Experimental Investigations on the Mechanical Properties, Microstructure and Corrosion Resistance of Cu-20Al-4Ni/SiC Composites Synthesized Using Powder Metallurgy

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Research Article

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Abstract

The present investigation pertains to synthesize aluminium bronze silicon carbide composite by powder metallurgy route. Three various weight percentages of silicon carbide (0, 2, 4 & 6) were reinforced with aluminium bronze matrix (Cu-20%Al-4%Ni) and the hydraulic press was used to prepare the green compact. This compact was heated at two different temperatures such as 650^0C and 750^0C using tubular furnace. The effect of silicon carbide on density, sinterability, compression test and hardness test was analyzed. The scanning electron microscope and energy dispersive spectroscopy were used to confirm the presence of alloying elements. The results showed that the sinterability and density were reduced with an increase in silicon carbide content. The composite reinforced with 6%SiC exhibited lowest compressive strength among other composites. The 4 wt.% SiC reinforced composites sintered at 750^0C has highest corrosion resistance.

1. Introduction

Metal matrix composite (MMC) is a composite material made up of a matrix and reinforcement material that has been combined to enhance mechanical, thermal, and physical properties. The need for better strength and corrosion resistance has pulled MMC in desired zone of manufacturing company. Composites have been used for aerospace, electronics and marine applications because they have a number of required and variable properties, such as high stiffness, high temperature resilience, increased wear resistance, and a low coefficient of thermal expansion.

Various techniques are used for production of composite depend upon reinforcement such as compo casting [1], liquid phase infiltration [2], squeeze casting and spray co-deposition [3].

Casting process has many hindrances due to some reasons such as non uniform dispersal of reinforcement in matrix, adverse reaction between matrix and reinforcement at high temperature, and heterogeneous matrix structure. Because of these constraints, bulk mechanical properties were affected as a result of differences between the strengthening and the matrix. These problems became more relevant as a result of these constraints [4, 5]. Considering these disadvantages, powder metallurgy (PM) is the apt method for production of composite. Particulate-reinforced composites prepared by PM have better properties with augmented metal working character which is the defined method for producing composite materials [6].

Common reinforcements added to the matrix are SiC, B_4C, graphite, NbC, TaC, TiB, TiB_{12}, TiC, WC, Mo, and Al_2O_3. SiC is the commercial reinforcement material added to the matrix in large volume followed by Al_2O_3 and TiC. The addition of particulates such as SiC, B4C, MgO, TiC and ZnO could drastically reduce the wear rate. Since the addition of SiC reinforcement strengthens the properties and reduces wear intensity, SiC particle is the most widely used [7].

Copper (Cu) is the most commonly used powdered alloying material due to its easy availability, cheap and potential to augment alloy properties. Cu powder has the potential to mix ready with master alloy, alloying elements, lubricants and graphite. Cu has a major impact on the material's mechanical properties. Cu reaches liquidus stage at 1083 ° C and widely spreaded well in the alloy. As an effect, Cu fills pores in the resulting alloys, increasing hardness and density [8]. Further addition of Cu with proportion of martensite yielded in enhanced tensile strength-ductility for balance of alloys containing 0–4 wt. % Cu [9]. Lowhaphandu et al. [10] analyzed the impact of inclusion of 10 wt. % Cu infiltration on 2D fracture resistance and fracture crack growth performance of PM-processed porous plan carbon steels subjected to various heat treatment conditions. From the polarization curve it was clearly indicated that the 99.5% bronze added with 3% of SiC, SiO_2, and 1.5 % of C has highest corrosion wear rate of 0.05mm/yr at the potential value of -284 mV in artificial acid rain condition [11].Abu et al [12] investigated Al2024 alloy powders having 160μm were mixed with different weight percentage of graphene sheet with 0%, 0.25%, 0.5%, 1%, and 2% to prepare specimen with the diameter of 20mm having 6mm length. It was prepared at 40 Mpa at the sintering temperature of 460^0C and 560^0C in open argon gas atmosphere condition. In the corrosion test the graph clearly indicates that corrosion rate seems very less with increasing with the percentage of graphene in the specimen. Aluminium with 2% graphene has maximum corrosion resistance at different exposure time compared with other specimen.

CuAl10Ni5Fe4 alloy powders were milled in Fritsch Pulverisette 6 model. Different milling times 0.5 to 40 hours were involved to create the specimen under the pressure of 700Mpa. Sintering temperature was used in this investigation at 900^0C for duration of 90 min. Electrochemical test were carried out with presence of 3.5% NaCl solution to calculate corrosion rate for the specimen under open atmospheric condition. From this corrosion test for the samples under as-cast and powder metallurgy methods, polarization curve indicates that the samples produced under powder metallurgy has massive corrosion resistance than the as-cast samples [13].Pure magnesium and magnesium powder with 10 wt.% of Al, 20 wt.% of Al, 50 wt.% of Al were used to prepare the specimen using milling method with the milling time of 2 hours, pressure of 300Mpa at a sintering temperature of 500^0 C for 1 hour. Sintering process was carried out in the tubular furnace under argon gas environment. Corrosion behavior of the samples was estimated for the samples which are immersed in 3.5% weight percentage of NaCl solution. By the polarization curve it was seems that increase in wt. % of aluminium increases the corrosion resistance of the samples [14].

