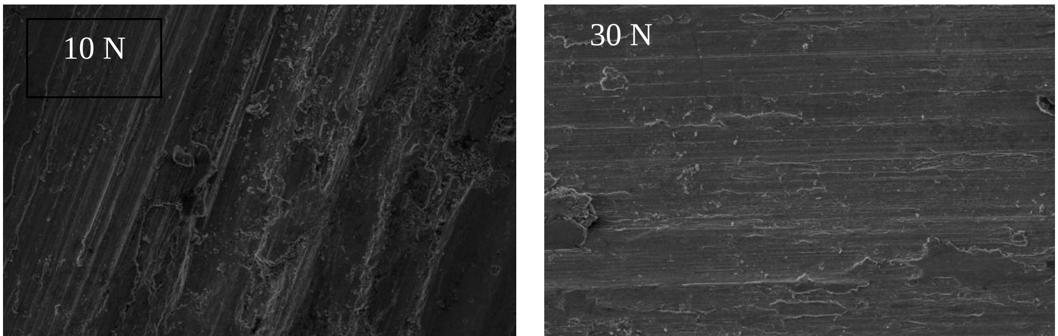


Fig: Isothermal heated (30mins) Pure Ti grade 2 Specimen Quenched in oil (2 stroke Servo Engine oil Semi Synthetic) from 920°C

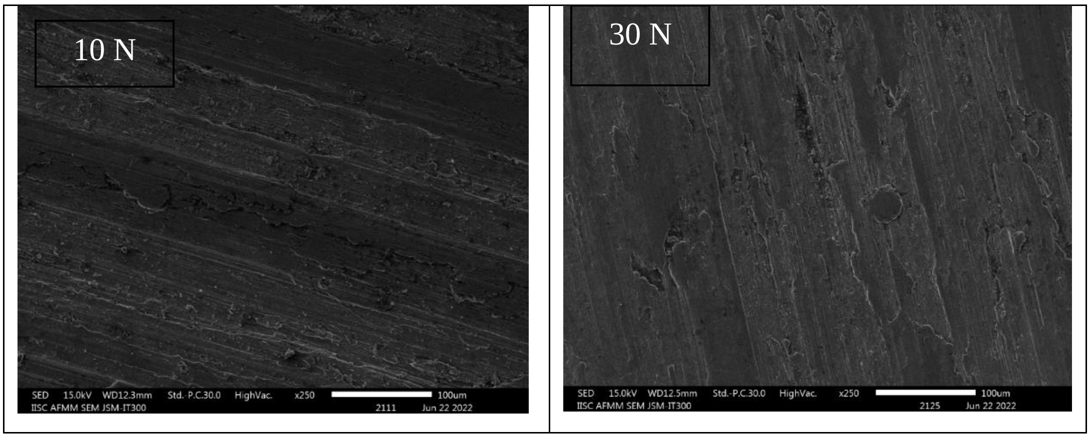


Fig: Isothermal heated (30mins) Pure Ti grade 2 Specimen cooled in the Furnace from 920°C

CONCLUSIONS

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

REFERENCES

1. Du, Zhaoxin, et al. "Effect of heat treatment on microstructure and mechanical properties of a new β high strength titanium alloy." Materials & Design 55 (2014): 183-190. https://doi.org/10.1016/j.matdes.2013.09.070
2. Khorasani, AmirMahyar, et al. "On the role of different annealing heat treatments on mechanical properties and microstructure of selective laser melted and conventional wrought Ti-6Al-4V." Rapid Prototyping Journal 23.2 (2017): 295-304. https://doi.org/10.1108/RPJ-02-2016-0022
3. Korkmaz, Mehmet Erdi, et al. "A short review on thermal treatments of titanium &nickel based alloys processed by selective laser melting." Journal of Materials Research and Technology (2021). https://doi.org/10.1016/j.jmrt.2021.12.061
4. Zhou, Hui-min, et al. "Mechanical properties of controlled memory and superelastic nickel-titanium wires used in the manufacture of rotary endodontic instruments." Journal of endodontics 38.11 (2012): 1535-1540. https://doi.org/10.1016/j.joen.2012.07.006
5. Schwab, Holger, et al. "Processing of Ti-5553 with improved mechanical properties via an in-situ heat treatment combining selective laser melting and substrate plate heating." Materials & Design 130 (2017): 83-89. https://doi.org/10.1016/j.matdes.2017.05.010
6. Zhang, Xiaobo, et al. "Effects of extrusion and heat treatment on the mechanical properties and biocorrosion behaviors of a Mg–Nd–Zn–Zr alloy." Journal of the mechanical behavior of biomedical materials 7 (2012): 77-86. https://doi.org/10.1016/j.jmbbm.2011.05.026

ACKNOWLEDGMENT

Authors thank Mr. Sagar Loni, Mr. K Mahanthesh, Mr. Kushal Patil, Mr Arun Kumar P G for conducting experiments and generation data