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Hardness and tensile properties of tungsten based heavy alloys prepared by liquid phase sintering technique

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A R T I C L E I N F O

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A B S T R A C T

Several tungsten heavy alloys based on W–Ni–Cu and W–Ni–Fe were made recently at DMRL by liquid phase sintering route. These alloys were heat treated and characterized in terms of density, hardness and tensile properties. Although the densities of W–Ni–Cu based heavy alloys were found to be relatively higher than those of W–Ni–Fe based heavy alloys, the former exhibited inferior tensile properties and hardness values than the latter alloys. In both these heavy alloys, un-melted solid tungsten particles were bonded together by the respective low melting matrix alloy. The strength of the matrix or the bonding strength of the interface (between tungsten particles and matrix) was found to control the nature of final fracture. Poorer matrix strength or interfacial strength was found to initiate the fracture by separation of tungsten particles either by matrix failure or by interface failure. On the other hand, tensile fracture takes place predominantly by cleavage fracture of tungsten particles, if both the matrix and interface are stronger than the tungsten particles. The tensile fractured surfaces were examined under scanning electron microscope (SEM). Failure stress is observed to be lower in case of separation of tungsten particles (due to matrix and interface failure) than that in case of cleavage fracture (transgranular fracture) of tungsten particles. SEM image of fractured surfaces clearly indicated that failure in case of W–Ni–Cu based heavy alloys was due to matrix and/or interface (between tungsten grain and matrix) failure, where as, W–Ni–Fe based heavy alloys were failed predominantly by cleavage fracture of tungsten particles. This was evidenced by poorer tensile properties obtained for W–Ni–Cu based heavy alloys as compared to those of W–Ni–Fe based heavy alloys. The present sets of results indicate that heavy alloys based on W–Ni–Fe and W–Ni–Cu can be strengthened by minor additions of Co, Mo and Fe selectively. Higher strength (>850 MPa) of the heavy alloys are associated with the finer tungsten grain size and cleavage fracture of tungsten particles. Where as, the lower strength is associated with the larger tungsten grain size and interface and/or matrix failure. It is found in this study that as the tungsten grain size decreases, the tensile fracture mode changes gradually from interface failure to matrix failure to tungsten grain cleavage failure.

1. Introduction

Tungsten based heavy alloys have high density, good mechanical properties and are easily machinable. Because of their good machinability, highly complicated shaped components can be made out of these alloys. As they posses very high density, the alloys can be used in a variety of applications such as kinetic energy penetrators, radiation shielding and counter weight materials [1].

According to Islam et al. [2] volume fraction of tungsten particle, particle size of tungsten, closeness of tungsten particles affect the mechanical properties of tungsten heavy alloys. He also explained that raw materials purity also affects the mechanical properties of these alloys. However, the tensile properties, density and hardness of these alloys largely depend on the chemistry. W–Ni–Fe based heavy alloys possess far superior tensile properties and hardness as compared to the W–Ni–Cu based heavy alloys [3]. Both the Ni/Fe or Ni/Cu ratio and the amount of W content also significantly influence the tensile properties of these alloys [3]. Song et al. reported that heavy alloys with Ni/Fe ratio of 4:1 shows best tensile properties and impact strength [4]. Bose and Kapoor [5] showed that lowering the W content of the alloys up to 90 wt.% causes improvement in ultimate tensile strength as well as elongation value of the sintered tungsten heavy alloys. They also observed that 92.5%W–(Ni–Fe–Co) alloy deformed with 95% showed a tensile strength of 1720 with concomitant elongation of 16%. Boris Katavik [6] explained that the 'mechanical properties of W–Ni–Co' with 'nickel to cobalt ratios ranging from 2 to 9' are far superior to that of W–Ni–Fe alloys. Bose and Kapoor [5] also showed that heavy alloys 'doped with Mo and Re' exhibit improved

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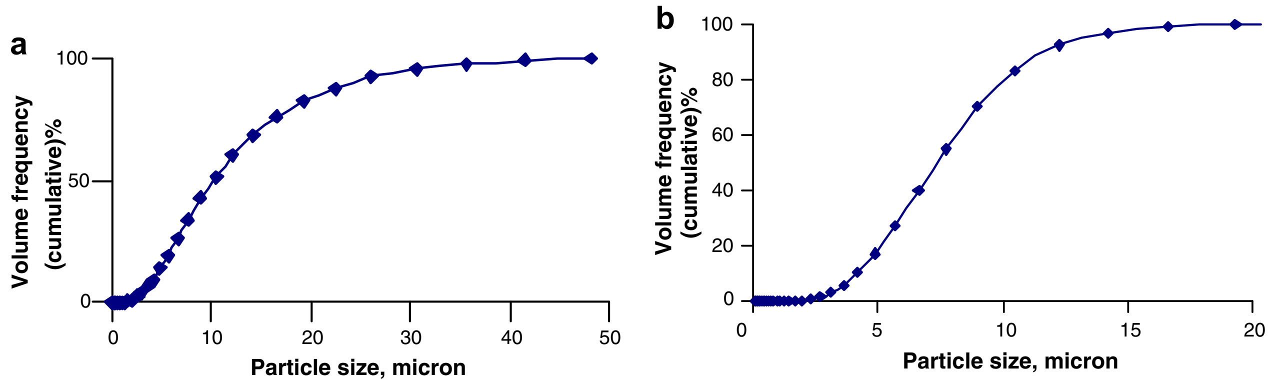

Fig. 1. Particle size distribution of (a) W powder [9] and (b) molybdenum powder.

