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Characterization of Functionally Graded Bronze Matrix Ceramic Reinforced Composite Materials

Serkan Islak*[1], Aimen Mohamed Abushraida[2]

Abstract

In this study, ceramic reinforced bronze matrix functionally graded materials (FGMs) were produced by using powder metallurgy method. B_4C, TiC, Mo_2C and SiC were selected as ceramic reinforcements. The samples with compositions bronze + 10% SiC, bronze + 10% B_4C, bronze + 10% Mo_2C, and bronze + 10% TiC were sintered at 750 °C for 90 minutes. Investigations were carried out to assess the mechanical properties and microstructures of specimens. For this purpose, optical microscope, scanning electron microscope (SEM-EDS), and X-ray diffraction (XRD) analysis were applied for microstructure investigations. Sample hardness testing was carried out with the help of Vickers hardness testing device. Composite layers of ceramic particles were homogeneously distributed. Little pore formation was observed. While the upper and lower composite layers of the FGMs produced were hard, the middle layer was found to be ductile. The highest hardness value was reached in the B_4C reinforced FGM.

Keywords: FGM, bronze, ceramic reinforcements

1. INTRODUCTION

Functionally graded materials (FGMs) are advanced composite materials that are characterized by variations in their composition or microstructure in a specific direction. The desired properties can be achieved in a single bulk material of FGMs, which makes them highly applicable for mechanical and tribological applications [1-3]. FGMs having superior properties are produced by combining different reinforcement phases. This FGM strategy eliminates the use of high cost surface engineering in several applications [4,5]. The selection of the reinforcement helps to achieve a high-level graded performance in these FGMs [6-8]. The development of composite materials with graded properties known as FGMs led to a revolution in the manufacturing of mechanical parts, particularly in the automotive, aviation and biomedical industries [9-11]. FGMs' components have certain useful characteristic properties, which meet the specific needs of certain industrial

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processes; therefore, they effectively overcome the shortcomings of traditional composite materials. FGMs have many advantages over conventional and composite materials, such as [12-15]: (i) FGMs have an interface layer, that is fully capable of attaching two components made of incompatible materials, which allows them to substantially increase the bond strength. (ii) FGM coating and interfaces can be used to reduce residual and thermal stresses. (iii) FGM coating can be used for connecting materials and eliminating endpoint and interface stresses. (iv) FGM coating not only enhances the strength of connections, as but it can also reduce the crack driving force [16-18].

During recent years, bronze matrix composites have gained widespread importance because they are utilizable in several technological applications. Since they have high conductivity but low mechanical strength, they are taken through dispersion strengthening process, which developed new composite materials with far better properties. Particles including carbides, oxides, and borides are not soluble in the bronze matrix. Moreover, they have high thermal stability to bear high temperatures that makes them a good choice for reinforcement process. Particulate-strengthened copper matrix composites allow making desirable improvements in the mechanical properties such as high temperature tolerance, improved tensile properties, increased stiffness, and better wear resistance [19-21].

In this study, ceramic reinforced bronze matrix FGMs were produced by using powder metallurgy method. Investigations were carried out to evaluate the mechanical properties and microstructures of specimens.

2. MATERIALS AND METHODS

The bronze (Cu-15Sn) powder was selected as the base matrix and the ceramic carbide reinforcements: B_4C, SiC, Mo_2C and TiC are chosen with 10% (mass fraction). The size and purity of the selected powder were: bronze powder (-325 mesh particle size, 99.9% purity), B_4C (-325 mesh particle size, 98% purity), SiC (400 mesh particle size, ≥ 97.5% purity), TiC (-325 mesh particle size, 98% purity), and Mo_2C (-325 mesh particle size, 99.5% purity). Figure 1 shows SEM images of the chosen powders used in the production of FGMs.

