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Effect of solution treatment temperature and cooling rate on the mechanical properties of tungsten heavy alloy

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ABSTRACT

The present study investigates the effect of solution treatment temperature and cooling rate on mechanical properties of a tungsten heavy alloy (89.6W-6.2Ni-1.8Fe-2.4Co). In addition to water quenching, rapid argon quenching has been attempted in this study since it is a relatively cleaner process and it can be used in conjunction with vacuum treatment. Since in these alloys, there is a possibility of incomplete dissolution of intermetallics or segregation of impurities during heat treatment, which results in scatter in the mechanical properties, it was decided that the solution treatment temperature for both water and argon quenching would be varied from 1100 to 1250 °C in order to see its effect on the microstructure and mechanical properties.

Solution treatment at varying temperatures followed by water quenching resulted in tensile strength ranging from 908 to 921 MPa and % elongation varied from 19% to 26%. On the other hand, the argon quenching heat treatment resulted in tensile strength in the range of 871–955 MPa and % elongation from 9% to 25%. No significant trend with respect to solution treatment temperature on tensile properties was seen in both argon and water quenched samples. % elongation to failure and impact values of water quenched specimens were better than those of argon quenched specimens for a given solution treatment temperature. The impact values appeared to improve with increasing solution treatment temperature in water quenched condition. The properties were correlated with underlying microstructure and fractographs of the failed specimens. The study showed the argon quenching may not be appropriate for the heat treatment of heavy alloys since it results in inferior mechanical properties as compared to water quenching.

1. Introduction

Tungsten heavy alloys are synthesized by liquid phase sintering [1,2] that results in two phase microstructure comprising nearly spherical tungsten particles surrounded by a matrix phase. This matrix phase that has a face centered cubic crystal structure holds tungsten particles together and also undergoes deformation thereby imparting desired mechanical properties. However as sintered microstructure is associated with inferior mechanical properties and this is attributed to numerous factors such as: (1) formation of intermetallics at W-matrix interface during cooling that leads to weakening of the interface [3], (2) presence of hydrogen leading to embrittlement since sintering is carried out in hydrogen atmosphere [4], (3) highly contiguous microstructure with large number of W-W interfaces which are preferential void/crack nucleation sites [4] and (4) segregation of impurities such as sulphur (S) and phosphorous (P) in the vicinity of the interface [3]. Segregation of phosphorus and sulphur along the interface boundaries in the case of as-sintered W-Ni-Fe alloys has been reported by Lea [5]. It has been observed that P gets homogeneously distributed along the interphase boundaries but adheres preferentially to the matrix phase during fracture. On the contrary, sulphur distribution along the interphase boundaries is less uniform but is detected on either side of the interphase boundaries after fracture. Nevertheless, presence of both P and S reduces the cohesive strength of the interphase boundary and results in interfacial failure. Inferior properties obtained in the as-sintered state can be ameliorated by (i) changing the sintering atmosphere from hydrogen to argon midway through the sintering cycle. Such a change in sintering atmosphere helps in pore degassing and improving the sintered ductility and strength [6] (ii) by using dry-wet hydrogen cycle [7] and (iii) by incorporating heat treatment. Heat treatment is especially employed to improve the ductility of the alloys so that they are amenable to swaging that involves warm deformation of 20–40%. The purpose of heat treatment is to avoid the formation of intermetallic, freezing the high temperature microstructure thereby preventing the segregation of deleterious elements such as S and P and removal of hydrogen. This was addressed in one of the early works of