Very limited investigation related to synthesis of bronze composites was found out. The present experimental work focuses on synthesizing of aluminium bronze-SiC composites and analyzing the effect of silicon carbide and sintering temperature on density, hardness, compressive strength, sinterability, and corrosion behavior on synthesized composites. The composites were also subjected to SEM and Energy Dispersive spectroscopy (EDS) analysis.

2. Materials And Methods

2.1 Synthesis of silicon carbide reinforced aluminium bronze composite

Aluminium bronze (Cu-20%Al-4%Ni) powder of purity 99.7 % was the matrix material and silicon carbide was the reinforcement. The SEM results of bronze powder and silicon carbide are shown in Fig. 1. Three different weight proportion of silicon carbide (0, 2, 4 & 6 wt. %) are reinforced with Cu- 20Sn using powder metallurgy. The required weight proportion of Cu- 20%Al -4% Ni and SiC were mixed using ball milling for 1 hour. Toluene was mixed with powder as lubricant and cold fusion of different powder was achieved prior to sintering because of using ball to powder ratio as 10:1 [15].

The phase identification for the ball milled powders were found using X ray diffraction equipment for the ball milled powders with various proportions of SiC (0, 2, 4 & 6 wt. %). Scan speed of 0.01°/s was used to determine the phase identification with Cu-Kα radiation (λ = 1.54060 A°). Figure.2a represents the presence of Cu with higher intensity peaks than other elements such as Fe, Ni and Zn. The corresponding peaks of SiC were clearly noticed to be increased with an increase in SiC content as shown in Figure.2 (b-c). The ball milled powder was compacted to cyclindrical green compact rod of diameter 20mm and the height 15mm using hydraulic press of capacity 250 kN with an appropriate set of punch and die. Green compacts were coated with suitable coating to harness the oxidation effect in order to obtain defect free compact. The compacts were sintered at two different temperatures: (a) 650°C (b) 750°C using tubular furnace of maximum capacity 1300°C. The heating rate for sintering was 5°C per minute and hold duration was 30 minutes. The sintered sample was shown in Fig. 3. According to ASTM E110, the rockwell hardness of the sintered composites was found out using Rockwell hardness machine. The compression test was carried out as per ASTM E9 standard.

The corrosion characteristic of synthesized composites was analyzed using potentio dynamic polarization experiment using electrochemical workstation with three electron setup. Aluminium bronze composite sintered compacts, AgCl, platinum wired were used as working electrode, reference electrode and counter electron respectively. The compacts were polished using an 800 grit emery and rinsed to remove greasy item using acetone. The 5% NaCl solution was prepared and electrodes were dipped in the prepared solution. The polarization test was carried out at specified rate of $1mVs^{-1}$. [16, 17, 18]

3. Results & Discussions

3.1 SEM analysis of sintered aluminium bronze composites

Figure 4 a and b shows the SEM results of, sintered aluminium bronze -2 wt.% SiC composite sintered at 650^0C and sintered aluminium bronze -2 wt.% SiC composite 750^0C respectively. Homogeneous wide spread of SiC in the bronze matrix along with micro pores as shown in Figure 3a. However, the pores formation increases with an increase in SiC reinforcement. Pore formation is the cause of more SiC content effectively restrains the grain boundary diffusion paths between the bronze powder particles [19].

Figure 4b shows the absence of voids in the microstructure and the distribution of SiC particles throughout the matrix is uniform. The higher sinter temperature caused better bonding strength between matrix and reinforcement. It was observed that microstructure witnessed absence of agglomeration and clusters. Figure 4c shows the microstructure of sintered aluminium bronze -4 wt.% SiC composite sintered at 750^0C From Figure 4c, it was noticed that entrenchment of SiC particles in bronze matrix due to the better interfacial bonding between matrix and reinforcement. Figure.5 (a-c) shows EDS results of sintered aluminium bronze composites. The presence of elements such as Cu, Al, Fe, Ni and SiC are confirmed by EDS results as shown in the same figure. Figure.5 (a-c) shows that SiC peaks are adjacent to copper peaks which point out that silicon carbide particulates are embedded with copper matrix. The entrapped of oxygen was confirmed by presence of corresponding peak in EDS result.

