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Strengthening of Forged Inconel Superalloy by Age Hardening Heat Treatment

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Abstract— **Inconel alloys are nickel based super alloys. They are oxidation and corrosion resistant materials. It is well suited for the service in extreme environments subjected to high pressure and kinetic energy. When heated, Inconel alloys form a thick and stable passivating oxide layer protecting the surface from further attack.**

Inconel 718 is a widely used age-hardenable nickel based super alloy for high temperature applications. It is used for the fabrication of gas bottle to store high pressure oxygen for space missions. The actual production of gas bottle is done by joining two hemispherical domes by electron beam welding. The hemispherical domes are made by closed die hammer forging.

An attempt has been made to study the mechanical properties of the dome such as tensile strength, hardness and impact strength after age hardening heat treatment. Also the effect of hammer blows on the strength of the dome is evaluated.

Microstructure analysis reveals that fine grains due to ageing is responsible for improved strength and hardness. In forging , 20 blows of hammer provides optimum tensile strength, hardness and impact strength.

I. INTRODUCTION

Inconel 718 is a high strength, corrosion-resistant, Nickel-based super alloy. The major elements that constitute in the alloy are Nickel, Iron, Chromium, Niobium and Molybdenum. The Inconel 718 alloy can be fabricated into complex parts. Its welding characteristics, especially its resistance to postweld cracking are outstanding. Inconel 718 alloy retains strength over a range of -253^{0}C to 650^{0}C [1]. The high temperature strength of the Inconel 718 is obtained by precipitation hardening [2].

To take advantage of precipitation hardening reaction [3, 4], it is necessary first to produce a solid solution. This is accomplished by solution heat treating. Its objective is to take into solid solution having the maximum practical amount of soluble hardening elements in the alloy. Solution heat treatment involves heating of the alloy at specified temperature below solidus (980^{0}C) followed by soaking the alloy for one hour to achieves homogeneous solid solution. Subsequently precipitation hardening by air quenching and age hardening have been carried out.

In wrought condition, Inconel 718 alloy consist of γ', γ'', δ in the primary γ matrix [5]. The degree of strengthening depends on the precipitation of γ' and γ'' in the γ matrix. Inconel 718 is strengthened by γ'' (Ni_3Nb). The γ'' forms at 720^{0}C [6]. In γ'' phase , Ni and Nb combines in the presence of Fe as catalyst to form the body centered tetragonal (BCT) Ni_3Nb which is consistent with the γ matrix. Thus γ'' is precipitated during the first stage of artificial ageing [7] at 720^{0}C. Once the γ'' phase is precipitated, the γ' can form in the areas between γ'' particles since the lower niobium content favors γ' precipitation. The alloy also contains Ti and Al which leads to the formation of γ ', Ni_3 (Al,Ti) phase which is ordered FCC. The precipitation of γ' occurs at about 620^{0}C. Along with these two phases γ' and γ'', during extended service exposure at higher temperature range up to 650^{0}C, there is a possibility of stable orthorhombic delta δ phase formation. The δ phase formation softens the material and thereby reduces the strength of the material [8].

II.PROCESS DETAILS

A. Selection of Raw Material

For the experimental investigation, the billets of Inconel 718 with size of Ø 240mm × 185 mm length was taken as the raw material. The billet was cut by using a band saw cutting machine. After cutting, billet was moved to forging section.

B. Forging Operation

The forging dies were preheated to a temperature of 400^{0}C. This was to reduce the heat transfer from the hot billet to the cold die. The dies used are shown schematically in figure 1.

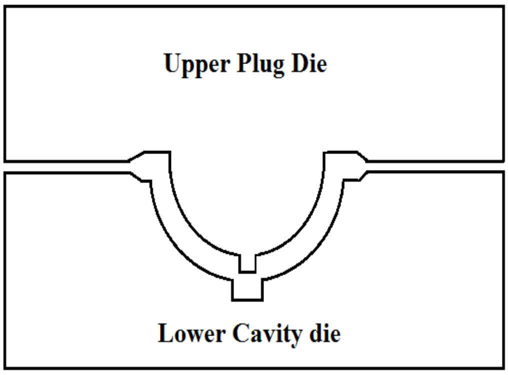

Figure 1.Dies used forging operation

The billets were heated to a temperature of 1050^{0}C and soaked for 3 hours. The heated billet was loaded onto a 16 tonne hammer forging machine. Closed die forging was carried out. The domes were obtained at the end of the forging process as shown in the figure 2.

