PRODUCTION AND CHARACTERIZATION OF Al - WC COMPOSITE POWDERS VIA MECHANICAL ALLOYING

M.Sc. Şelte A., Assoc. Prof. Dr. Özkal B.
Istanbul Technical University, Metallurgical and Materials Engineering Department, PML Laboratories,
34469, Maslak, Istanbul, Turkey
selte@itu.edu.tr, ozkal@itu.edu.tr

Abstract: *Mixtures of 10, 20 and 30 wt. % of tungsten carbide powder and aluminum powder were ball milled for 2, 4 and 8 hrs to investigate the effect of percentages of the reinforcement and mechanical alloying time on microstructural properties of the produced composite powders. Finer particles were tried to obtain in ductile matrix. The milled powders were analyzed using X-ray diffraction (XRD). Nano/micro particle size and distribution (PSD) technique was used to measure particle size and distribution. Scanning electron microscopy (SEM) was also performed to observe particle morphology.*

Keywords: NANO COMPOSITE POWDERS, Al-WC SYSTEM, MECHANICAL ALLOYING

1. Introduction

Despite of their poor friction and low wear resistance, aluminium alloys have been mostly preferred to use on automotive, aircraft and marine applications because of their low density and high specific strength, [1-5].

Aluminium-based metal matrix composites with small amount of particle size ordered as discontinuous hard phases as reinforcement have paid attention to remarkable research interest during recent years, [6]. Particularly, Al-based composites reinforced with ceramic particles are being demanded due to their high strength-to-weight ratios accompanied with high mechanical properties such as high strength, high modulus, high specific stiffness, fatigue resistance and wear resistance, [7]. These kind of metal matrix composites (MMCs) have been considered as the excellent candidates for automotive, aircraft and marine applications for a very long time, [8], [9]. Nevertheless, tungsten carbide (WC) is interesting reinforcing clearly leading very high hardness values and composite benefits [10-13].

In this respect, the aim of this study is to investigate the effects of particle size and amount of carbide addition on the production of Al-WC composite powders and to perform a detailed characterization of finer particles. The motivation of this study is related with the results of our previous findings during mechanical alloying of Cu-WC system [14].

2. Experimental Procedure

In this study, Al (Alfa Aesar, -325 mesh, 99.5% purity) and WC powders (Alfa Aesar, -325 mesh, 99.5% purity) were used. Powders were mechanically alloyed for 2, 4 and 8 hours. Elemental Al and WC powders were blended to constitute the composition of Al–10/20/30 wt% WC (hereafter called as Al10WC, Al20WC and Al30WC). Blended powders were mechanically alloyed (MA'd) for 2, 4 and 8h using a Spex™ Duo Mixer/Mill 8000D with a speed of 1200 rpm in a tungsten carbide (WC) vial with WC balls having a diameter of 6.35 mm (1 = 4 inches). The vials were sealed inside a Plaslabs™ glove box under purified Ar gas (99.995% purity) to prevent oxidation during MA. The ball-to-powder weight ratio (BPR) was 10:1. Powder particle size and distributions (PSD) were carried out in a Malvern™ Mastersizer Laser particle size analyser according to Mie's theory using ethanol as a dispersant. Finer particles were measured in Microtrac™ NanoFlex. All powders were dried at 100^{o}C to remove moisture for measuring true densities which were measured in Micromeritics™ AccuPyc II 1340 Gas Pycnometer under He atmosphere.

3. Results and Discussion

Particle size and distribution of initial powders were illustrated in the Figure 1.

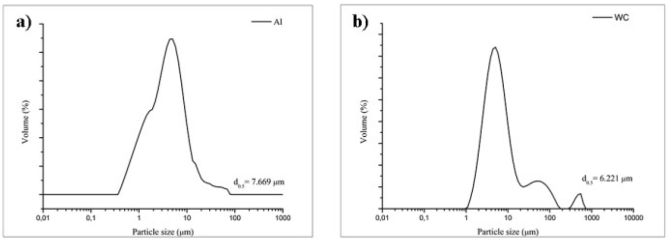

Figure 1. *Particle size and distribution of initial powders*

The d(0.5) value of particle sizes were found for initial Al and WC powders as 7.669 µm and 6.221 µm, respectively. As seen from the figures, WC powder particle size has a wide range of size distribution in coarse particle sizes. After performing mechanical alloying process, powder particle size and distribution of powders were described in Figure 2.