3.2 Effect of silicon carbide and sintering temperature on density of aluminium bronze matrix

Figure.6 reveals the densification characteristics of composites sintered at 650 °C and 750 °C. The green density of the composites decreases linearly up to composites containing 4 wt.% SiC and subsequent addition of 6 wt.% SiC descends down drastically. In the same way, sintered densities of the composites were observed to decrease linearly with an increase in SiC reinforcement. Addition of 2% SiC particle leads to decrease in green density, sintered density at 650^0C and sintered density at 750^0C by 4.12%, 6.02% and 5.72%, respectively. Furthermore, inclusion of 4% SiC over aluminium bronze alloy leads to decrease in green density, sintered density at 650^0C and sintered density at 750^0C by 8.33%and 5.82%, respectively. The sintered density possesses high density than that of green compact density, because green compacts have voids and this could be the main cause for the lower density. The void formation rise across the formulation due to the decrease in wettability by the addition of particulates [20]. The composite sintered at 750^0C possesses higher sintered density than composite sintered at 750^0C Increased contents of reinforcements obstructs the dislocation movements which tends to an increase in dislocation density [21].

3.3 Effect of silicon carbide and sintering temperature on hardness and compressive strength of aluminium bronze matrix

It is clearly observed that unreinforced aluminium bronze sintered at 650°C possesses lowest hardness (23 HRC) among the four PM aluminium bronze composites. The hardness values for the sintered composites at 750°C are higher than the composites sintered at 650°C which is represented in Figure.7. The hardness values increases with an increase in proportion of SiC up to 4%, then hardness decreases. The composite (4 wt.% SiC) exhibits highest hardness of 32HRC. The increase in hardness may be attributed to the combined effect of particulates and a smaller matrix grain size [22].This is due to the better bonding between matrix and reinforcement which is evident in Figure.4c. The variations in hardness values among the four composites are not very significant. The maximum percentage of increase in hardness was 11.1%, which was noticed for 2% SiC reinforced aluminium bronze. The compressive strength increases linearly with an increase in SiC material, as shown in Figure.8.There is slight rise in compressive strength with an increase in sintering temperature. Maximum compressive strength of 490Mpa was observed for 4% reinforced composites, which was sintered at 750^0 C. Subsequent inclusion of SiC causes decrease in compressive strength. As a result, the gap between reinforcements becomes less when more reinforcement added to the matrix and dislocation pile up occurs which causes reduction in elongation [23]. Among the sintered composites at 750^0C, 6% reinforced composites witnessed lowest compressive strength of 400 MPa. There is not much appreciable increase in compressive strength with respect to silicon percentage.

3.4 Effect of silicon carbide and sintering temperature on sinterability of aluminium bronze matrix composites

Sinterability is the function of the densification process. As it is obvious from Figure.9, the inclusion of SiC in the bronze matrix caused sinter ability to decline. This may be due to the hindrance of reinforcement in achievement of near densification. Among the composites sintered at 750 °C, 6% SiC reinforced possesses lowest sinterability of 0.44 which indicate lesser ability of densification. This could be due to the (a) low compressibility (b) hindrance for the metal to metal contact by reinforcement in order to prevent bonding [24,25]. Sintering temperature has great influence on sinterability because the overall sinterability for 750^0C is higher than 650^0C. This is due to the higher diffusion rate at higher temperature.

3.5 Effect of silicon carbide and sintering temperature on corrosion of the aluminium bronze matrix composites

The compressive strength and hardness for the 6% SiC reinforced composites sintered at both 650°C and 750°C possesses low values. Therefore, 6% SiC reinforced composites was eliminated for corrosion investigation. The corrosion test was performed with 5% NaCl solution for the specimen. Polarization graphs plotted in Figure.10 and Figure.11 indicates the parameters like potential (V) and current (A) which was calculated by using Tafel plots. Figure.10 (a-c) indicates the polarization curves for 0% SiC, 2% SiC and 4%SiC composites sintered at 650^0C. From the figure.8 indicates the corrosion rate was increased much better with increase in weight percentage of SiC. From the figure.11 (a-c) indicates the polarization curve for 0% SiC, 2%SiC, and 4%SiC composites sintered at 750^0C. 4% SiC composites sintered at 750^0C possesses superior corrosion resistance than 4% SiC composites sintered at 650^0C. Because of the incorporation of SiC, the corrosion resistance of the aluminium bronze composites improved noticeably as compared to its purest form. This improvement in corrosion resistance may be due to the proper formation of passive layer due to the SiC reinforcements [23]The sintering temperature has the significant role in improving the corrosion resistance. The corrosion resistance was enhanced with increase in both sintering temperature as well as reinforcement [24].

Conclusion

- Silicon carbide reinforced aluminium bronze composites was successfully synthesized using powder metallurgy.

