Journal of Manufacturing Engineering, March 2018, Vol. 13, Issue. 1, pp 032-034

SME
ESTD 2005

MICROSTRUCTURAL RESPONSE OF INCONEL 690 SUPER ALLOYSTO ARTIFICIAL AGEING

***Jaimon D. Quadros[1], Vaishak N L[2] and Suhas[3]**

[1]Department of Mechanical Engineering, Birla Institute of Technology, Offshore campus, Ras-Al- Khaimah, UAE
[2, 3] Department of Mechanical Engineering, Sahyadri College of Engineering and Management, Mangalore, India

ABSTRACT

Modern manufacturing processes require materials possessing properties that can be used for applications like turbines, heat exchangers, condensers etc. One such material is the Inconel 690 bearing various properties like high strength at elevated temperature, toughness, resistance to degradation in corrosive or oxidizing environment, etc. The present work is mainly focused on the study of hardness of Inconel 690 in As Forged condition and at ageing conditions of 725°C for 4 hours respectively. The As Forging is done by hot working the Inconel alloy at 1200°C for delivering high strength and resisting hot deformation. Also SEM (Scanning Electron Microscope) analyses of both the specimens are being conducted in order to analyze and understand the effect of ageing. The hardness measurement for the aged specimen was done on a Rockwell hardness testing machine on a B scale after air cooling of the specimen to room temperature. The experiments showed that the hardness of the Inconel alloy decreased from 82 HRB to 59 HRB (Rockwell B Hardness) after being subjected to heat treatment and ageing. From the morphology of the aged specimen it was observed that, there is formation of large grain boundaries in the same grain directions and also drastic increase in the grain size which relieved the internal stresses due to ageing.

Keywords: *Ageing, Inconel 690, hardness, microstructure.*

1. Introduction

The evolution of super alloys is mainly due to the significant development in gas turbines. Today in many industries metallic alloys are been used at high temperatures and corrosion-resistant applications. Such metallic alloys which possess an extraordinary combination of properties like high temperature strength, toughness and resistance to the degradation in corrosive or oxidizing environment Pollock *et al.* [1]. One of the new nickel based super alloy having excellent resistance to corrosion and elevated temperatures is Inconel 690 (Hong *et al.* [2]). The high chromium nickel content gives the alloy an excellent resistance to various corrosive aqueous media and high-temperature applications. Very few studies have been reported on the ageing of Inconel 690 super alloys. A few studies have been reported herewith. Kim *et al.*[3] investigated the sliding and fretting wear properties of Inconel 600 and 690, which are the steam generator tube materials. They observed that sliding and fretting wear tests of thermal treated Inconel 690 has better wear resistance than high temperature mill annealed Inconel 600. Also it was noticed that the wear and tear due to stick and slip has very prominent effect on the fretting wear behavior of the steam generator tubes. Vishal *et al.* [4] studied the dry sliding wear behavior of Inconel 600 employing Taguchi's L_{27} orthogonal array by which they obtained the optimum influencing parameters by reduction in experiments. It was noted that wear rate was independent of the apparent contact area. Hong *et al.* [5] examined the wear properties of Inconel 690 tubes used in steam generators at various environmental conditions like temperature variation, air environment and water environment to determine the occurrence of reciprocating sliding wear, with the aid of SEM analysis. Inconel 690 has evolved into a workhorse alloy for turbine engine applications for many reasons including affordability, weldability and a good balance of high temperature mechanical properties. However, some of the characteristics desirable for engine applications can result in producibility difficulties. In view point of this, the alloy can be easily machined if the hardness of the alloy can be controlled. Thus the present study aims at varying the hardness of Inconel 690 alloy by subjecting it to water quenching and ageing. The detailed composition for Inconel 690 super alloy is shown in Table 1.

**Corresponding Author - E- mail: jaimonq@gmail.com*

Table 1. Composition of As Forged Inconel 690.

Element	Ni	Cr	Fe	C	Si	Mn	S	Cu	P	Ti	Al	Mo	Co
%	59.90	30.08	9.15	0.002	0.16	0.17	0.002	0.011	0.007	0.31	0.153	0.019	0.027

2. Materials and Methods

This research work used As Forged material of Inconel690 rods of 8mm diameter. The specimen is cut to a length of 30mm as per ASTM G99 standards and then the edge is ground using a grinding machine. The hardness of As Forged, aged Inconel 690 was determined on a Rockwell hardness testing machine using B- scale as per ASTM E18 standards. The major load applied was 150N and minor load was 10N. The test surface was flattened using a lathe machine. As the test specimens were ready for heat treatment, the specimens were separated into 2 sets. The two sets of specimen were As Forged Inconel 690, and Inconel 690 aged at 725^{0}C. For this work, the heat treatment procedure was employed as the ageing process. The first sets of specimens (As Forged) are tested for hardness. Then the next sets of Inconel specimens are aged as follows: i) The specimens are solution treated to 1040^{0}C and then water quenched to room temperature; ii) Then ageing is done for specimens up to 725^{0}C for 4 hours and air cooled to room temperature.