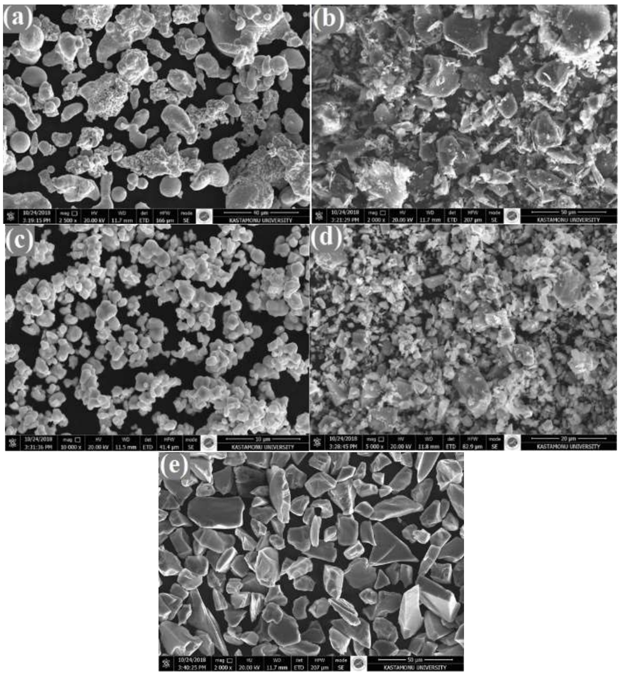

Figure 1. SEM images of powders:(a) bronze, (b) B_4C, (c) Mo_2C, (d) TiC, and (e) SiC

The test samples preparation for different types of reinforcements were carried out in several stages that are summarized in the following steps:

• Mixing: For the mixing process, the powders were subjected to mixing for 45 minutes at speed of 20rpm.

• Compact pressing process: In this process, the powders were placed in a cylindrical mold with a 13mm diameter. The 10% (mass friction) reinforcement powder was added to the powder matrix in lower and upper layers and pressed at 500MPa to produce a 6mm thick cylindrical composite sample with a 13mm diameter (with three 2mm layers), as shown in Figure 2.

• Sintering: The samples were sintered in a tube furnace under a protective argon gas atmosphere. The sintering temperature was 750 ºC and the duration was 90 min. with a heating and cooling rate of 10 ºC/min. In the literature, the sintering temperature was not exceeded 700 ºC in order to avoid liquid phase sintering for Cu-15Sn [22].

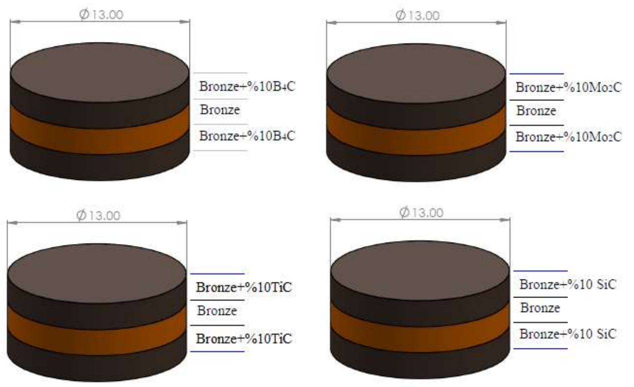

Figure 2. The samples shape and dimensions

For determining the hardness level of the produced samples, we used a Shimadzu HMV-G21 model digital microhardness machine at 200 g load. For accurate determination of hardness, hardness values were measured from the upper, middle, and lower layers of the samples. The hardness values of these layers were taken from different regions and these values were taken into the medium. These different hardness values are given as the error bar in the hardness graph.

For metallographic examinations, the obtained metallography samples were cleaned on 60-1200 mesh papers. Then, the surfaces of the samples were polished with the help of diamond spray. For microstructure investigations, the samples should be etched for 20 seconds in 5 g $FeCl_3$+50ml HCl+100 ml H_2O solution. Energy dispersive spectroscopy (EDS), scanning electron microscopy (SEM), and X-ray diffraction (XRD) were used to understand the phase structures. For SEM analysis, a FEI QUANTA 250 FEG brand SEM device was used. Phases of samples were identified by mean of X-ray diffraction using a Bruker D8 Advance model diffractometer.

3. RESULTS AND DISCUSSION

Figure 3-6 shows the structures of FGMs. In these photographs, triple (composite-middle-composite) layers and enlarged photographs of these regions as well as interface parts are seen in detail. The composite layers and the middle part are clearly distinguished. The B_4C, Mo_2C, TiC and SiC grains were distributed in a similar manner and relatively homogeneously in the bronze matrix. These ceramic particles are located in places where the bronze grains meet. There was no breakage and crack formation at the interface surface. Pore formation was observed in the FGMs.