- XRD examination of the ball milled powders confirms the presence of Cu, Al, Ni and Silicon carbide.
- SEM results shows uniform distribution of SiC particles throughout the Cu-20%Al-4%Ni- 4% SiC composites sintered at 750^o C and also revealed the pore formation in Cu-20%Al-4%Ni- 2% SiC composites sintered at 650^o C.
- 6 wt.% SiC reinforced composites has lowest density of other three composites.
- The green and sintered density of Cu-20%Al-4%Ni- 4% SiC composites sintered at 750°C possess better density than samples sintered at 650°C.
- 4 wt.% SiC reinforced composites sintered at 750^{o}C possesses highest compressive strength of the other three composites. Further inclusion of SiC (6 wt.%) in Cu-20%Al-4%Ni matrix deteriorates compressive strength of the composites from MPa To MPa.
- The sinterability of the Cu-20%Al-4%Ni- SiC composites decreases with an increase in reinforcement.
- The corrosion resistance of the Cu-20%Al-4%Ni-SiC composites sintered at 750 ^{o}C was higher than Cu-20%Al-4%Ni- 4% SiC composites sintered at 650^{o}C.

Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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The authors did not receive support from any organization for the submitted work.

Conflict of interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Author contributions

L.Mamundi Azaath: conceptualization, Methodology U.Natarajan: Supervision, G.Veerappan: Data manipulation, M.Ravichandran: review and editing, S.Marichamy- review and editing.

Availability of data and material

Data sharing not applicable

Compliance with ethical standards

The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare that there is no conflict of interest.

Consent to participate

Not applicable.

Consent for Publication

Yes granted.

