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Optimization of Mechanical Alloying Parameters of Cu25W Electrical Contact Material

S. Biyik[a,*] and M. Aydin[b]

[a]Karadeniz Technical University, Abdullah Kanca Vocational School, Department of Machinery and Metal Technologies, Trabzon, Turkey

[b]Karadeniz Technical University, Department of Mechanical Engineering, Trabzon, Turkey

In this study, the effect of mechanical alloying parameters, namely the effect of process control agent, ball-to-powder weight ratio and milling duration, on the synthesis of Cu25W composite powder was investigated. Planetary-type ball milling equipment was used to conduct mechanical alloying experiments. Stearic acid was used as the process control agent in order to establish a balance between cold welding and fracturing. The optimum amount of stearic acid was determined as a function of particle size and milling time at constant speed. By using this optimum amount of process control agent, three different ball-to-powder weight ratio values were also employed, and the effect of ball-to-powder weight ratio on particle size and morphology of Cu25W composite powders was investigated. The microstructural evolution of the milled powders was characterized using scanning electron microscopy and laser diffraction analysis. The test results have shown that the morphology and particle size distribution of the milled powders change significantly depending upon the milling parameters. In addition, higher ball-to-powder weight ratio values tend to lower the milling duration for the same amount of particle size reduction. However, particle size reduction suffers beyond the maximal value of ball-to-powder weight ratio, especially in the later stages of mechanical alloying.

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1. Introduction

Optimization studies enable scientists to find the optimal solution for a certain problem across a wide variety of disciplines [1–4]. For example, the optimization of electrical contact materials for particular applications is crucial for the reliable operation of relays and contactors [5]. The performance of electrical contacts is mainly affected by material transfer between contacts due to the arc-erosion phenomenon. Material parameters, such as composition and homogeneity of the powder mixture, also play an important role in switching performance. Hence, conventional powder metallurgy method is combined with mechanical alloying (MA) technique to obtain composites having fine and homogeneous dispersion of refractory metals, such as tungsten and molybdenum, within the matrix.

Composite materials are used in a wide range of applications [6–13]. A lot of work has been done towards producing and evaluating the electrical performance of contact materials [14–21]. However, the effect of MA parameters on the production of Cu25W contact material has not yet been investigated in detail. Therefore, the purpose of this study is to optimize MA parameters for the production of this material. This study is of vital importance to increase lifetime of the contacts.

*corresponding author; e-mail: serkanbiyik@ktu.edu.tr

2. Experimental procedures

In this study, Cu (44 μm, 99% purity) and W (average particle size (APS) of 12 μm, 99.9% purity) powders were used as the matrix and the reinforcement materials, respectively. Both powders (Fig. 1) were supplied by Alfa Aesar Corporation. A planetary-type ball mill (Fritsch Pulverisette 6) was used to carry out milling experiments with a milling speed of 300 rpm and a ball-to-powder weight ratio (BPR) of 10:1. W powders were added to Cu powders in the amount of 25 wt.%.

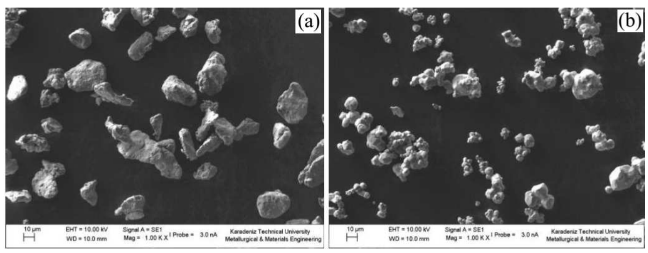

Fig. 1. Morphology of as-received (a) Cu and (b) W powders.

First, MA experiments were conducted to determine optimum PCA content. For this aim, various amounts of stearic acid (0, 0.5, 1, 2 and 3 wt.%) were added separately to powder mixtures. After determining the optimum PCA content, several different MA tests were carried out to define optimum BPR value. Following each test, with BPR values of 5:1, 10:1 and 20:1, the powder samples were withdrawn for particle size measurements by laser diffractometry (Mastersizer 2000, Malvern Instruments).

Morphological evolution of the powder mixture with the increasing milling duration was also investigated by scanning electron microscopy (SEM; Zeiss Evo LS 10).

3. Results and discussion

The average particle size (APS) values of the Cu25W powder mixture with respect to PCA content and milling duration are listed in Table I. The curves in Fig. 2 were plotted using the APS values from this table.