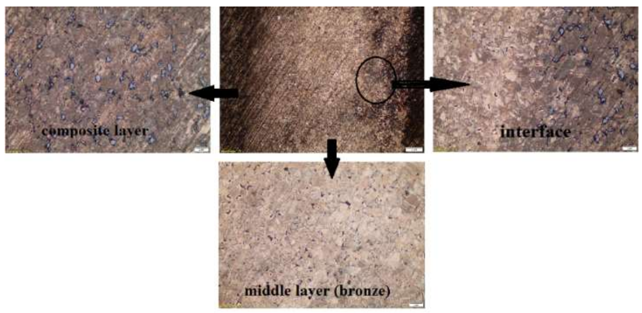

Figure 3. Optical microscope images of B_4C reinforced bronze matrix FGM

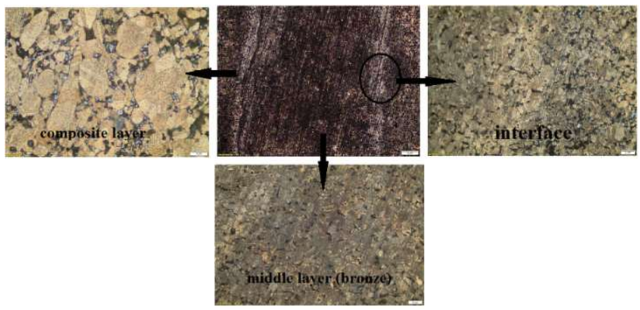

Figure 4. Optical microscope images of Mo_2C reinforced bronze matrix FGM

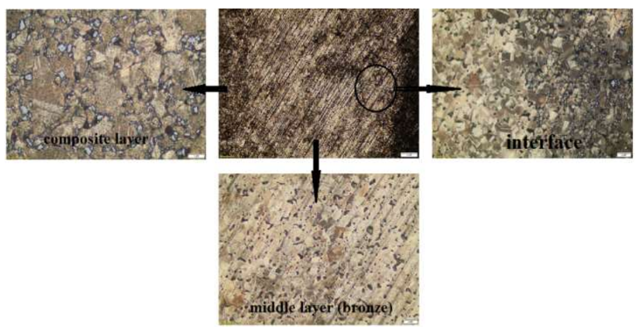

Figure 5. Optical microscope images of TiC reinforced bronze matrix FGM

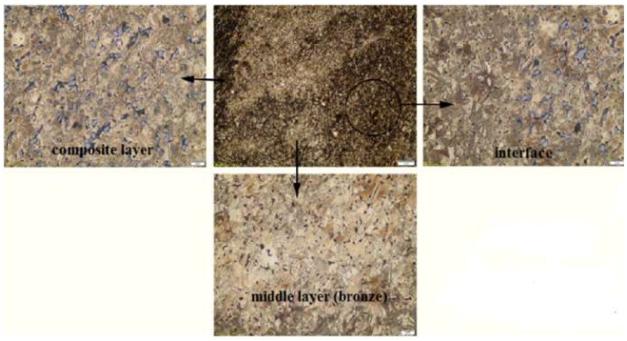

Figure 6. Optical microscope images of SiC reinforced bronze matrix FGM

FGMs have been analyzed by using SEM-MAP analysis to determine the distribution of reinforcing particles (Figure 7). The basic elements are Cu and Sn. The other elements are B, Mo, Ti, Si and C. It is clear that reinforcing particles are distributed uniformly. The homogeneous distribution of the elements has a positive effect on the physical, chemical and mechanical properties of the material [23].