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Figures

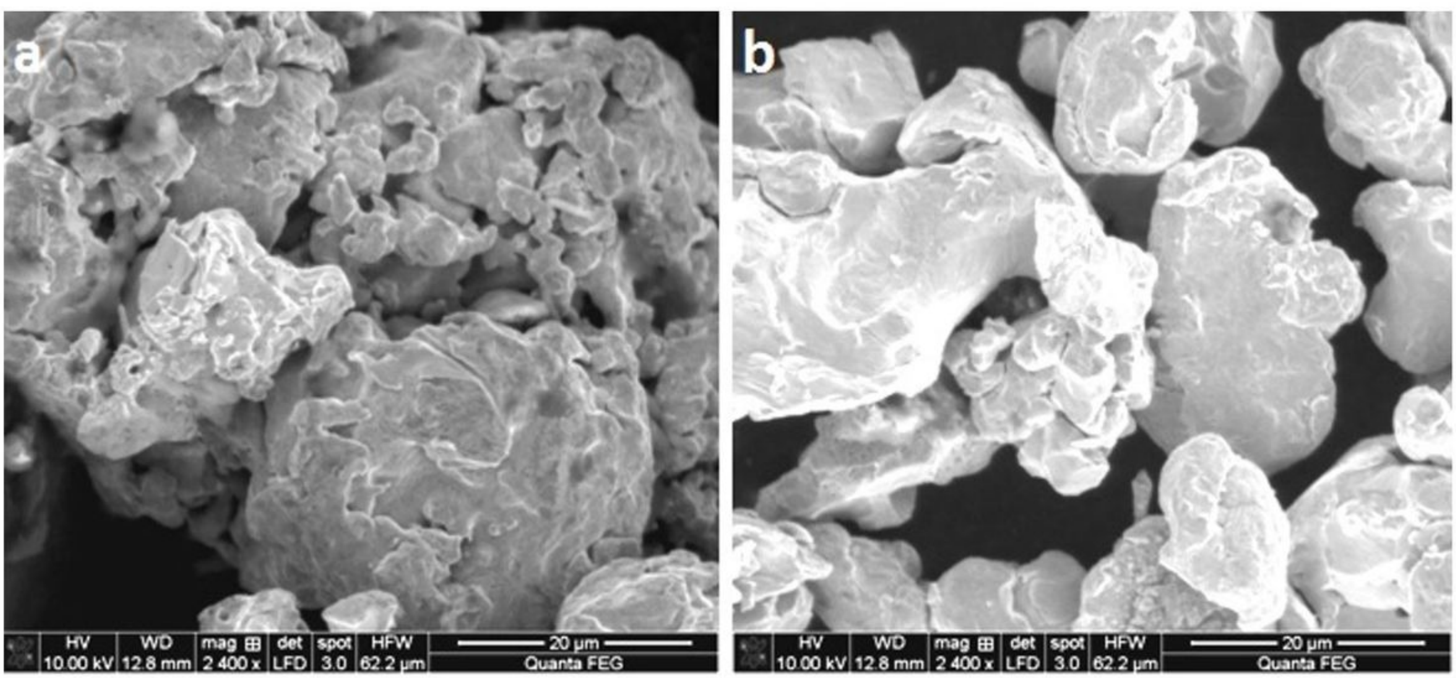

Figure 1

SEM result of (a) Bronze powder (Cu-20%Al-4%Ni) (b) Silicon Carbide powder

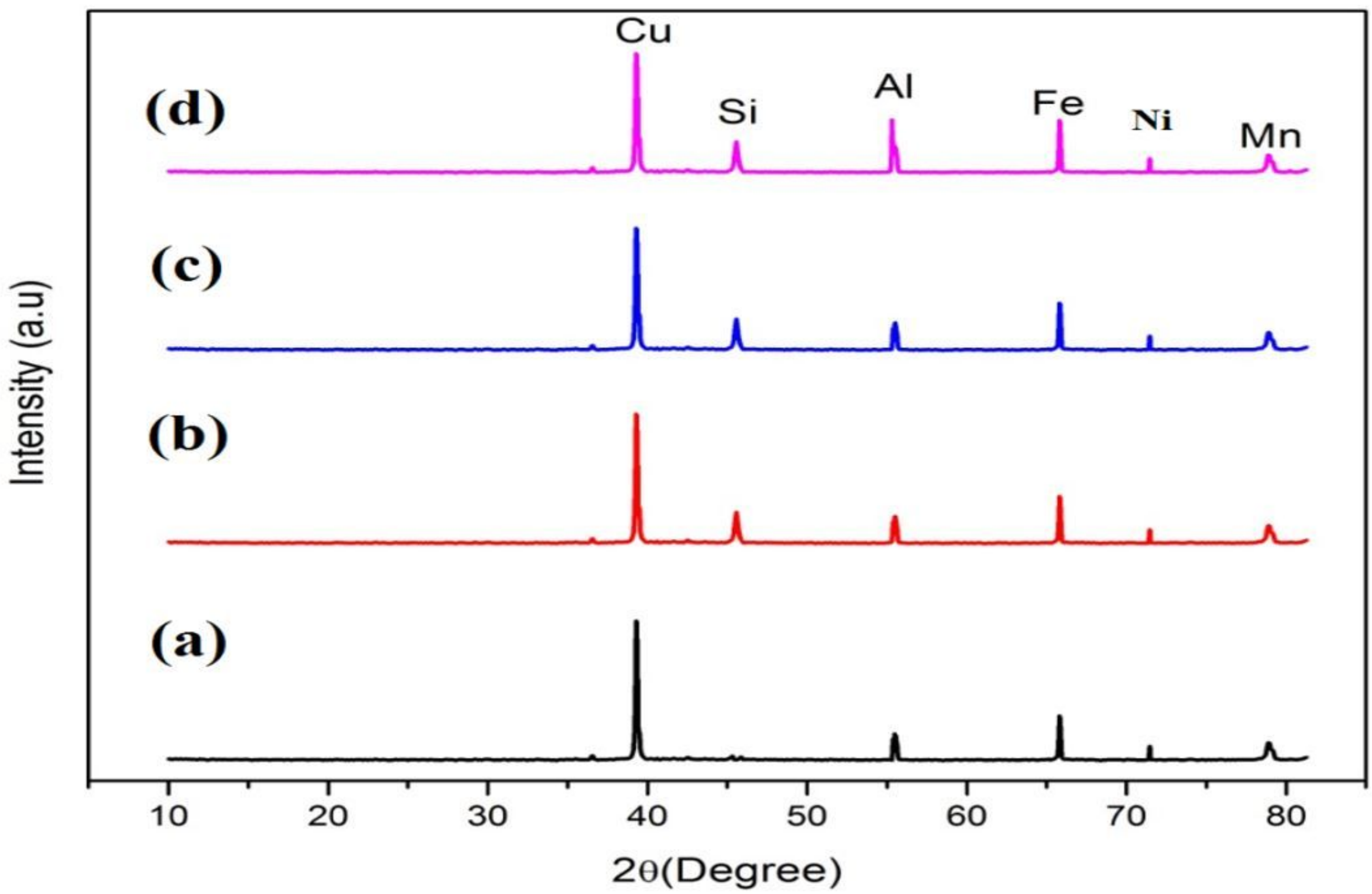

Figure 2

XRD results of sintered Aluminium bronze-SiC (0, 2, 4 & 6 wt.%)