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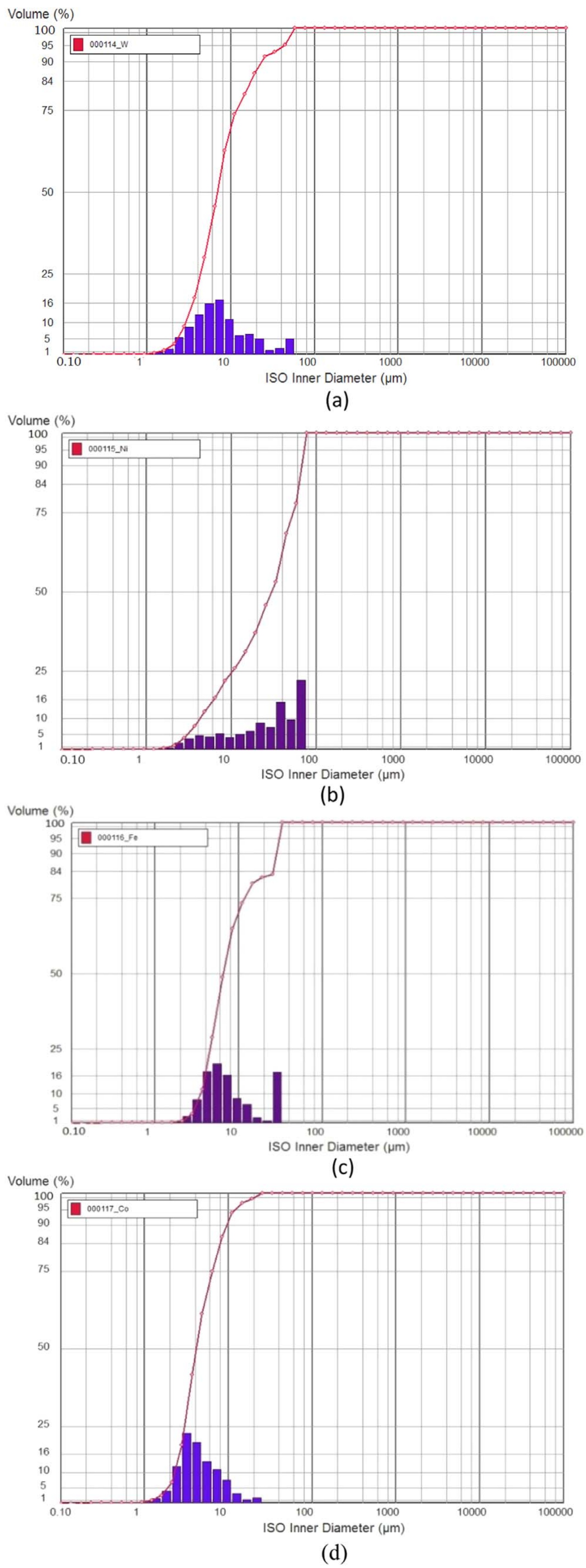

Fig. 1. Particle size distribution of (a) W, (b) Ni, (c) Fe and (d) Co. Near normal distribution in case of (a) W and (d) Co. While (b) Ni is skewed towards higher size, there appears to be dual size distribution in case of (c) Fe.

Table 1
Particle size of powders as measured by Ochio particle size analyser.

Element	Mean Particle dia (µm)
W	11
Ni	33
Fe	11
Co	5

German and Bourguignon [4]. They subjected a 95% W heavy alloy to heat treatments in hydrogen and argon atmosphere followed by furnace cooling (slow cool) and water quenching (rapid cool). While as sintered material exhibited inferior mechanical properties, superior properties were obtained in solution treatment in argon followed by water quench. Argon heat treatment resulted in the removal of dissolved hydrogen and water quenching prevented any possible segregation of interstitials near grain boundary or precipitation of intermetallics thereby leading to enhancement of mechanical properties. Solution treatment in hydrogen atmosphere lead to properties that were intermediate between as sintered and argon solution treatment/ water quench. Solution treatment in vacuum followed by water quenching has also been reported to improve the mechanical properties by avoiding hydrogen embrittlement and impurity segregation [8,9].

Industrially oil quenching is a preferred practice since it not only ensures rapid quenching, it can also be used in conjunction with a vacuum furnace where a vacuum level of 10^{-4} to 10^{-5} Torr results in more efficient removal of hydrogen. However, there are certain limitations associated with such a process. Firstly, the process is not very clean especially because of the evolution of gases during quenching that may contaminate the vacuum chamber and deteriorate the performance of the furnace over long usage. Oil quenching facility necessitates two separate chambers: one for solution treatment and the other for quenching with a quick transport mechanism to reduce the time lag (quench delay) from solution treatment chamber to the oil bath. Such a system is relatively more complex and may be highly maintenance intensive. Additionally, because of the twin arrangement, despite a quick transfer mechanism, possibility of quench delay is always there that may have implications on impact property. Water quenching will involve two different heat treatment furnaces: (1) vacuum furnace for solution treatment for the removal of hydrogen, (2) an inert gas furnace for resolutionising and quenching.

Argon quenching that is routinely used for aerospace alloys may be one of the alternatives [10]. Not only it is a relatively cleaner process [11], it can be accomplished in a single chamber thereby obviating the provision for a twin chamber. Also, the quenching can be carried out relatively more rapidly thereby eliminating the concern of quench delay. However, a possible limitation of such a set up is the cooling rate that is not rapid enough. While the earlier versions of argon quenching furnace could not achieve high cooling rates because of the lower pressure (5 bar) with which argon is introduced inside the furnace, recent furnaces can realize high cooling rates because of substantial increase in the pressure levels (15 bar). Therefore, the present study explores the possibility of introducing argon quenching in the heat treatment of tungsten heavy alloys and evaluating mechanical properties as a function of solution treatment temperature. High pressure argon quenching has been employed in order to see its effect on mechanical properties. Simultaneously, water quenching has also been carried out in order to benchmark the efficacy of argon quenching for realising desired mechanical properties with respect to water quenching. Different solution treatment temperatures have been employed. Detailed microstructure, mechanical properties and fractography characterisation of the alloy have been carried out in order to arrive at their interrelationship, the influence of solution treatment and quenching medium.