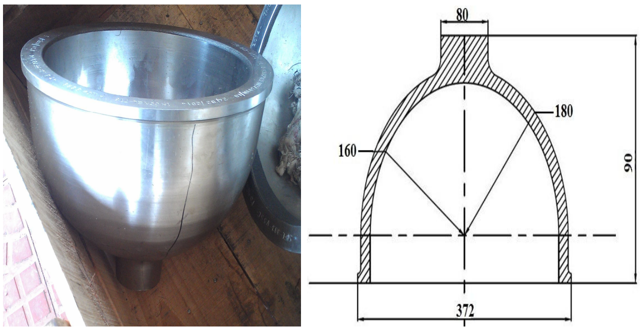

Figure 2. Forged dome

C. Heat Treatment

The composition in percentage of Inconel 718 alloy used for the investigation is given below :

Nickel 52.5% ; Iron 19% ; Chromium 18.3% ; Niobium 5.45%; Molybdenum 2.95% ; Titanium 1.03% ; Aluminium 0.45%.

To understand the phase transformation in Inconel 718 alloy during heat treatment, Ni-Nb equilibrium diagram is given in figure 3.

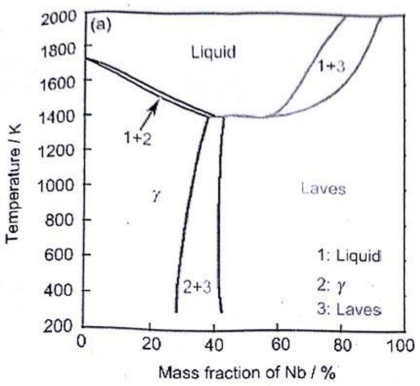

Figure 3. Ni-Nb phase diagram

The forged Inconel 718 dome was loaded into the pit furnace for solution heat treatment. The dome was heated to 980^{0}C and set to soak for 1 hour. Afterwards, the dome was cooled by air blower.

The dome after air cooling was artificially age hardened. The dome was loaded into a pit furnace. The dome was heated to 720^{0}C and set soak for 8 hours. Then it was furnace cooled to 620 ^{0}C and set to soak for 8 hours. Finally it was air cooled.

The whole heat treatment can be understood by the Time-Temperature curve plotted in the figure 4.

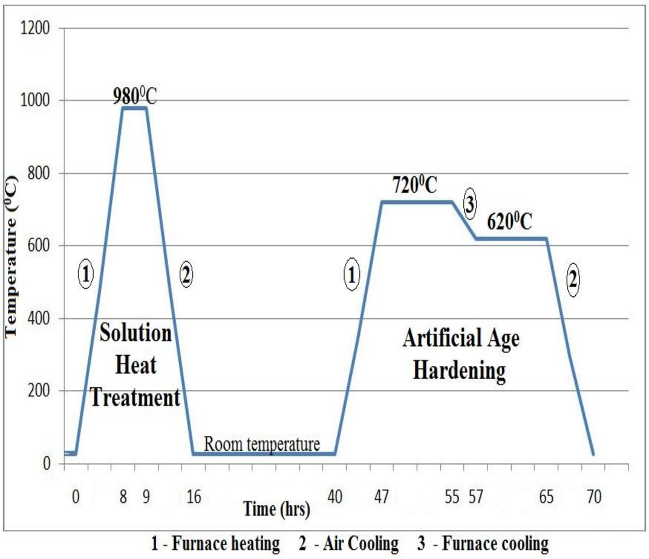

Figure 4. Time-Temperature curve for heat treatment

D. Testing

After age hardening heat treatment, test samples as per ASTM standards were prepared by cutting specimens from the dome and subjected these for various tests as shown in figure 5.

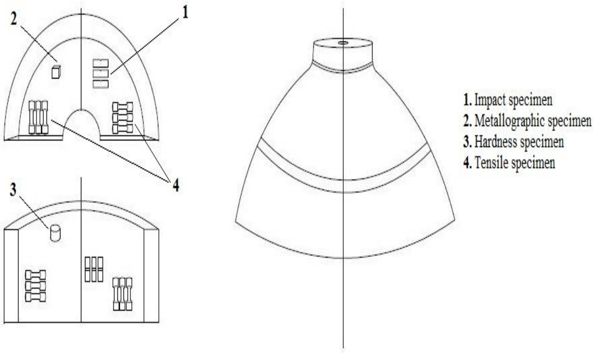

Figure 5. Specimen cut for testing

1. Microstructural Analysis.

The specimens were prepared as per ASTM E112. These specimens were polished using different grit sized papers and finally etched using Kalling's reagent for 8-15s. The etched samples were then viewed through the optical microscope.

2. Tensile test

The test coupons were removed from the dome. The tensile specimens were prepared as per ASTM E8 standard and tensile tests were carried out using Universal Testing Machine. The tensile properties such as ultimate tensile strength, proof strength, %elongation and %reduction in area are determined.