It was found that particle size had generally decreased with increasing milling duration. The minimum particle size (0.726 microns) was obtained in the powders having 2 wt.% of stearic acid, after milling for 25 h. Cold welding dominates the fracturing of the powders having lesser amounts of stearic acid, especially at contents of 0.5 and 1 wt.%. Here, it should be also emphasized that the amounts of stearic acid, larger than 2 wt.%, decrease the number of ball-to-powder collisions and reduce the efficiency of particle size reduction. By comparing the APS values obtained from each experiment, optimum PCA content is determined as 2 wt.%.

TABLE I

Average particle size values (d_{50}, μm) of Cu25W powder mixture as function of PCA content and milling duration.

PCA content	Milling duration [h]					
[wt.%]	0.5	1	4	10	16	25
0	27.771	32.743	32.760	17.225	9.366	6.964
0.5	26.911	23.869	28.296	26.096	25.130	21.462
1	20.490	38.544	26.239	16.646	15.947	9.792
2	24.401	25.190	12.765	7.290	1.933	0.726
3	25.679	27.038	22.286	13.394	6.463	1.775

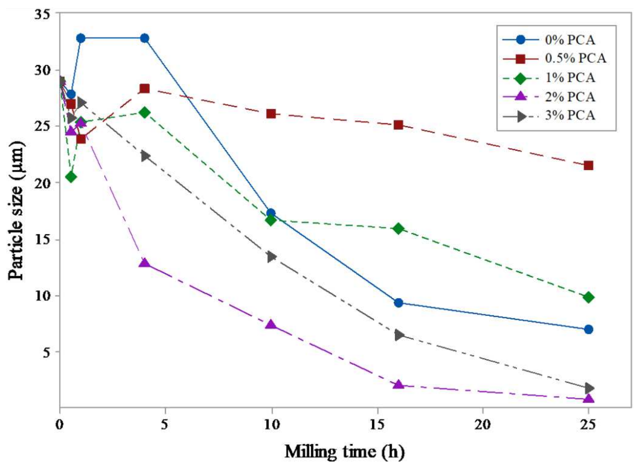

Fig. 2. Particle size variation of Cu25W powder mixture as a function of PCA and milling duration.

The APS values of the Cu25W powder mixture with respect to BPR value and milling duration are listed in Table II. The curves in Fig. 3 were plotted using APS values from this table. As can be seen from Fig. 4, powder particles exhibit different morphology with increasing BPR value and milling duration.

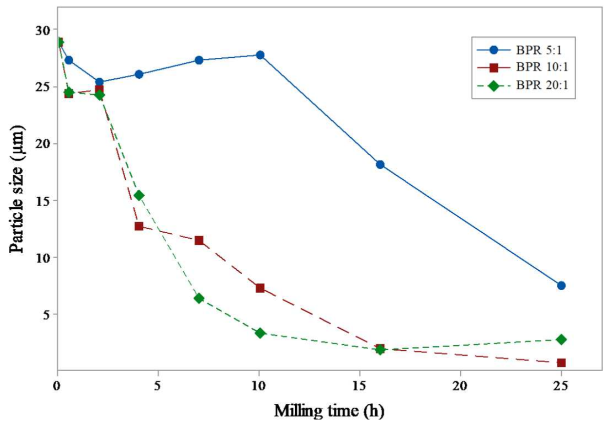

Fig. 3. Particle size variation of Cu25W powder mixture as a function of BPR and milling duration.

Fracturing of powder particles is flattening them due to the increase in cold welding at a BPR of 5:1 (Fig. 4a, d, g and j). Therefore, flake morphology lasts even after 25 h (Fig. 4m). However, with the increase in BPR value, fracturing (size reduction) continues repeatedly throughout the milling period. Thus, a more homogeneous dispersion of W reinforcement particles in the Cu matrix was achieved at a BPR of 10:1, owing to balance between cold welding and fracturing (Fig. 4b, e and h). As can be seen from Fig. 4e and f, high BPR values (10:1 and 20:1) promote fracturing after 4 h of milling duration.

With continued milling up to 16 h, the efficiency of particle size reduction was very high at a BPR of 20:1 (Fig. 4c, f and i). 16 h of milling duration (Fig. 4k and l) may be referred as the point of intersection (approx. 1.8 μm). However, after this critical point, further reduction in particle size was only achieved at a BPR of 10:1 (0.726 μm).

On the other hand, the increment in particle size may be attributed to the increase in cold welding, due to the increasing amount of grinding balls at higher BPR values. Therefore, optimum BPR value was determined to be 10:1. When comparing each milling experiment, the powder morphology was different at various BPR values, namely it was flaky at 5:1 (Fig. 4m), equiaxed at 10:1 (Fig. 4n), and flaky plus semi-equiaxed at 20:1 (Fig. 4o). Besides, the powder yield decreases beyond the optimal BPR value.

