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The influence of Fe content on spreading ability of tungsten heavy alloys matrix on tungsten surface

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Abstract

The results of experimental study of tungsten spreading ability with W-Ni-Co-Fe matrix are presented. The aim of these investigations was to see how Fe concentration in W – Ni – Co matrix influences the wettability of tungsten grains during liquid phase sintering. Four green compact specimens containing 50%W, 10%Co and Ni + Fe = 40% but with different Ni to Fe ratio were prepared. The cylindrical specimen 5mm diameter and 5mm height were put on clean pure tungsten substrate and then 20 minutes heated at 1520°C in hydrogen atmosphere. After heating the specimens were carefully measured and then the specimens for structure observations were prepared. It was concluded, that increase of Fe content decrease the melting temperature of W – Ni – Co alloy. The melting point decrease caused by Fe content increase substantially the spreading ability of tungsten substrate with W – Ni – Co alloy. Metallography investigations showed some microstructure changes in "reaction zone" identified in tungsten substrate – ($WNi_{40-x}Co_{10}Fe_x$) interface. The results of the study confirmed our earlier observations that even relative small Fe addition promotes Weight Heavy Alloys (WHA) liquid phase sintering.

Keywords: WHA, Spreading ability, Microstructure, Liquid phase sintering

1. Introduction

Tungsten and its alloys are structural materials used in different branches of industry and science, (nuclear power engineering, radiation shields in medicine, counterweights in the instruments, machine building, vibration damping devices, electrical contacts, darts and many more [1,2]. Because of high density, strength and ductility theses alloys are now used also for kinetic energy penetrators. In this specific application tungsten heavy alloys belonging to weight heavy alloys – WHA materials replaces depleted uranium (DU) alloys because its radioactivity.

Recently, numerous investigations have been carried out to improve mechanical properties WHA, including their penetration capabilities as kinetic energy penetrators (KEP) [3-9]. Penetration capability is known to improve by enhancing the adiabatic shear deformation resulting in the so called "self-sharpening" behavior of KEP [10]. Magness and Farrand [11] explained this effect in terms of the forming frequency of adiabatic shear bands which in turn could be enhanced by the refinement of microstructure of tungsten heavy alloys [12]. Microstructural factors, such as tungsten grain size, matrix volume fraction and tungsten – tungsten contiguity, have been known to effect the deformation and fracture behavior of WHA's. As follows from many studies one of the most important microstructure elements influencing the mechanical properties of tungsten heavy alloys is contiguity which strongly depends on matrix volume fraction. If take into account that in typical KEP material tungsten amount reaches even 92% by weight it is very difficult if possible at all to provide the microstructure where all tungsten grains are enveloped with matrix. Typical microstructure of tungsten heavy alloy often called composite is show in Fig. 1.

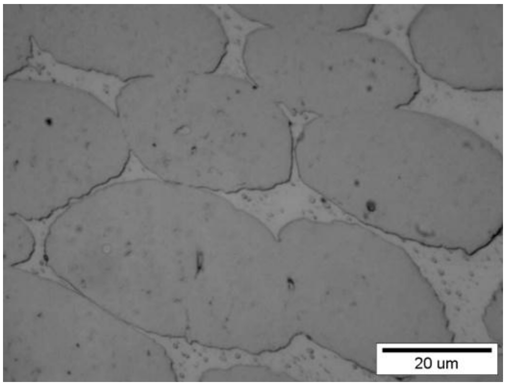

Fig. 1. The typical microstructure of tungsten heavy

The mechanical behavior of tungsten composite depends strongly on contiguity. Small contiguity provides high strength and ductility whereas high contiguity is responsible for brittleness of tungsten composites. This is reflected by character of fracture surface (Fig. 2). As can be seen in first photo (Fig. 2a) the fracture surface is characterized high ductility matrix and many cleavage planes. The ductility of the matrix is confirmed by many dimples formed during tensile test. During tensile, the matrix being typically Ni – base alloy is strain strengthened and reach the value high enough to cause cleavage of tungsten grains in {100} type planes.

This is possible only, when the strength of matrix – tungsten grain interface is higher then needed for initiating of cleavage in tungsten grains. The fracture surface show in Fig. 2b is different. We can see many flat surfaces which are the sites of tungsten – tungsten immediate contact. These kind of tungsten – tungsten grain boundaries are much weaker compared with tungsten – matrix interfaces. This is why the cleavage planes are seldom observed on the fracture surface.

There is no question that in case of WHA of given tungsten content contiguity value depends on wettability, which is responsible for penetrating of liquid matrix between tungsten grains.

The aim of this study is to find if and how the Fe content in Ni – W – Co matrix influences the wettability of tungsten grains in tungsten composite.

a.

b.