3. Brinell hardness test

The brinell hardness tests were carried out as per ASTM E10 using brinell hardness testing machine. The test specimen was placed on the anvil in such a way that the specimen was in contact with the indenter ball. The load was applied and the indentation was measured by a brinell microscope having a transparent scale engraved in the field of view. The brinell hardness number was calculated by the equation:

$$\text{BHN}= \frac{W}{(\pi D/2)\ (D-(D^2-d^2)^{1/2})}$$

4. Impact Test.

Impact strength was determined by Charpy test. The charpy test was done as per ASTM E23 standard by taking samples from the cut dome. The specimen is set in the vise in the impact testing machine. The swinging pendulum weight is raised to a standard height of one metre. The pendulum is released to hit the specimen behind the V-notch. The specimen ruptures and the energy needed to rupture is noted directly from the dial in the impact testing machine.

III. RESULTS & DISCUSSIONS

1. Microstructure analysis

Microstructure of the dome after heat treatment is shown in the figure 6.

The microstructure of the dome gives recrystallized fine grains and annealing twins. It shows grain boundary precipitates which resist the grain boundary sliding when stressed and thereby increases the strength of the dome.

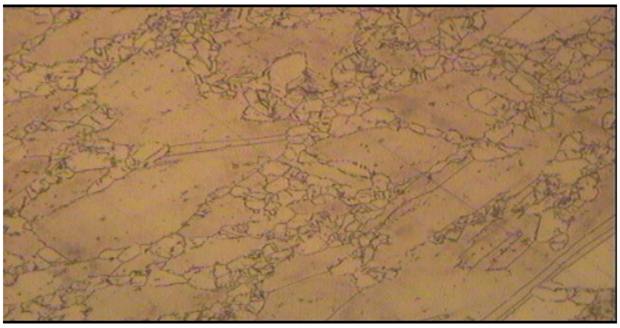

Figure 6. Microstructure of the dome at optimum hammer blows

1. Tensile test

Tensile strength of the dome was determined and plotted as shown in figure 7.

From the observations, it is clear that the tensile strength increases up to 20 blows (1476 MPa) and slightly decreases with further blows. Hence it is conducted after 20 blows, further increase do not help strength.

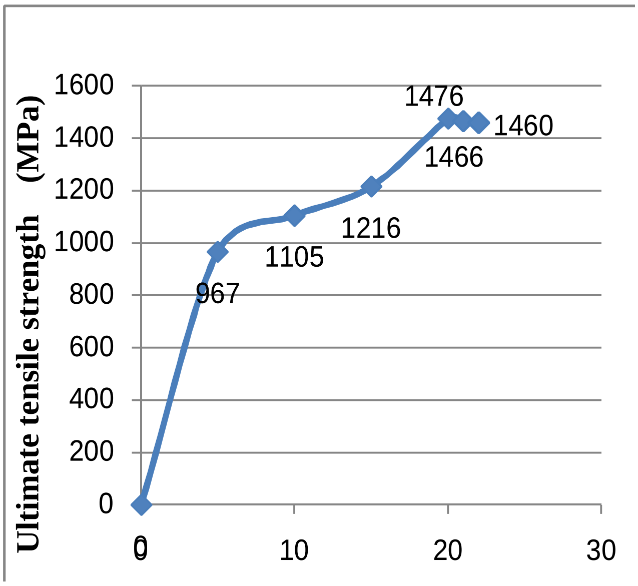

Figure 7. Effect of number of hammer blows on Tensile strength

The hot forging of the billets into dome increase the tensile strength from 910 MPa to 1104 MPa due to strain hardening.. Also the age hardening of the dome further increases the strength up to 1476 MPa. The variation in tensile strength of the dome is shown in the figure 8. Hence age hardening enhances the strength of test by 33.5 percent.

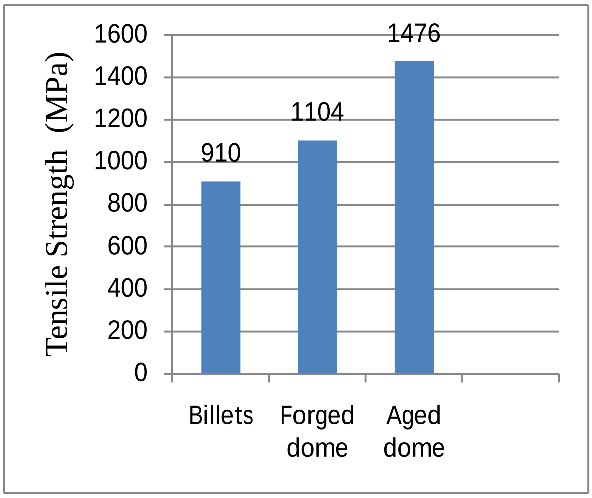

Figure 8. Effect of forging and heat treatment on tensile strength

2. Brinell hardness results

The brinell hardness number of the domes are also found and plotted as shown in figure 9.

