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Tensile and impact properties of microwave sintered tungsten heavy alloys

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ABSTRACT

The present study investigates the interrelationship between microstructure, tensile and impact properties of microwave sintered tungsten heavy alloys. Alloys of two different compositions were microwave sintered and conventionally liquid phase sintered using similar heating rate, followed by microstructure and mechanical property evaluation. The tensile properties of microwave sintered alloys were significantly superior to those of liquid phase sintered alloys in both the compositions. Excellent impact properties were obtained in microwave sintered alloys, without any subsequent heat treatment or processing. In order to understand the reasons for the improvement, a detailed comparative study of microstructural features in both microwave and conventionally sintered alloys was carried out and it was observed that both tensile and impact properties of these alloys were largely influenced by tungsten–tungsten contiguity; the weakest link in the microstructure. Microwave sintered alloys were found to exhibit substantially lower contiguity as compared to the conventionally sintered alloys and consequently their properties were found to be superior as compared to the conventionally sintered alloys.

1. Introduction

High density materials are preferred for developing kinetic energy penetrators so as to concentrate a large mass and therefore energy in a relatively small perforating volume [1]. Though high density (between 17 and 18.6 g/cm^3) of tungsten heavy alloys makes them a candidate material for kinetic energy penetrators, extremely demanding conditions in terms of stress and strain rate during the launch of the penetrators, has hindered the development of heavy alloy penetrators. Therefore, development of tungsten heavy alloys with improved mechanical properties still attracts the attention of material scientists. Several investigations have strongly emphasized on the fact that the microstructural factors such as tungsten particle size, matrix volume fraction, tungsten–tungsten contiguity, dihedral angle and tungsten–matrix interfacial strength, largely affect the mechanical properties and eventually the deformation behavior of heavy alloys [2–5].

It is reported that the tensile behavior of tungsten heavy alloys is dependent on tungsten–tungsten contiguity, showing an increasing trend with decreasing contiguity [2]. Tungsten–tungsten contiguity has been found to be responsible for the variation in impact energy obtained from unnotched Charpy tests [3]. An increase in ductile–dimple failure of the matrix has been observed with decreasing contiguity explaining the improvement in mechanical properties. Ryu et al. have also made similar observations of increasing Charpy impact energy with increasing matrix volume fraction and decreasing contiguity [4]. Liu et al. [5] have observed that the tungsten–matrix interfacial strength influences the toughness of these alloys significantly. Tungsten content around 90% has been reported to result in an optimum combination of tensile strength and elongation compared to alloys with either lesser or higher tungsten content [2].

Some of the very recent investigations reported by Ravi Kiran et al. [6] also indicate that the mechanical properties are dependent on the tungsten content, contiguity and matrix volume fraction. Li et al. [7] have investigated the mechanical properties of spark plasma sintered 93W–5.6Ni–1.4Fe heavy alloys and have reported a strong dependence of mechanical properties on the microstructural parameters. All these investigations strongly emphasize the fact that the mechanical properties of tungsten heavy alloys are indeed dependent on the microstructural features, irrespective of the composition and the processing method.

In this context, microwave sintering has also been found to alter the microstructural features and thereby the mechanical properties of tungsten heavy alloys. Upadhyaya et al. [8] have studied the effect of heating mode on the microstructure and mechanical properties of 92.5W–6.4Ni–1.1Fe alloy. It has been reported that microwave sintering results in lesser tungsten grain

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coarsening and improved tensile properties compared to conventionally sintered alloys. 92.5W–6.4Ni–1.1Fe alloy is a non-optimal matrix composition alloy (7:3 Ni–Fe being considered optimal to avoid intermetallics) and yet does not form any intermetallic in microwave sintering owing to the fast heating rates. Mondal et al. [9] have compared microwave sintered and conventionally sintered 90W–7Ni–3Cu alloys and reported that microwave sintered compacts had relatively more refined microstructure, higher hardness and higher flexural strength compared to the conventionally sintered compacts. Similar improvements in microstructure and mechanical properties in microwave sintered 93W–4.9Ni–2.1Fe heavy alloy are reported by Liu et al. [5].

The present investigation aims at a comparison between microwave sintered and conventionally sintered tungsten heavy alloys of composition 90W–7Ni–3Fe and 90W–6Ni–2Fe–2Co. Co addition to W–Ni–Fe alloy leads to increase in tungsten–matrix and tungsten–tungsten interface cohesive strength, thereby enhancing ductility and impact energy of the alloy [10]. Moreover, higher strain hardening has been reported in Co containing alloy because of the decrease in stacking fault energy [10]. A detailed comparison of microstructure and mechanical properties of the alloys produced by two routes is carried out and a rationale for improvement in mechanical properties of microwave sintered alloy is provided in terms of microstructure. The dependence of tensile properties on the microstructural parameters; W–W contiguity in particular, is in agreement with the reported investigations. Substantially improved impact strength of microwave sintered alloys has been reported for the first time and it has been observed that the impact strength also is influenced by W–W contiguity.