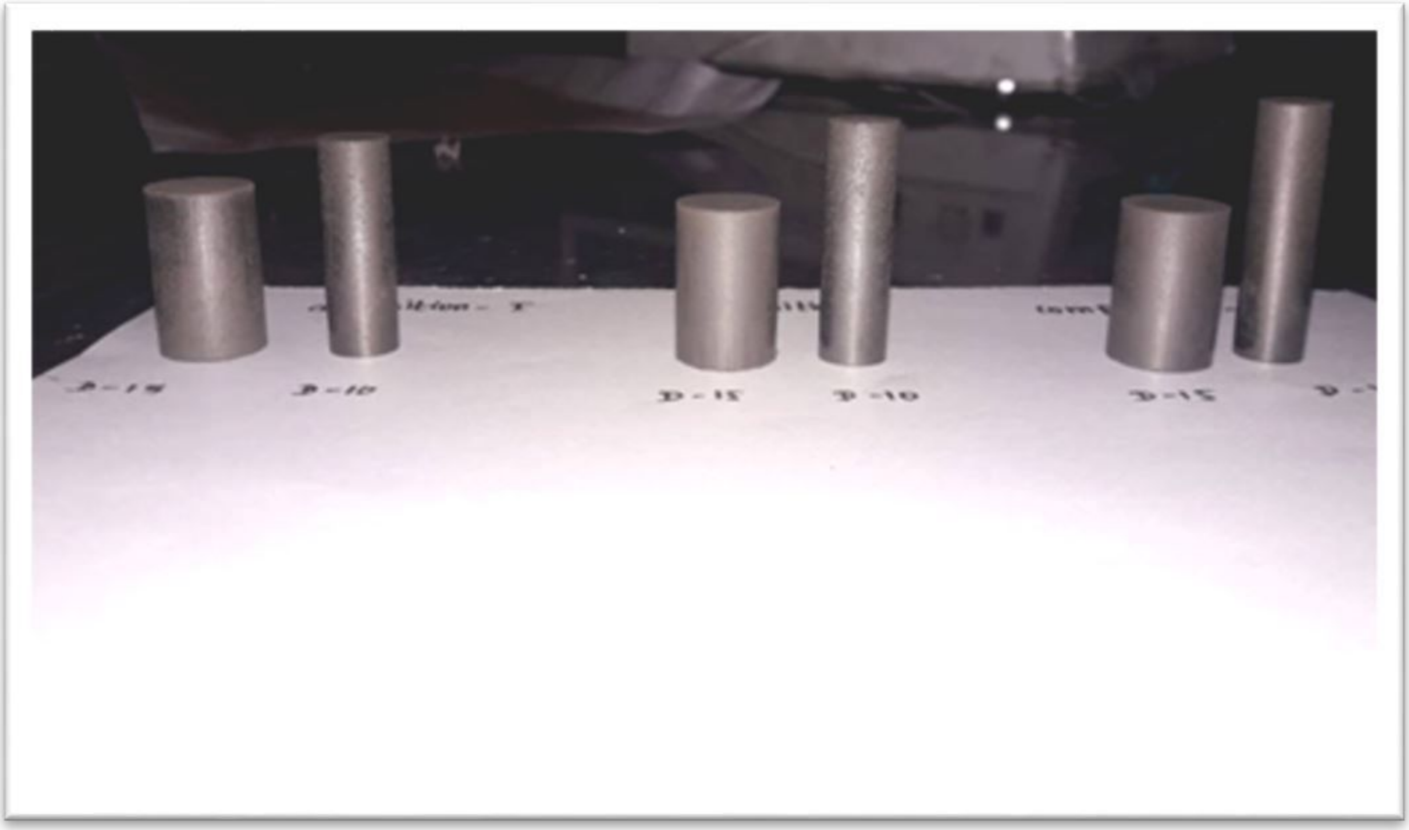

Figure 3

Sintered composites (Cu-20%Al-4%Ni/SiC)

