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Mechanical Disintegration of Al-W-B Waste Material

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Abstract

A composite material (CM), containing boron-tungsten fibres and aluminium-alloy matrix is investigated. A method of grinding has been used for processing of CM Al-W-B. The grinding has been carried out in several stages in order to obtain a powder with pre-determined particle size. A morphology of Al-W-B CM particles is described. Particle size depends on the degree of comminution, and is defined within the range of 1–350 µm. The CM powder contains milled aluminium-alloy matrix and finely dispersed boron and tungsten. The chemical composition of the investigated material has been established. Results of the study of morphology and particle dimensions of the Al-W-B CM powder, and crushing mechanism are shown. A dependence of energy spent on the degree of milling is shown. Possible applications of the Al-W-B composite powder as a ligature in metallurgy, and for a composite ceramics are noted.

1. Introduction

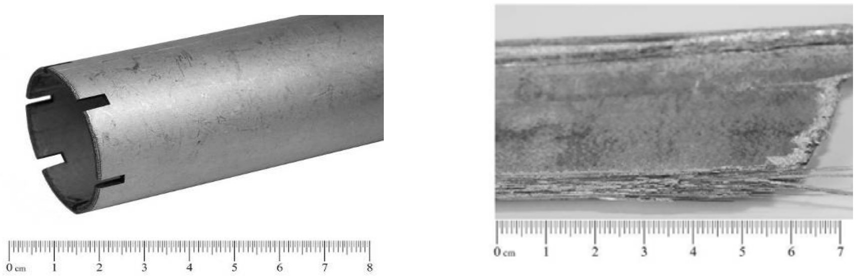
Fibrous composite materials with metal matrices are efficiently used in the newest branches of engineering [1,2], because of their durability, low density and good mechanical properties [3]. Amongst such materials, aluminium composites reinforced with boron, tungsten and silicon carbide fibres [4] are well known. Properties of these composites are described in refs [5,6]. Generally, properties of CMs depend on the manufacturing process parameters, volume content of fibres and other factors.

Issues of recycling and waste management of CMs at various stages of their manufacture and disposal are raising. Due to the fact that boron and tungsten are high-melting-point materials, and considering their relatively high value in the form of powder, one of the best uses of the CM waste is converting it to a powdered state. This approach for the first time has been examined by the authors in ref [7]. In this paper the research for further effective use of the powder material is presented.

2. Properties of the starting material

In the present research the technological waste of Al-W-B CM, in the form of tubes (Fig. 1a) and bands (Fig. 1b), was used as the starting material.

In a hot-pressed material, B-W fibre had a unidirectional structure and was well fixed in an aluminium matrix. Fibres were obtained by decomposition of boron trichloride vapour on tungsten filaments. Then, the surface of fibres was sputtered by aluminium. Thus obtained prepregs were subsequently stacked in layers and subjected to hot pressing (Fig. 2). This technology is broadly described in refs [8-10].



1a) 1b)

Fig.1. Technological waste of Al-W-B composites
a) tube (diameter: 35 mm, length: 100-200 mm); b) plate (200x45x4 mm)

EDS-Energy Dispersive X-Ray Spectroscopy [11] was used to establish the composition of the recycled Al-W-B CM waste. It was found, that the Al-W-B composite material consisted of a tungsten wire (99,99% pure), a boron fibre (99,99%) and an aluminium alloy matrix containing 90.34% Al, 5.81% Mg, 2.42% Mn and 1.32% Fe. According to micrographs it can be stated that the material contains 53.87 vol.% boron fibre, 45.43 vol.% aluminium matrix and 0.70 vol.% tungsten wire. The composition of the source material, and the powder mixture, is given in Table 1.

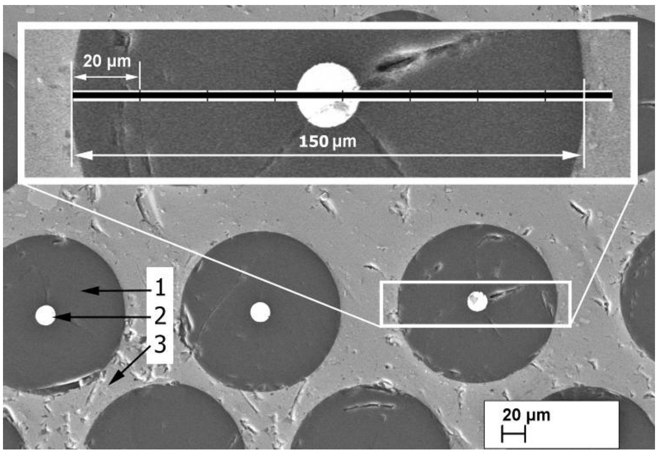


Fig.2. Microstructure of the Al-W-B CM before grinding. 1 - boron fibre (150 µm in diam.), 2 - tungsten wire (17 µm in diam.), 3 - aluminium alloy matrix.