Table 1
Properties of tungsten, nickel, iron and cobalt powders (as-received grade).

Properties	Tungsten	Nickel	Iron	Cobalt
Apparent density, g/cm^3	4.7	2.1	3	3.1
Tap density, g/cm^3	7.1	4.2	4.2	4.4
Particle shape	Cuboidal	Irregular	Spherical	Irregular
Particle size (D_{50}), μm	26.1	27.1	7.2	18

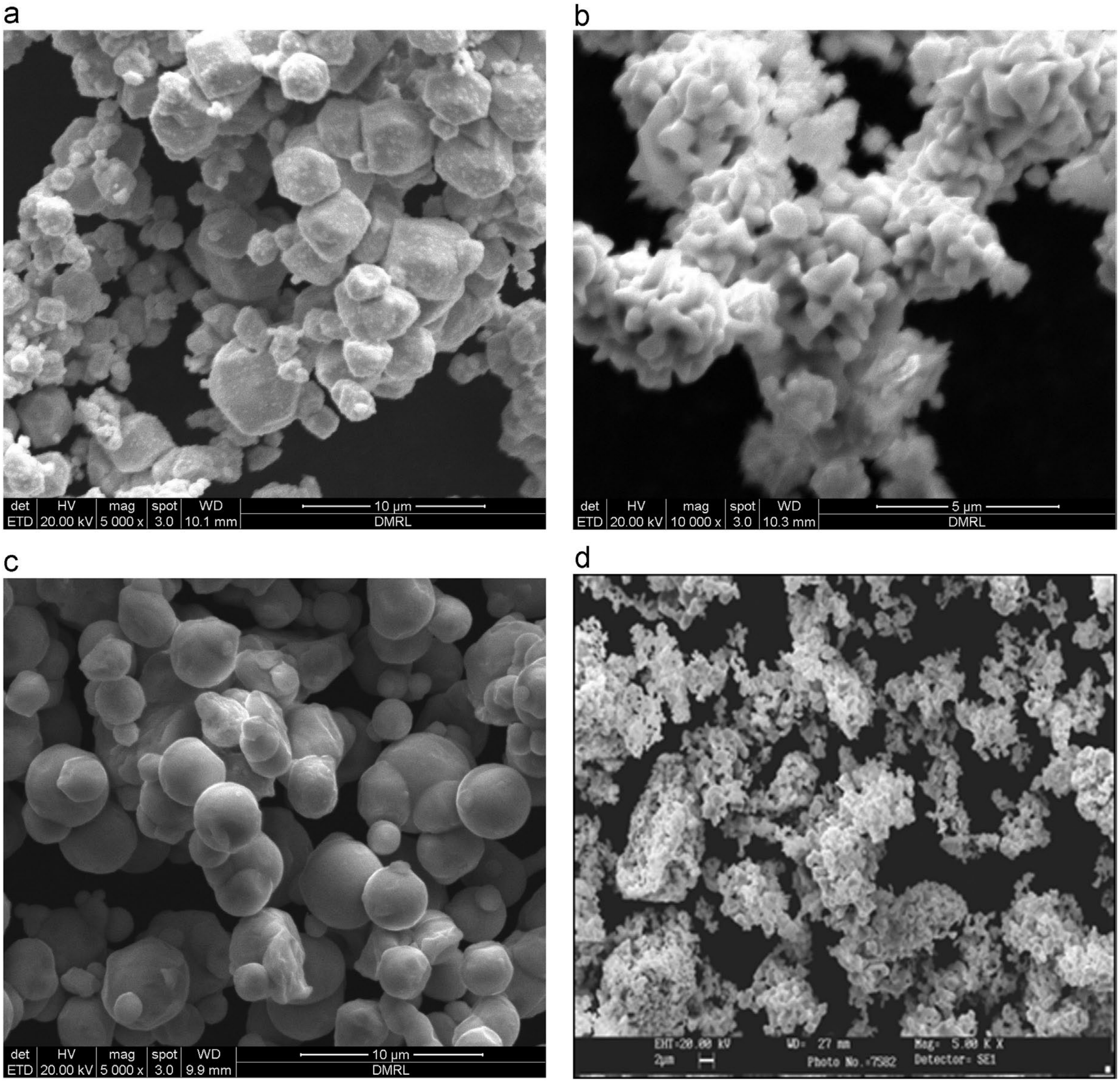

Fig. 1. Scanning electron microscopy images of as-received (a) tungsten powder, (b) nickel powder, (c) iron powder and (d) cobalt powder.