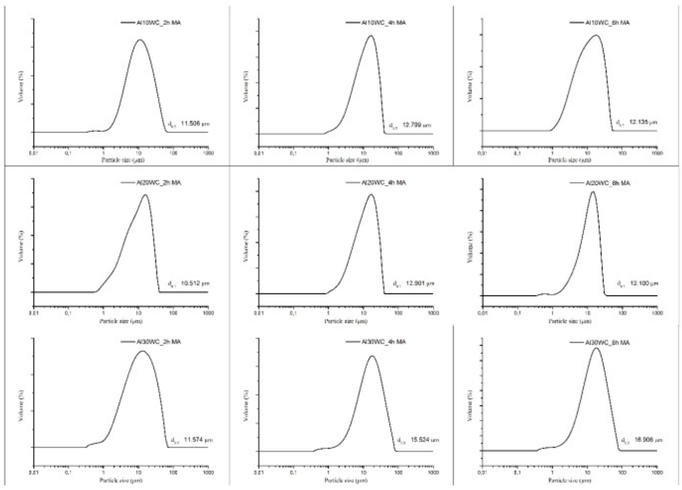

Figure 2. *Particle size and distribution of initial powders*

As seen from the figure, mean particle size of the powders changed slightly according to mechanical alloying (MA) time and hard phase amount. It is clearly seen that, MA time can be effective while the presence of high amount of hard phase. Otherwise, small amount of changes occurred by increasing milling time. It can be concluded from the figure that the agglomeration tendency increased even the mean particle size decreased.

True densities of the MA'ed powders were given in Table 1. And Table 2 summarizes the theoretical densities of the systems.

Table 1. *True densities of MA'ed powders*

Powder	Milling Time (h)	True Density (g/cm^3)
Al10WC	2	2,81
	4	2,86
	8	3,27
Al20WC	2	3,06
	4	3,28
	8	3,28
Al30WC	2	2,90
	4	2,96
	8	3,30

Table 2. *Theoretical densities of the powder compositions studied.*

Powder	Theoretical Density (g/cm^3)
Al10WC	2,94
Al20WC	3,24
Al30WC	3,59

The true densities values of MA'ed powders measured by gas pycnometer are considerably lower than theoretical densities for early milling times. This was occurred for Al10WC powder until 8 hours milling time, in where it was 4 hours for Al20WC. Besides, all measured densities for Al30WC were below the calculated value. This could have been existed by the high faults, misorientations of metal sublattice which is regulated by metal structural vacancies. Therefore, the imperfection in milling of Al-WC in high rate of WC is higher than Al-WC in low rate of WC can be deduced from these results.

Figure 3 shows the XRD patterns of the milled powders. All the detected peaks are characteristic of the Al (ICDD No: 04-0787) and WC (ICDD No: 89-2727).

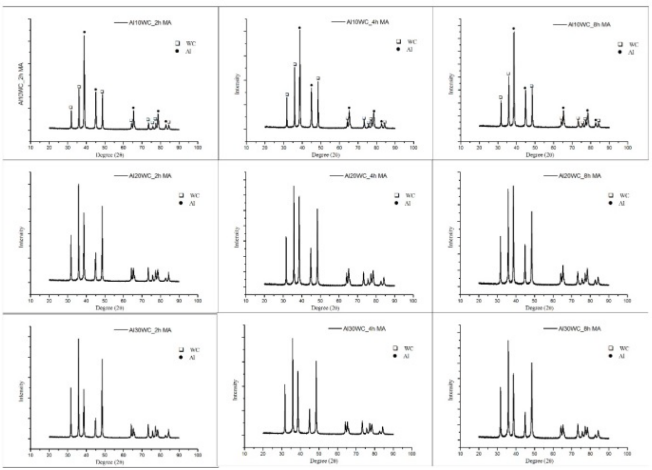

Figure 3. *XRD patterns of MA'ed powders*

Peaks belong to Al and WC powders can be seen clearly from the figure. It was observed that Al peak intensities increased and the peaks broadened by increasing milling time. Slight sliding in Al peaks was also detected. It was concluded that these attitudes appeared as a result of distortion and misorientation in lattice of Al owing to tensile and compressive loadings occurred by mechanical alloying. This situation was verified by calculating strain rates and changes in d spacings of Al peaks which were given in Table 3 and Table 4. However, the percentage of WC addition affected the broadening and intensities of Al peaks until 30 wt.% of WC. This can be a consequence of exceeding the maximum number of atoms which were needed for formation of hard-core solution. Therefore the increasing changes in intensity and peak broadening commenced to decline in the presence of high amount of WC addition.