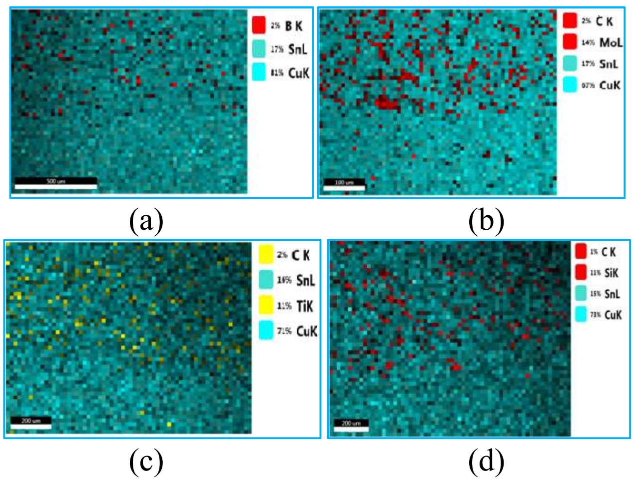

Figure 7. SEM-MAP analysis of FGMs: (a) B_4C, (b) Mo_2C, (c) TiC and (d) SiC

XRD analysis was performed for FGMs to determine whether a phase that would bind the matrix and the carbide particles at the interface. Figures 8 shows the XRD analysis of FGMs. No intermetallic compound was formed between the carbide particles and the matrix. This is due to the absence of any chemical reaction between the matrix and the carbides. In the bronze matrix, α-Cu and Cu_3Sn phases were formed as seen from XRD graphs. These phases were also identified in the literature on bronze [24]. In addition, carbide phases are clearly seen in XRD graphs.

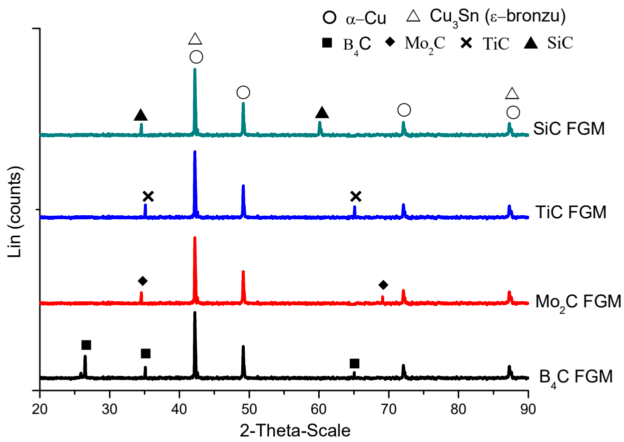

Figure 8. XRD analysis of the FGMs

The hardness graph of FGMs is shown in Figure 9. The hardness value of the middle layer is about 95 $HV_{0.2}$, while the hardness values of composite layers are 210 $HV_{0.2}$ for B_4C, 130 $HV_{0.2}$ for Mo_2C, 176 $HV_{0.2}$ for TiC and 197 $HV_{0.2}$ for SiC. The hardness of the composite layers is very high hardness compared to the middle layer. This rate of increase is about 35% in Mo_2C additive, 100% in SiC additive, 75% in TiC additive and approximately 121% in B_4C additive. Several factors cause a growth in hardness. The hardness of the composite elements, the dispersion strengthening effect and the effect of the hard particles on the movement of dislocations, depending on the mixture rule [25, 26]. Since the composite layers are harder than the middle layer, the wear resistance of the composite layers is expected to increase. This is in agreement with other studies [27-29]. An increase in fatigue strength is expected in FGMs with hard outer layers. This is another effect of high hardness on mechanical properties [30].