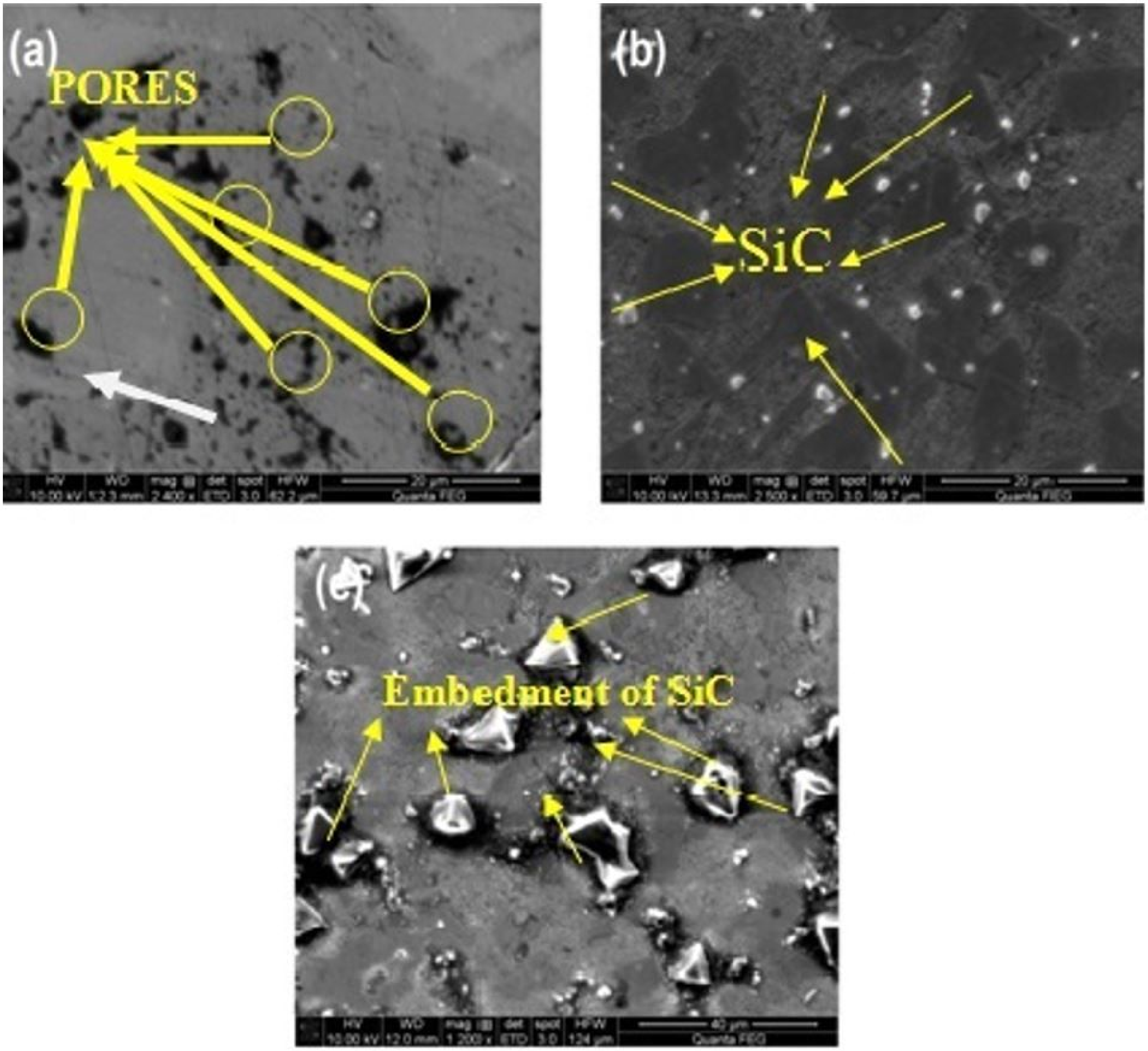

Figure 4

SEM images of sintered aluminium bronze (a) 2 wt.% SiC composite sintered at 6500 C (b) 2 wt.% SiC composite sintered at 7500C (c) 4 wt.% SiC composite sintered at 7500C