B	Al	W	Mg	Mn	Fe
47.05	43.26	5.06	2.78	1.16	0.63

Table 1. Composition of the Al-W-B CM (wt.%).

Prior to grinding the boron-tungsten fibres were tested for microhardness by two laboratories (Table. 2): CFI (Institute of Solid State Physics, Riga, Latvia) using the technique described in [12], and CSM (Peseux, Switzerland) [13].

Laboratory	Microhardness, GPa										Average, GPa
CFI (Riga)	38,34	35,82	35,28	35,82	35,60	33,73	38,10	42,44	37,56	35,88	36,86
CSM (Peseux)	33,71	33,23	33,59	32,39	33,53	33,29	33,46	35,91	36,03	36,42	34,16

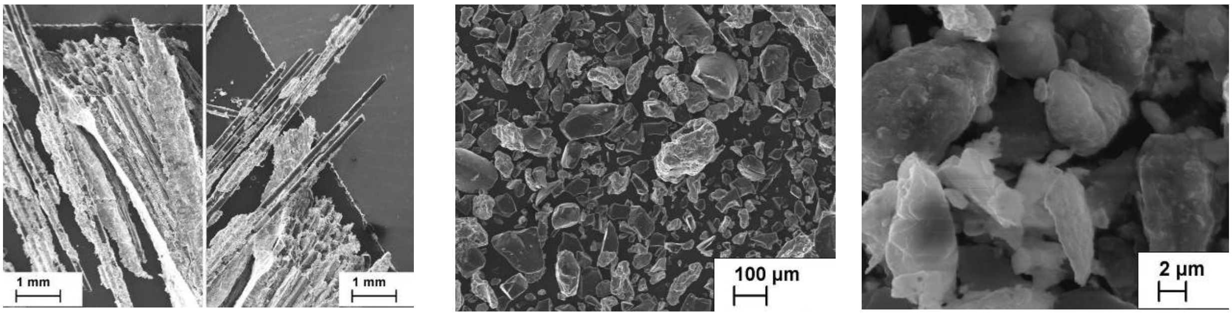
Table 2. Comparison of microhardness of boron fibres.

The microhardness of tungsten wire was 41.4 GPa. Due to much smaller values of microhardness of aluminium matrix - 2.0 GPa [1414], this component of the Al-W-B CM has not been studied.

3. Grindability of the Al-W-B composite material

Mechanical comminution of hot-pressed fibrous CMs consumes a considerable amount of energy, due to their high durability and wear resistance. In the present work the comminution process was carried out in several stages using a multifunctional disintegrator (DS-series) [15] designed in Tallinn Technical University (Estonia). The mechanical disintegration consisted of:

- Pre-crushing of the waste material to pieces smaller than 200x45x4 mm (Fig. 3a) in a jaw crusher
- Intermediate grinding of the pre-crushed material down to ~130 µm (Fig. 3b) by means of the multifunctional disintegrator DS-A3 [16].
- Fine grinding into 1-35 µm particles (Fig. 3c) in the laboratory disintegrator-separator DSL-175 operated in inertial and centrifugal modes.