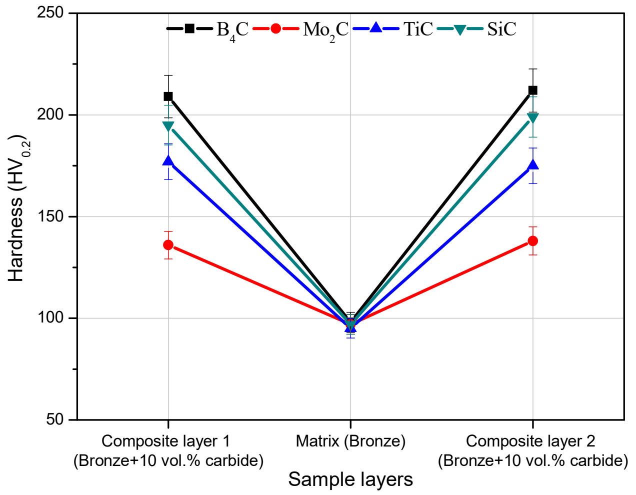

Figure 9. Hardness graph

4. RESULTS

In this study, the microstructure and hardness properties of the FGMs were experimentally investigated in detail. Ceramic reinforced bronze matrix FGMs were successfully produced by using powder metallurgy method. It is seen from both optical photographs and SEM-MAP images that ceramic particles were homogeneously distributed. At the microstructure, little pore formation was observed. The hardness of the FGMs showed an increase with reinforcements. While the hardness of the matrix was about 95 $HV_{0.2}$, the maximum hardness was measured in bronze-10%B_4C composite as 212 $HV_{0.2}$.

REFERENCES

[1] Z. Zhong-tao, L. Ting-ju, Y.Hong-yun, Z. Jian and L. Jie, "Preparation of Al/Si functionally graded materials using ultrasonic separation method", *China Foundry*, 5, 3, pp. 194−198, 2008.

[2] S.C. Ram, K. Chattopadhyay and I. Chakrabarty, "High temperature tensile properties of centrifugally cast in-situ Al-Mg_2Si functionally graded composites for automotive cylinder block liners", Journal of Alloys and Compounds, 724, pp. 84-97, 2017.

[3] N. Radhika and R. Raghu, "Development of functionally graded aluminum composites using centrifugal casting and influence of reinforcements on mechanical and wear properties", *Transactions of Nonferrous Metals Society of China*, 26, pp. 905−916, 2016.

[4] S. Jamian, Y. Watanabe and H. Sato, "Formation of compositional gradient in Al/SiC FGMs fabricated under huge centrifugal forces using solid-particle and mixed-powder methods", Ceramics International, 45, 7, pp. 9444-9453, 2019

[5] H. Kwon, G.G. Lee, M. Leparoux and A. Kawasaki, "Functionally graded dual-nano particulate-reinforced aluminum matrix composite materials", *Journal of Physics: Conference Series*, 419, pp. 1−4, 2013.

[6] Y. Miyamoto, W.A. Kaysser, B.H. Rabin, A. Kawasaki and R.G. Ford, (1999). Functionally Graded Materials Design, *Processing and Applications. Springer, US, Boston*, 1999.

[7] S. Heuer, T. Lienig, A. Mohr, T. Weber, G. Pintsuk, J.W. Coenen and C. Linsmeier, "Ultra-fast sintered functionally graded Fe/W composites for the first wall of future fusion reactors", Composites Part B: Engineering, 164, pp. 205-214, 2019.

[8] Z.L. Chao, L.T. Jiang, G.Q. Chen, J. Qiao, Z.H. Yu, Y.F. Cao and G.H. Wu, "The microstructure and ballistic performance of B_4C/AA2024 functionally graded composites with wide range B_4C volume fraction", *Composites Part B: Engineering*, 161, pp. 627-638, 2019.

[9] G. Udupa, S.S. Rao and K.V. Gangadharan, "Functionally Graded Composite Materials: An Overview", *Procedia Materials Science*, 5, pp. 1291-1299, 2014.

[10] S. Decker and L. Krüger, “Mechanical properties of a CrMnNi steel/Mg-PSZ-FGM processed by asymmetric Spark Plasma Sintering”, Materials & Design, 115, pp. 8-16, 2017.

[11] A. Toudehdehghan, J.W. Lim, K.E. Foo, M.I.N. Ma’arof and J. Mathews, “A brief review of functionally graded materials”, *MATEC Web of Conferences*, 131, EDP Sciences, 2017.

[12] G. Cui, Q. Bi, S. Zhu, L. Fu, J. Yang, Z. Qiao and W. Liu, “Synergistic effect of alumina and graphite on bronze matrix composites: Tribological behaviors in sea water”, *Wear*, 303, 1-2, pp. 216-224, 2013.

[13] C. Wu, R. Shi, J. Zhang, G. Luo, Q. Shen, Z. Gan and L. Zhang, “Synthesis of functionally graded AA7075-B4C composite with multi-level gradient structure”, Ceramics International, 45, 6, pp. 7761-7766, 2019.