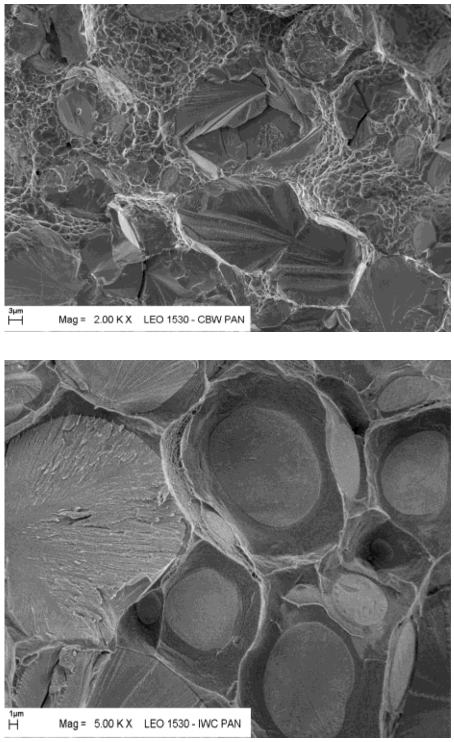

Fig. 2. The fracture surface of tungsten composite with: a – small contiguity and b – high contiguity

2. Experimental procedure

For experiment four green compact specimens with chemical composition given in table 1 were prepared. The specimens were a cylinder 5mm diameter and 5 mm height. Then the specimens were placed onto pure tungsten substrate and located in furnace where they were heated 20 minutes at temperature 1520°C at hydrogen atmosphere which is typical for tungsten heavy alloy liquid phase sintering.

Table 1.
The chemical composition of W – Ni – Co – Fe alloys

Specimen number	Chemical composition [% in weight]			
	W	Co	Ni	Fe
5	50	10	36	4
6			37	3
7			38	2
8			39	1

After cooling whole set was photographed and then the specimens for metallography investigations were prepared. First they were sectioned in axis plane and after including in resin grinded and polished. The Metallography observations were carried with Olympus IX-70 light microscope using different magnifications and mode of observations. The wetting angles were measured on the micrograph. Besides of wetting angle measurement the microstructure of the alloys with different chemical composition was investigated.

2. Results

Fig. 3 illustrates the photos of the W-N-Co-Fe specimens with different Fe content (table 1). It is very easy to see that the specimens have different geometry changing with Fe content. We can see that the higher Fe concentration in W-N-Co-Fe heavy alloy the higher spreading susceptibility on tungsten substrate which is confirmed by specific ring around the specimen (Fig. 3a). Moreover, it can be seen the high of the specimen decrease with Fe content increase (Fig. 3b).

a.
b.

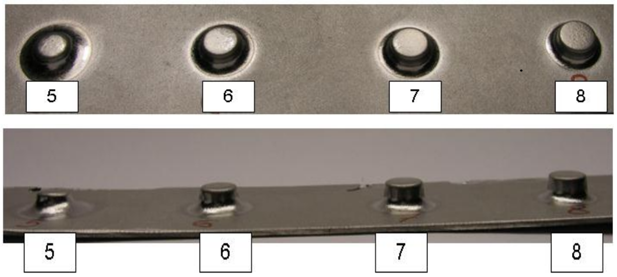

Fig. 3. The photos of the specimens after 20 minutes heating at the temperature 1520°C in hydrogen atmosphere

Because of difficulties in performing the real wettability experiment which need the microscope equipped not only with heating stage but also assuring hydrogen atmosphere, the authors decided to describe the influence of Fe content on the WHA behavior using the semi-quantitative information gathered from specimen geometry measurements. To reach this goal the photos of the specimens were magnified and then the geometry of the specimens measured. The values measured are depicted in Fig. 4.

a. b.

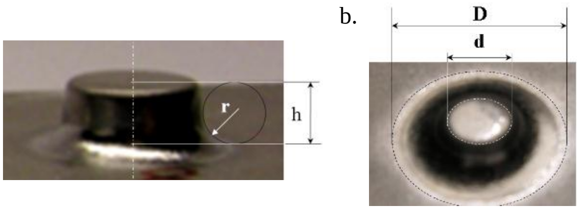

Fig. 4. The values measured from geometry of the specimens: a – height – h, and radius of curvature, b – top (d) and bottom (D) diameter

Table 2.
Results of specimen measurements

Specimen number	D [mm]	d [mm]	h [mm]	r [mm]
5	14,2	6,2	2,7	3,5
6	12,1	6,8	3,1	2,6
7	11,7	7,2	3,3	2,0
8	11,2	7,1	3,5	1,3

Results of these measurements are collected in table 2. These results were used for preparing of the graph illustrating the Fe content influence on the geometry of the W-Ni-Co alloys after 20 minutes heating at the temperature 1520°C. The graphs are presented in Fig. 5.

a.
b.
c.
d.

