

# EFFECT OF SHALLOW AND DEEP CRYOGENIC TREATMENT ON TRIBOLOGICAL PROPERTIES OF MONEL K-500

K. N. PANDEY<sup>1</sup>, Ketan GUPTA<sup>2</sup>

<sup>1</sup> Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India;  
Email: [knpandey@mnnit.ac.in](mailto:knpandey@mnnit.ac.in); [ketangupta19@gmail.com](mailto:ketangupta19@gmail.com)

## 1. Introduction

Cryogenic treatment is the process of treating work pieces to cryogenic temperatures in order to remove residual stresses and improve wear resistance on steels. It is considered as a process to reduce the retained austenite content and improve the performance of materials. Monel K-500 [1] is a nickel-copper alloy, precipitation hardenable through additions of aluminum and titanium. These alloys are well known for their corrosion resistance in a wide range of Environments such as sea water, acids, alkalis and sour oil. They are extensively used for components such as condenser tubing, marine fittings, pump shafts and impeller, and oil well drill collars [2-4]. The SCT and DCT are extensively studied for number of material and found as a novel technique for materials property improvement [5-9]. In the present work, the effect of shallow and deep cryogenic treatment (SCT and DCT) on the mechanical and tribological properties of Monel K-500 is studied. For comparison, conventionally heat treated samples were also tested.

## 2. Experimentation

### 2.1 Material:

The nominal composition of the alloy is given Table 1.

**Table 1.** Composition of Monel K-500 (wt %).

Ni	Cu	C	Mn	Fe	S	Si	Al	Ti
63	27-33	0.25	1.5	2	0.01	0.5	2.30-3.15	0.35-0.85

### 2.2 Heat treatments:

The austenizing temperature of Monel K500 is 875°C [15]. Therefore for annealing, the samples were heated from 30°C to 875°C in 3 hours and maintained at 875°C for 1 hour. After that the furnace was switched-off and samples were allowed to cool within the furnace itself.

While performing the quenching operation, the samples of Monel K 500 were heated at a rate of 5°C /min from 30°C (room temperature) to 875°C, at this temperature it is kept for an hour and then quenched in water to 30°C. During shallow cryogenic heat treatment (SCT) the samples were cooled from 30°C to -80°C by putting in the contact of vapour of liquid nitrogen. They were kept at -80°C for 5 hours and brought back to the room temperature of 30°C.

During deep cryogenic heat treatment the samples were dipped in liquid nitrogen to bring temperature from 30°C to -196°C. They were kept at -196°C temperature for 24 hour and then placed outside to regain temperature room temperature of 30°C. The Time Temperature plot for the Deep Cryogenic Treatment (DCT) of Monel K-500 is shown in Fig 2.

### 2.3 Tests

Vicker micro hardness measurement was performed using Radical Micro Tester-201 by means of Vickers indenter with of 1N dwelled for 15s. The indenter used in Vicker hardness test is a diamond type with square based pyramid base which has sides inclined to each other at 136°.

Wear Tests were performed on DUCOM Wear and Friction co-efficient Monitor, TR-20-M100 (Pin-On-Disc wear testing machine) as per the ASTM wear testing standard G99. For this 90 cylindrical specimens of 10mm diameter and 40mm length were prepared. The ends of specimen were made flat for proper contact during pin-on-disc wear test. The test is done by rotating a computer- face test disk against a stationary test specimen pin.

Tensile Test specimens of different heat treated including SCT and DCT material were prepared as per ASTM E8M-16a standard. A 25kN servo hydraulic test machine of BISS was used to conduct tension tests.



Fig. 1. Tension test specimen.

### XRD Analysis

X-ray diffraction was performed in order to identify different phases in the material. XRD was carried out on a Rigaku 2500VB2p/PC diffractometer with Cu K $\alpha$  radiation. 5 samples were prepared of size 10mm in diameter and 2mm in length.

### 3. Results and Conclusions

It was observed that the application of a deep cryogenic treatment to Monel K-500 steel increases hardness and decreases structural defects, providing a dispersed network of fine carbides after the subsequent tempering stages. Tempering improved the strength of the material significantly.

In hardness test, it was found that deep cryogenic treated samples increased significantly (up to 10.51%) whereas in quenching and shallow cryogenic treated samples it increased nominally (2.77% and 3.88% respectively).

Ultimate tensile strength of DCT sample was obtained as 744.047 MPa whereas for SCT sample it was 671.897 MPa. Stress Strain curve for Untreated, Annealed, CHT and SCT samples is more or less similar. Maximum tensile strength was observed maximum for DCT samples. Strain before fracture is least in case of DCT Samples as compared to other Heat treatments (Table 2). Maximum tensile strength of DCT samples is attributed to the formation of higher volume fraction of martensite and due to precipitation of carbides due to cryogenic treatment.

Wear tests were conducted on pin-on-disc friction and wear test set-up as per L<sub>9</sub> orthogonal array of Taguchi design with load, wear track diameter and disc rotation as control factors. Three levels of these control factors were applied. For SCT, disc rotation was most significant parameter followed by wear track diameter and load. For DCT samples, disc rotation was most significant parameter followed by load and wear track diameter. In the initial stage of sliding weight loss was rapid and continuous with increase in sliding time. This indicated a completely steady-state behaviour. Sliding for long time and sliding over long distances causes hardening of the surface layer compounds of the waste debris and decreases the wear rate. Wear rate was minimum for DCT and maximum for annealed samples.

Table 2. Comparison of Ultimate Tensile Strength and strain at fracture point

S.No.	Sample Name	Ultimate Tensile Strength (MPa)	Fracture Strain (mm/mm)
1	Untreated	631.478	0.2622
2	Annealed	604.391	0.2769
3	CHT/Quenched	617.909	0.2747
4	SCT	671.897	0.27477
5	DCT	744.047	0.0779

The X-ray diffraction patterns characterized martensitic peaks, but there was no evidence of peaks corresponding to austenite. Therefore, it can be inferred that the volume fraction of austenite is below the detection threshold of the equipment. The microstrain in annealed, SCT and DCT samples were 0.201831, 0.187860 and 0.260543 respectively. Increase in microstrain increased the strength.

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