TABLE II

Average particle size values (d_{50}, μm) of Cu25W powder mixture as function of BPR and milling duration.

	Milling duration (h)						
BPR	0.5	2	4	7	10	16	25
5:1	27.356	25.363	26.116	27.394	27.792	18.158	7.459
10:1	24.401	24.789	12.765	11.502	7.290	1.933	0.726
20:1	24.500	24.300	15.479	6.408	3.247	1.789	2.692

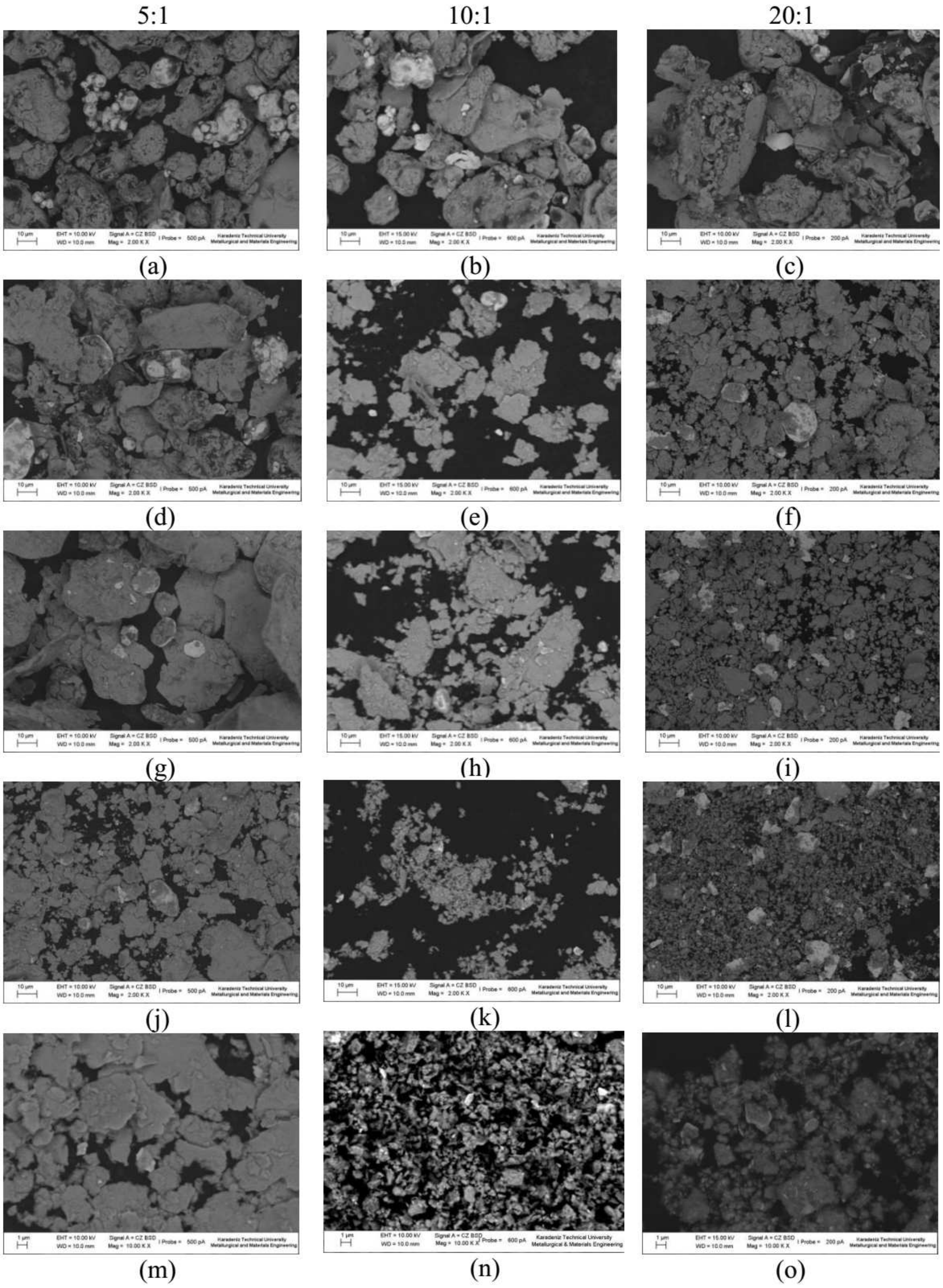

Fig. 4. Morphology of the Cu25W powder mixture, milled with different BPRs for various values of milling duration; (a,b,c) 0.5 h, (d,e,f) 4 h, (g,h,i) 7 h, (j,k,l) 16 h and (m,n,o) 25 h.