3a) 3b) 3c)

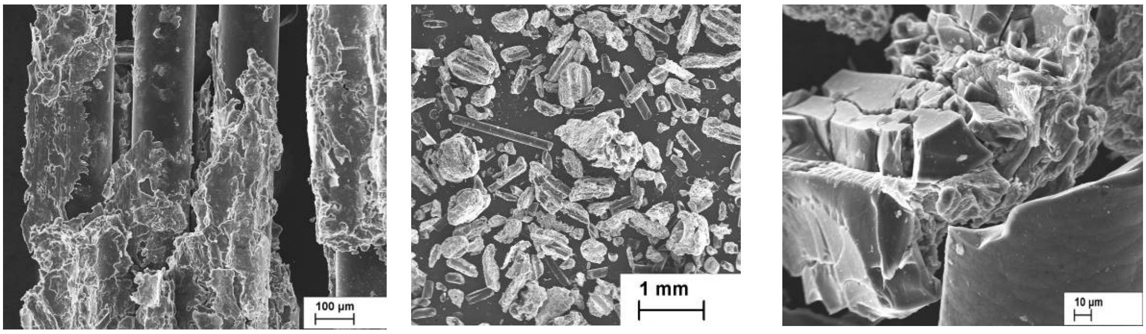
Fig.3. The progression of the Al-W-B CM waste grinding: a) source material; b) powder ground by the disintegrator DS-A3; c) final product.

4. Grindability assessment

In order to assess the grindability of a composite material, a number of consecutive grinding operations were performed and a relationship between the average particle size d_{50} (mm) and specific energy of crushing E_S (kWh/t) was established. The CM's fracture mechanism can be described as a set of stages:

1. Transverse breaking of structure constituents on a macro-scale (Fig. 4a) which happens in a jaw-crusher. The material maintains the fibre-to-matrix bonding.
2. During the preliminary crushing in disintegrator mills, after a series of intense impacts a separation of composite constituents occurs (Fig. 4b)
3. Further destruction occurs, i.e. a gradual de-bonding between B-W fibres and Al matrix as well as between boron and tungsten wire (Fig. 4c).
4. Finally, the components of the Al-W-B CM become detached from each other and continue to be reduced in size under shock loads.

Obtained product represents a mixture of powdered boron, tungsten fibres and crushed aluminium matrix.



4a) 4b) 4c)

Fig.4. Al-W-B composite material: a) after crushing in a jaw crusher; b) morphology of the Al-W-B composite powder after direct grinding with an energy E_S = 9,8 kWh/t; c) destruction of B-W fibres and their detachment from the matrix.

5. Dynamics of milling

Determination of the particle size distribution was carried out on the vibratory sieve shaker Analysette 3 PRO for materials with particle size of between 0.02-25 mm and the laser diffraction particle sizer Analysette 22 Compact for powders finer than 300 μm. Table 3 shows a relationship between the degree of crushing and particle size distribution.

Degree of crushing	E_S kWh/t	Mesh size, mm												d_{50}
		25	11,2	5,6	2,8	1,4	0,71	0,355	0,18	0,09	0,045	0,02	<0,02	
		Fraction %												
1*	4,9	0	15,2	34	20	8	4,5	4,5	4,4	6,3	3,2	0	0	0,73
2*	9,8	0	2,6	28	25	11	6,2	6,4	6,5	9,4	3	1,2	0,6	0,37
4*	19,6	0	0	12	26	12	8,2	8,9	9,7	15,2	5,2	2,3	0,8	0,24
8*	39,2	0	0	4,6	18	11	8,9	11,6	13	20	7,5	4,1	1,1	0,17
16*	78,4	0	0	1,5	6	3,8	11,9	15,5	17,4	26,8	10,1	5,5	1,5	0,13

Table 3. Particle size distribution and
energy dependence on the degree of crushing the Al-W-B CM

6. Possibility of practical application

A preliminary study of the microstructure and properties of the new material allows to make assumptions regarding a possible applications of the powdered Al-W-B composite material. First, it could be used as the source of boron in the production of aluminium alloys. As an example [17], green compacts (produced by Riga Technical University) made of Al-W-B powder which can be used as alloying additives are shown (Fig.5.).

a) b) c)

Fig.5. Green compacts made of Al-W-B powder:
a) a ring 60x25x8 mm; b) plates 15x30x8 mm; c) cylinders ø8x10 mm

The compacted Al-W-B pieces are injected into the bath with molten aluminium at 700-750°C.
Another area of possible application of composite powders is manufacturing of grinding/polishing tools [18], where the mechanically disintegrated Al-W-B composite powder is consolidated under pressure by the electrosintering process.

5. Conclusion

Studies have shown good prospect of milling waste Al-W-B composite material. The size and shape of particles along with their properties depend on the method and duration of grinding. Compacts made of the Al-W-B powder can be used for improving the properties of alloys and ceramic materials.

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