[14] M. Uysal, R. Karslioglu, H. Akbulut and A. Alp, “Characteristics Bronze/Al_2O_3 (Ni) Reinforcement Metal Matrix Composite Produced by Current Activated Sintering”, *Proceedings of the 2nd International Congress APMAS2012*, April 26-29, Antalya, Turkey, 2012.

[15] K. Arslan and R. Gunes, “Experimental damage evaluation of honeycomb sandwich structures with Al/B_4C FGM face plates under high velocity impact loads”, Composite Structures, 202, pp. 304-312, 2018.

[16] R. Kumar and C.N. Chandrappa, “Synthesis and characterization of Al-SiC functionally graded material composites using powder metallurgy techniques”, *International Journal of Innovative Research in Science, Engineering and Technology*, 3, 8, pp. 15464–15471, 2014.

[17] F. Erdemir, A. Canakci and T. Varol, “Microstructural characterization and mechanical properties of functionally graded Al2024/SiC composites prepared by powder metallurgy techniques”, *Transactions of Nonferrous Metals Society of China*, 25, pp.3569–3577, 2015.

[18] D.T. Sarathchandra, S.K. Subbu and N. Venkaiah, “Functionally graded materials and processing techniques: An art of review”, *Materials today: Proceedings*, 5 10, pp. 21328-21334, 2018.

[19] J. Sobczak and L. Drenchev, “Metallic Functionally Graded Materials: A Specific Class of Advanced Composites”, *Journal of Materials Science & Technology*, 29, 4, pp. 297-316, 2013.

[20] M. Naebe and K. Shirvanimoghaddam, “Functionally graded materials: A review of fabrication and properties”, *Applied Materials Today*, 5, pp. 223-245, 2016

[21] C.Y. Huang and Y.L. Chen, “Design and impact resistant analysis of functionally graded Al_2O_3–ZrO_2 ceramic composite”, Materials & Design, 91, pp. 294-305, 2016.

[22] S. Islak and H. Çelik, “Effect of sintering temperature and boron carbide content on the wear behavior of hot pressed diamond cutting segments”, *Science of Sintering*, 47, 2, pp. 131-143, 2015.

[23] S. Buytoz, F. Dagdelen, S. Islak, M. Kok, D. Kir and E. Ercan, “Effect of the TiC content on microstructure and thermal properties of Cu–TiC composites prepared by powder metallurgy”, *Journal of Thermal Analysis and Calorimetry*, 117, 3, pp.1277-1283, 2014.

[24] S. Islak, D. Kir and H. Celik, “Investigation of the usability of cubic boron nitride cutting tools as an alternative to diamond cutting tools for the aircraft industry”, *Archives of Metallurgy and Materials*, 58, 4, pp. 1119-1123, 2013.

[25] S. Yang, Z. Guo and M. Xia, “Effect of TiB Content on the Properties of Al-TiB

Composites", *Science of Sintering*, 50, 2, pp. 237-244, 2018.

[26] S. Islak, "Mechanical and Corrosion Properties of AlCu Matrix Hybrid Composite Materials", *Science of Sintering*, 51, 1, pp. 81-92, 2019.

[27] O. Carvalho, M. Buciumeanu, S. Madeira, D. Soares, F.S. Silva and G. Miranda, "Optimization of AlSi–CNTs functionally graded material composites for engine piston rings", *Materials & Design*, 80, pp. 163-173, 2015.

[28] S.R. Bakshi, D. Lahiri and A. Agarwal, "Carbon nanotube reinforced metal matrix composites – a review", *International Materials Reviews*, 55, 1, pp. 41–64, 2010.

[29] A.M. Al-Qutub, A. Khalil, N. Saheb and A.S. Hakeem, "Wear and friction behavior of Al6061 alloy reinforced with carbon nanotubes", *Wear*, 297, pp. 752–761, 2013.

[30] A. Bhat, Vamsi K. Balla, S. Bysakh, D. Basu, S. Bose and A. Bandyopadhyay, "Carbon nanotube reinforced Cu–10Sn alloy composites: mechanical and thermal properties", *Materials Science and Engineering: A*, 528, pp. 6727–6732, 2011.