4. Conclusions

According to MA experiments with different PCA contents, particle size generally decreases with increasing milling duration. The minimum particle size (0.726 microns) was obtained in the powders having 2 wt.% of stearic acid, after milling for 25 h. Cold welding dominates the fracturing in the powders having smaller amounts of stearic acid, especially with a content of 0.5 and 1 wt.%. Excess amounts of stearic acid decrease the number of the ball-to-powder collisions and the efficiency of particle size reduction. Therefore, optimum PCA content is determined to be 2 wt.%.

Plastic deformation and agglomeration are observed in the powder mixture milled with a BPR of 5:1, whereas size reduction becomes apparent at higher BPR values. In addition, higher BPR values tend to lower the milling duration for the same amount of particle size reduction. However, particle size reduction suffers beyond the maximal value of BPR, especially in the later stages of MA. The rate of size reduction increases with increasing BPR value up to some extent (16 h). Hence, the optimal value of BPR is determined to be 10:1. The powder morphology is different at various BPR values, namely it is flaky at 5:1, equiaxed at 10:1, and flaky plus semi-equiaxed at 20:1.

Excessive or prolonged milling durations cause some of the powder charge to become stuck to the inner walls of the vial due to the increase in temperature and due to cold welding, especially at a BPR of 20:1. This situation counteracts the further reduction in particle size. Besides, the powder yield is decreased beyond the optimal BPR value and milling time. Therefore, the powders should not be milled longer than 25 h.

Acknowledgments

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References

[1] A. Nobakhti, *Cognitive Computat.* **2**, 97 (2010).

[2] J. An, Q. Kang, L. Wang, Q. Wu, *Cognitive Computat.* **5**, 188 (2013).

[3] Y. Hei, W. Li, M. Li, Z. Qiu, W. Fu, *Cognitive Computat.* **7**, 359 (2015).

[4] M. Bilal, H. Mujtaba, M.A. Jaffar, *Cognitive Computat.* **7**, 680 (2015).

[5] P.G. Slade, *Electrical Contacts: Principles and Applications*, CRC, Boca Raton 2014.

[6] S. Biyik, M. Aydin, *Acta Phys. Pol. A* **127**, 1255 (2015).

[7] M. Mansoor, M. Shahid, *Acta Phys. Pol. A* **128**, B-276 (2015).

[8] A. Yusefi, N. Parvin, *Fusion Engin. Design* **114**, 196 (2017).

[9] I. Akkurt, R.B. Ermis, P. Bas, K. Gunoglu, *Acta Phys. Pol. A* **128**, B-34 (2015).

[10] I.K. Yilmazcoban, S. Doner, *Acta Phys. Pol. A* **130**, 342 (2016).

[11] A. Moghanian, F. Sharifianjazi, P. Abachi, E. Sadeghi, H. Jafarikhorami, A. Sedghi, *J. Alloys Compound.* **698**, 518 (2017).

[12] N. Ozsoy, M. Ozsoy, A. Mimaroglu, *Acta Phys. Pol. A* **130**, 297 (2016).

[13] B. Buyuk, A.B. Tugrul, M. Cengiz, O. Yucel, G. Goller, F.C. Sahin, *Acta Phys. Pol. A* **128**, B-132 (2015).

[14] S. Biyik, F. Arslan, M. Aydin, *J. Electronic Mater.* **44**, 457 (2015).

[15] S. Biyik, M. Aydin, *Acta Phys. Pol. A* **129**, 656 (2016).

[16] Z.J. Lin, S.H. Liu, J.G. Li, J.L. Chen, M. Xie, X.D. Li, M. Zhang, Q. Zhu, D. Huo, X.D. Sun, *Mater. Design* **108**, 640 (2016).

[17] Y.P. Wang, H.Y. Li, *Metallurg. Mater. Trans. A* **48**, 609 (2017).

[18] N. Ray, B. Kempf, G. Wiehl, T. Mutzel, F. Heringhaus, L. Froyen, K. Vanmeensel, J. Vleugels, *Mater. Design* **121**, 262 (2017).

[19] H.J. Noh, J.W. Kim, S.M. Lee, H. Jang, *Tribol. Int.* **111**, 39 (2017).

[20] Z. Wei, L. Zhang, T. Shen, Z. Qiao, H. Yang, X. Fan, L. Chen, *J. Mater. Engin. Perform.* **25**, 3662 (2016).

[21] N. Ray, B. Kempf, T. Mutzel, L. Froyen, K. Vanmeensel, J. Vleugels, *Mater. Design* **85**, 412 (2015).