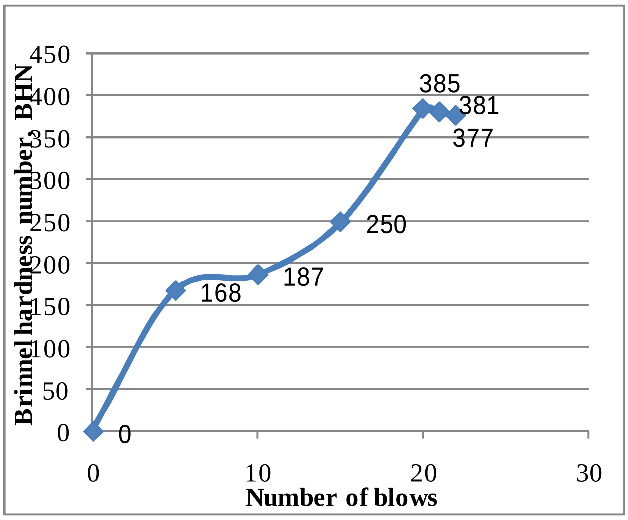

Figure 9. Effect of number of hammer blows on Brinnel hardness number

From the observation made, it is clear that brinell hardness number of the dome had increased up to 20 number of hammer blows (385 BHN) and further blows slightly reduces the hardness. This is due to the over heat of the dome due to friction between the dies and the work piece.

3. Impact strength

Impact strength of the domes were also found out and plotted as shown in the figure 10.

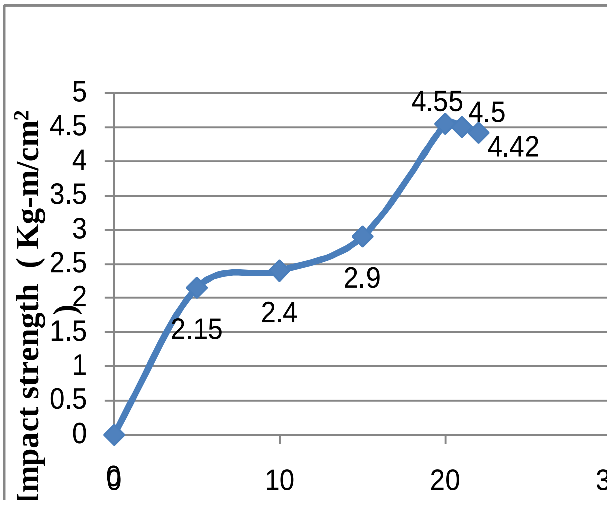

Figure 10. Effect of number of hammer blows on Impact strength

Again, the impact strength of the dome also shows an increase up to 20 blows (4.55 Kg-m/cm^2) and further blows shows a decline in impact strength. This is because of the overheat due to friction between the die and dome.

IV. CONCLUSION

In the present work, the following conclusions are drawn:

1. Inconel 718 Nickel-Iron super alloy taken for the investigation is best suited for precipitation hardening heat treatment for improving the strength of forged components.
2. Higher hammer blows improves the strength of the component up to 20 blows. Further blows reduces the strength because of overheat due to friction.
3. Micro examination reveals that, there is recrystallized fine grains and some annealing twins and are responsible for increasing strength.
4. Precipitation hardening heat treatment increases the strength of the Inconel 718 dome by 33.5%.

REFERENCES

1. ASM handbook for nickel and nickel alloys, fabrication of nickel alloys and heat treatments, pp 754-759, 1993.

2. H.J. Beattie and W.C. Hagel, “Intragranular Precipitation of Intermetallic Compounds in Complex Austenitic Alloys,” *Trans. AIME*, 221 , pp. 28-35, February 1967.

3. J.W. Martin, " Precipitation Hardening " Pergamon press, New York, 1968.

4. J.W.Brooks, " Metallurgical stability of Inconel 718", 1988.

5.Vidhi Acharya, D.K.Basa, G.V.S. Murthy, " Microstructural characterization of intermetallic precipitates in Inconel 718", NDT.net, pp 34-39,2005.

6. G. D. Smith And S. J. Patel, "The Role Of Niobium In Wrought Precipitation-hardened nickel-base Alloys",

Special Metals Corporation,3200 Riverside Drive, Huntington, WV 25705, 2005.

7.C.M.Kuo,Y.T.Yang, H. Y. Bor, C.N.Wei, and C.C.Tai, “Aging effects on the microstructure and creep behavior of Inconel 718 super alloy, ”Materials Science and Engineering A, vol. 510-511, pp.289–294, 2009.

8. Moukrane Dehmas,Jacques Lacaze, Aliou Niang, and Bernard Viguier, " TEM study of high temperature precipitation of delta phase in inconel 718", Hindawi publishing corporation, pp 512-515, may 2011.