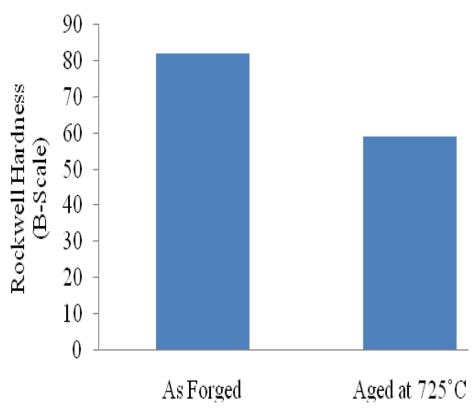
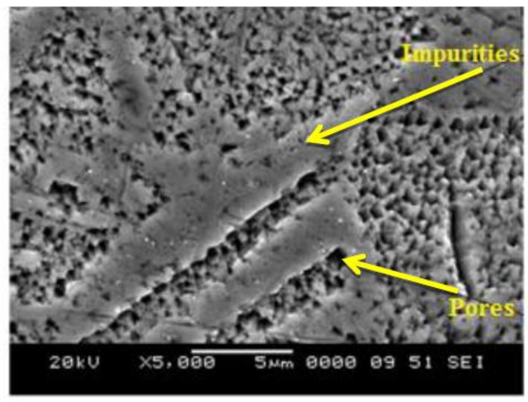


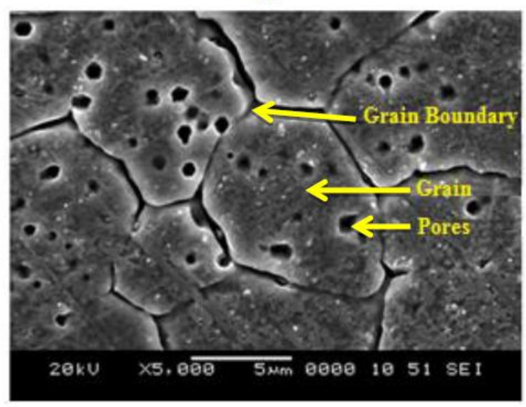
Fig. 1 Rockwell hardness variation in the forged and aged Inconel 690.

3. Results and discussion

The hardness of As Forged and aged Inconel specimens have been represented in terms of Rockwell hardness number measured on a B-Scale. It is clearly evident from Fig. 1 that, for aged Inconel 690 the hardness of the material drastically reduces from 82



(a)



(b)

Fig. 2 Microstructure of a) As Forged Inconel 690; b) Aged Inconel 690.

Also ,the decrement in hardness leads to the increment in wear loss and this may be due to the flow of the metal during the ageing process [3, 4]. For the analysis of Inconel 690 specimen JEOL (JSM-6380LA) Analytical Scanning Electron Microscope has been used. The resolution of the instrument is about 5nm and the range of magnification is about15 to 10,000X. The SEM images of the test specimens clearly show distinct morphological patterns such as voids, impurities, cracks, grain boundaries, etc. The effect of temperature and heat treatment processes also plays a vital role in the changes of morphology of Inconel 690 [4]. It is evident from the (Fig. 2a) that, many pores are formed due to the forging of the original material. Also the grain boundaries are not clearly visible.

The morphology of Inconel 690 aged at 725°C (Fig. 2b) concludes that, there is a decrease in the number of pores. This decrease in the number of pores may be due to the solution treating of the specimen at 1040°C and water quenching before the actual ageing process [4, 5]. Moreover solution treatment entraps the internal stresses within the specimen. It is also found that there is formation of large grain boundaries and there is drastic increase in the grain size. This leads to reduction in the resistance offered to wear loss, as the internal stresses get relieved due ageing and loose bonding between the grains [5, 6].

4. Conclusions

The effect of ageing on the hardness and microstructure on the ageing of Inconel 690 super alloy has been studied extensively in the present study. The main findings include: The ageing of Inconel 690 reduces the hardness of the material drastically from 82 HRB to 59 HRB due to the occurrence of softening effect on the material. The morphology of Inconel 690 shows that effect of temperature and heat treatment play a vital role in characterization of the material. The aged Inconel 690 showed lesser number of pores and visible grain boundaries thereby entrapping internal stresses when compared to As Forged Inconel 690.

References

1. *Pollock T M and Tin S (2016), "Nickel-Based Super alloys for Advanced Turbine Engines: Chemistry, Microstructure and Properties", Journal of Propulsion and Power, Vol. 22, 361-374.*

2. *Hong J K, Kim I S, Park C Y and Kim E S (2005), "Microstructural effects on the fretting wear of Inconel 690 steam generator tube", Wear, Vol. 259, 349–355.*

3. *Kim D G and Lee Y Z (2001) "Experimental investigation on sliding and fretting wear of steam generator tube materials", Wear, Vol. 250, 673–680.*

4. *Vaishal J B, Jitendra M M, Malhar R T and Bhargav H U (2010), "Wear Behavior in Dry Sliding of Inconel 600 Alloy using Taguchi Method and Regression Analysis", Procedia Technology, Vol.23, 383–390.*

5. *Hong J K and Kim I S (2003), "Environment effects on the reciprocating wear of Inconel 690 steam generator tubes", Wear, Vol. 255, 1174-1182.*

6. *Long X, Wang Z H, Jie L, Yonghao L and Tetsuo S (2016), "Microstructural characterization of subsurface caused by fretting wear of Inconel 690TT alloy", Materials Characterization, Vol. 115, 32-38.*