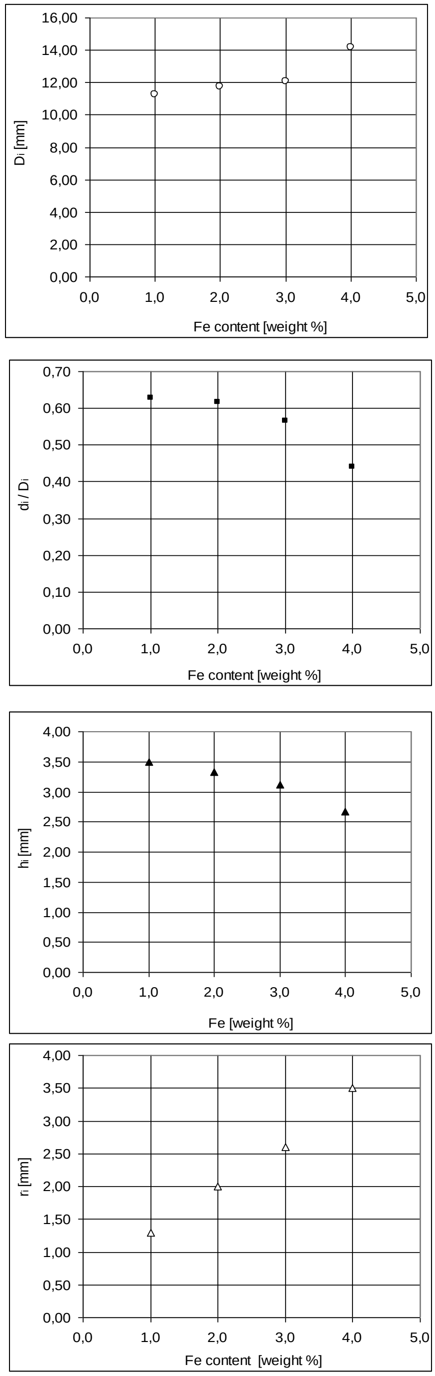

Fig. 5. The influence of Fe concentration in WHA matrix on the parameters characterizing the specimens geometry after 20 minutes heating at temperature 1520°C in hydrogen atmosphere: a – D_i, b – d_i/D_i, c – h_i and d - r_i

The main conclusions following from these graphs are that increase of Fe concentration in WHA matrix increases its spreading ability on tungsten. This in turns can suggest that behavior of W-Ni-Co-Fe alloy follows mainly from Fe influence on melting temperature of the matrix. It is really surprising that such relative small differences in Fe concentration in W-Ni-Co-Fe alloy have so large influence on its melting temperature.

3. Summary and conclusions

The interpretation of results received in the experiment needs the knowledge of quaternary system diagram. On the other hand quaternary diagrams are very rarely especially for such specific alloys like this being the subject of this elaboration. So the authors were able to use ternary (W-Ni-Co) and binary (W-Ni, W-Co, Ni-Fe, Co-Fe) equilibrium systems diagram to discuss the results obtained in the experiment.

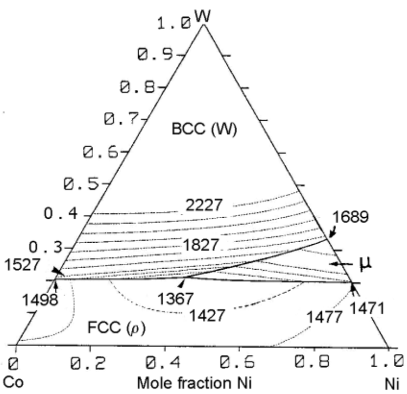

Fig. 6. The projection of liquidus in Co-Ni-W equilibrium system [13]

The most useful looks the last two, which we suspect should help us to see how much Fe addition influence the melting point of the matrix. The melting temperature pure Ni and Co equals 1455 and 1495^{o}C respectively. An increase of Fe concentration in both systems causes small decrease of liquidus. The minimum liquidus temperature is reached at approximately 40 weight % of iron. If consider that the sintering temperature in our experiment being 1520^{o}C, although 20 minutes only, was a little higher than the temperature of liquidus, we should not be surprised that the specimen started to melt. Because the Fe addition into W-Ni-Co alloy decrease the melting temperature it is obvious that the higher its content in the regime 1-4% the higher overheating and thus more pronounced spreading ability of the matrix.

So the main conclusion which can be drawn from our experiment is that Fe content facilitates penetration of matrix between tungsten grains in liquid phase sintering in given temperature. This in turns permits producing of “sound” WHA, in other words the high strength materials with pretty good fracture toughness.

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