Table 3. *Strain rate changes (%) in Al peaks against milling time.*

Powder	MA Time (h)	Strain Rate (%)
Al10WC	2	0.2123
	4	0.3911
	8	1.3226
Al20WC	2	0.3566
	4	0.6127
	8	1.6115
Al30WC	2	0.3324
	4	0.4469
	8	1.2901

Table 4. *Strain rate changes in d-spacings (%) in Al peaks against milling time.*

Powder	MA Time (h)	Change in d-spacings (%)
Al10WC	2	0.4155
	4	0.7101
	8	0.7088
Al20WC	2	0.6859
	4	0.9948
	8	0.8523
Al30WC	2	0.8523
	4	0.8367
	8	0.8107

Strain rates were determined by calculating the arithmetic mean of dominant three planes. D-spacings were estimated only by taking account of (111) plane of Al. As seen from the Table 3 and 4, strain rates increased by increasing milling time. After high percentage of reinforcement material, WC, this increase has become declining parabolic. Changes in d-spacings were determined on the same shifting direction. Hard core solid solution was considered to be a basis for this situation for high rate reinforcement existence.

Scanning electron microscope (SEM) micrographs were given in Figure 4.

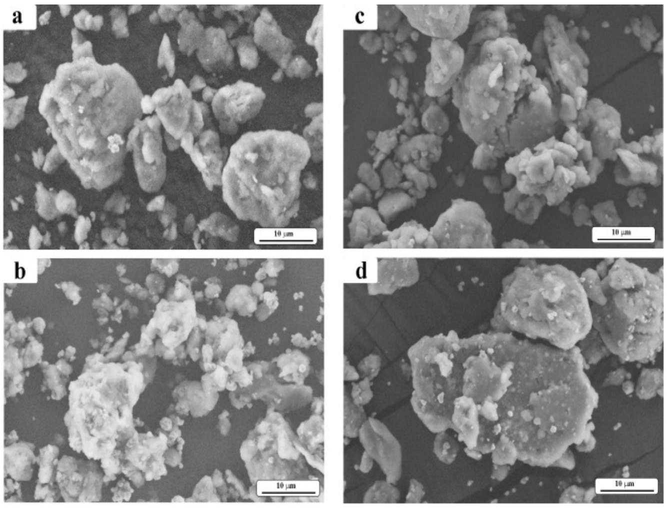

Figure 4. *SEM images of a) Al10WC 2h MA, b) Al10WC 8h MA, c) Al30WC 2h MA and d) Al30WC 8h MA at x2000 magnification.*

The effects of hard phase ratio and mechanical alloying time on the morphology of composite powders can be easily distinguished. The higher the hard phase rate, the more agglomeration tendency can be observed. In other respects, finer carbide particle existence increased by milling time and hard phase raise. WC particles were seems to be covered with Al particles and it was considered that the agglomeration tendency rate was multiplied as a result of increasing ductile Al milling time. Smaller and finer WC particles which were achieved via milling in the ductile Al matrix can also be seen in Figure 5.

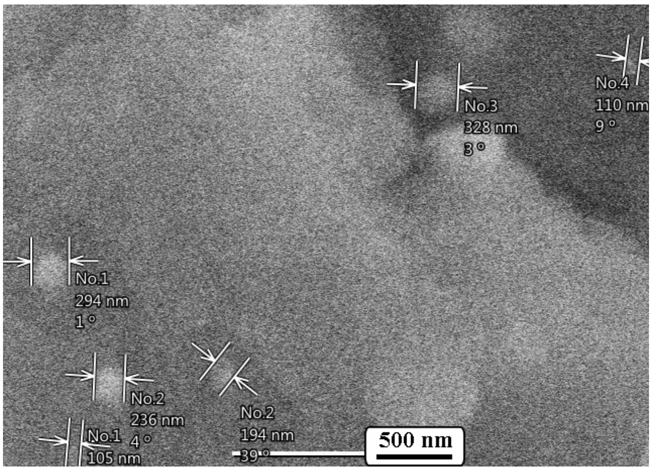

Figure 5. *SEM images Al30WC 8h MA at x25000 magnification.*

As seen from the Figure 5, it possible to obtain finer, submicron and nano particles. The presence of both phases provided suitable environment for production of nano structured powder composite despite the increasing tendency of agglomeration. It was clearly observed that obtaining finer/nano particles with increasing milling time by the existence of ductile matrix was convincingly possible.