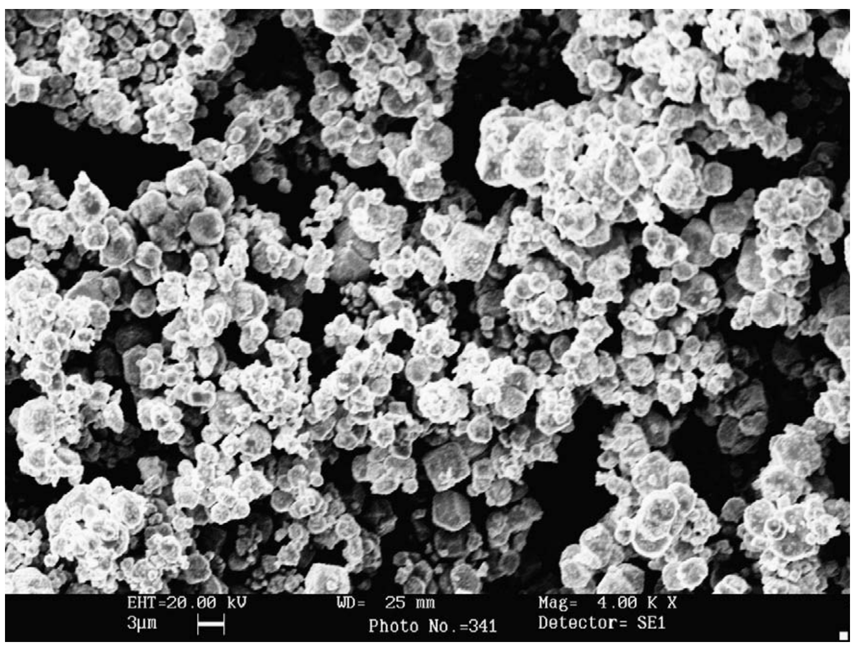

Fig. 2. SEM image of as-received tungsten powder utilized in this study [9].

yield strength as compared to unalloyed heavy alloys. However, according some study, pointed out by Liu et al. [7], higher Mo addition to tungsten heavy alloys leads to brittleness due to formation of precipitated phase. Although Re is very effective strengthener for tungsten heavy alloys according to Bose and Kapoor [5], its use is very restricted because of its very high cost.

Alloying elements also were found to influence the failure mode of tungsten heavy alloy in tension by way of modifying matrix strength, interfacial (between tungsten grain and matrix) strength and tungsten grain strength. Liu et al. [7] again pointed out that interfacial strength between tungsten particle and matrix affect the toughness of these alloys significantly. The present work is thus directed to understand the different types of tensile failure mechanisms in tungsten heavy alloys and also aims to establish a correlation between the strength and failure mode in tensile loading.

2. Experimental

Four W–Ni–Cu base heavy alloys with different W content and varied Ni/Cu ratio and three W–Ni–Fe base heavy alloys with different W content as well as varied Ni/Fe ratio were prepared by liquid phase sintering at 1500 °C for 1.5 h in H_2 atmosphere in

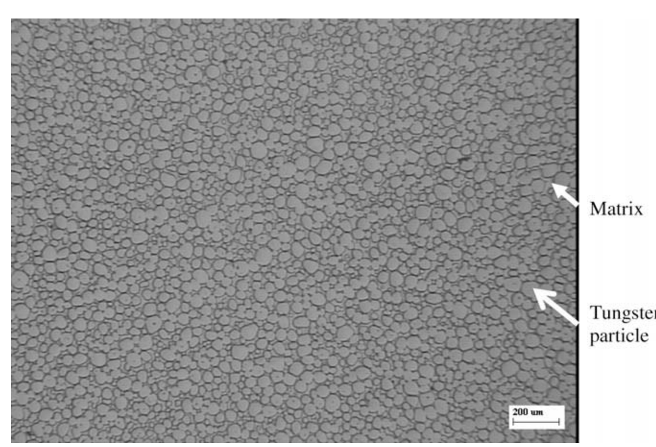

Fig. 3. Optical microstructure of W-90.5, Ni-7.2, Fe-1.8, Co-0.45, Mo-0.05 alloy. Vol.% of matrix is 11–15, vol.% of tungsten particles is 85–89% and average tungsten particle size is 30 μm.