4. Conclusions

In this study, the behaviors of WC and Al powders during mechanical alloying were investigated. According to results of the experiments these conclusions were obtained:

1. Although the mean particle size and the distributions of particle analysis applied to different mechanical alloyed powders does not show a significant difference, it was possible to observe finer hard particles inside of Al matrix during microstructural examinations.
2. Al peaks shifted slightly to the same direction. This was concluded as a result of distortion at crystal occurred by WC atoms which tried to constitute hard core solid solution.
3. It was observed that the strain value increases for longer mechanical alloying times.

References

[1]. C.L. He, Q. Zhou, J.T. Liu, X.W. Geng, Q.K. Cai, Effect of size of reinforcement on thickness of anodized coatings on SiC/Al matrix composites, Materials Letters, 62, 2008, 2441.

[2]. M. Yandouzi, P. Richer, B. Jodoin, SiC particulate reinforced Al–12Si alloy composite coatings produced by the pulsed gas dynamic spray process: Microstructure and properties, Surface and Coatings Technology, 203, 2009, 3260.

[3]. R.L. Sun, Y.W. Lei, Microstructure and hardness of laser clad SiCp–Al composite coatings on Al alloys, Materials Letters, 62, 2008, 3272.

[4]. S.O. Chwaa, D. Kleina, F.L. Tomaa, G. Bertranda, H. Liaoa, C. Coddeta, A. Ohmori, Microstructure and mechanical properties of plasma sprayed nanostructured TiO2–Al composite coatings, Surface and Coatings Technology, 194, 2005, 215.

[5]. S. Yang, N. Chena,W. Liua, M. Zhong, In situ formation of MoSi2/SiC composite coating on pure Al by laser cladding, Materials Letters, 57, 2003, 3412.

[6]. S.C. Tjong, Novel nanoparticle-reinforced metal matrix composites with enhanced mechanical properties, Advanced Engineering Materials, 9, 2007, 639.

[7]. A.A. El-Daly, M. Abdelhameed, M. Hashish, Walid M. Daoush, Fabrication of silicon carbide reinforced aluminum matrix nanocomposites and characterization of its mechanical properties using non-destructive technique, Materials Science & Engineering A, 559, 2013, 384.

[8]. S. Bathula, R.C. Anandani, A. Dhar, A.K. Srivastava, Microstructural features and mechanical properties of Al 5083/SiCp metal matrix nanocomposites produced by high energy ball milling and spark plasma sintering , Materials Science and Engineering: A, 545, 2012, 97.

[9]. H.R. Hafizpour, A. Simchi, S. Parvizi, Analysis of the compaction behaviour of Al–SiC nanocomposites using linear and non-linear compaction equations, Advanced Powder Technology, 21, 2010, 273.

[10]. H.C. Man, Y.Q. Yang,W.B. Lee, Laser induced reaction synthesis of TiC+WC reinforced metal matrix composites coatings on Al 6061, Surface and Coatings Technology, 185, 2004, 74.

[11]. G. Bolelli, L. Lusvarghi, M. Barletta, HVOF-sprayed WC–CoCr coatings on Al alloy: Effect of the coating thickness on the tribological properties, Wear, 267, 2009, 944.

[12]. R. Jendrzejewski, K. Van Acker, D. Vanhoyweghen, G. Śliwiński, Metal matrix composite production by means of laser dispersing of SiC and WC powder in Al alloy, Applied Surface Science, 255, 2009, 5584.

[13]. M.H. Staia, M. Cruz, N.B. Dahotre, Wear resistance of a laser alloyed A-356 aluminum/WC composite, Wear, 251, 2001, 1459.

[14]. A. Selte, B. Ozkal, Infiltration behavior of mechanical alloyed 75 wt.% Cu - 25 wt.% WC powders into porous WC compacts, Archives of Metallurgy and Materials, 60, 2015 1565.