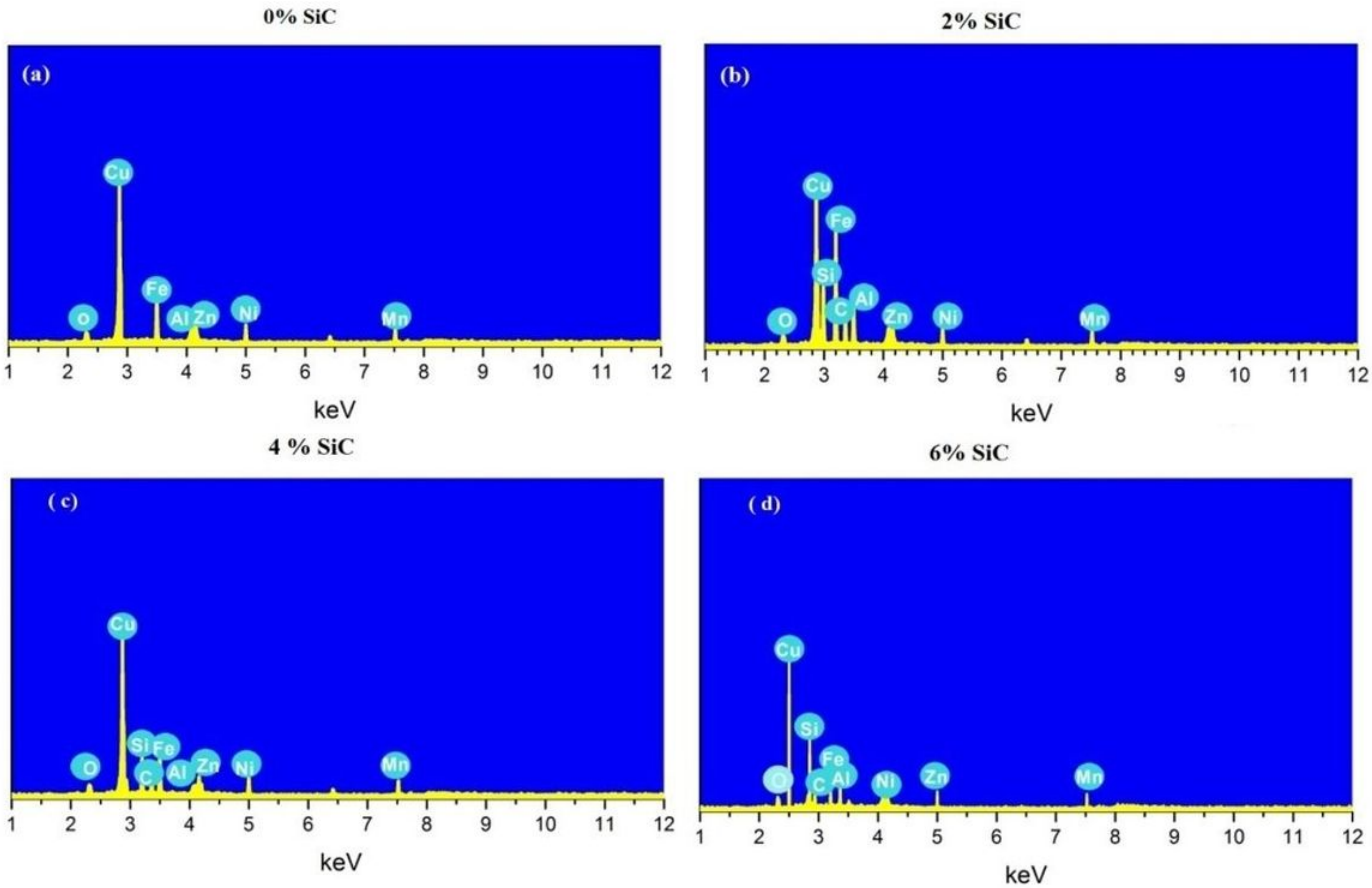

Figure 5

EDS results of sintered aluminium bronze composites

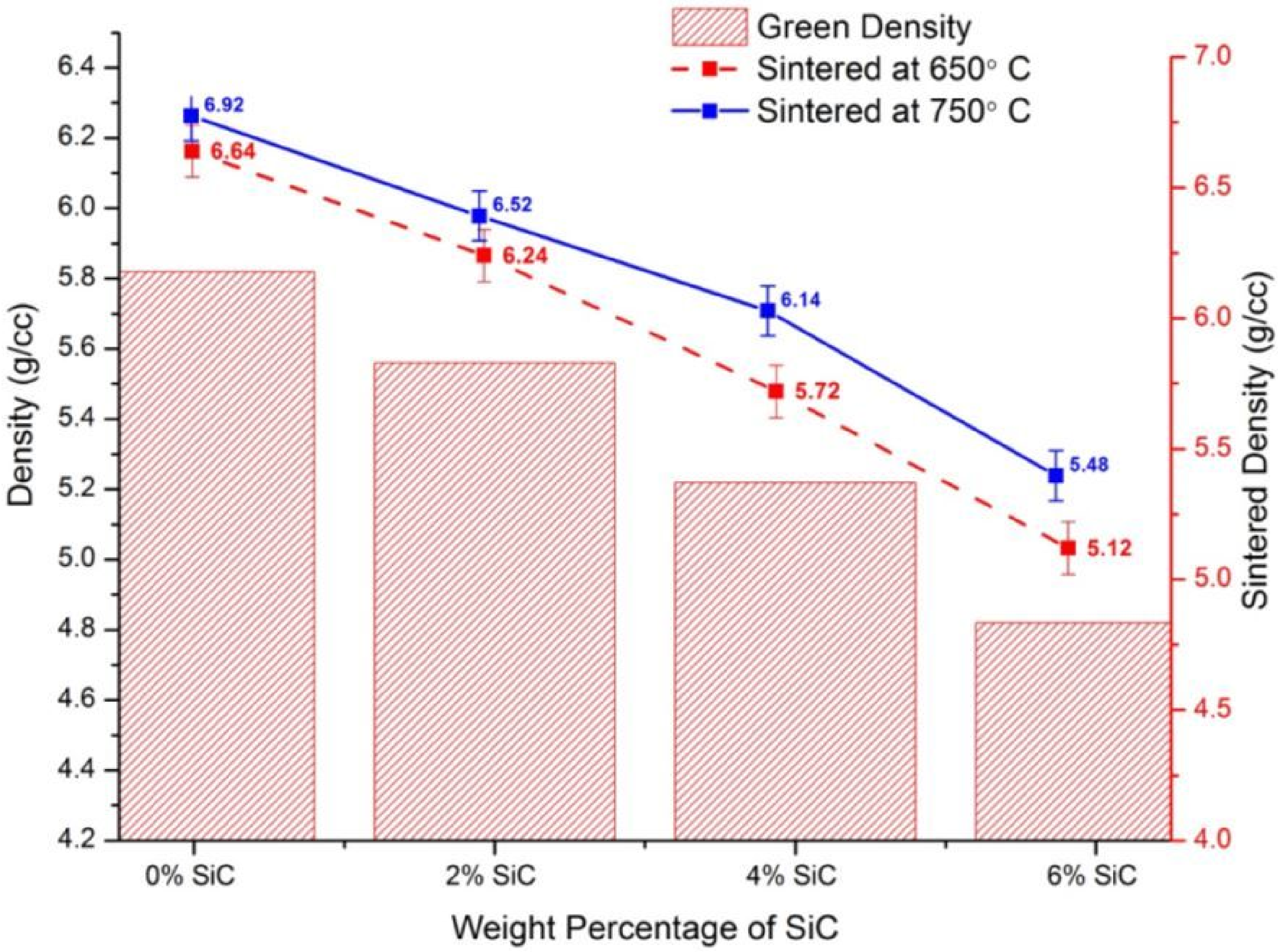

Figure 6

Influence of Sintering temperature on Density

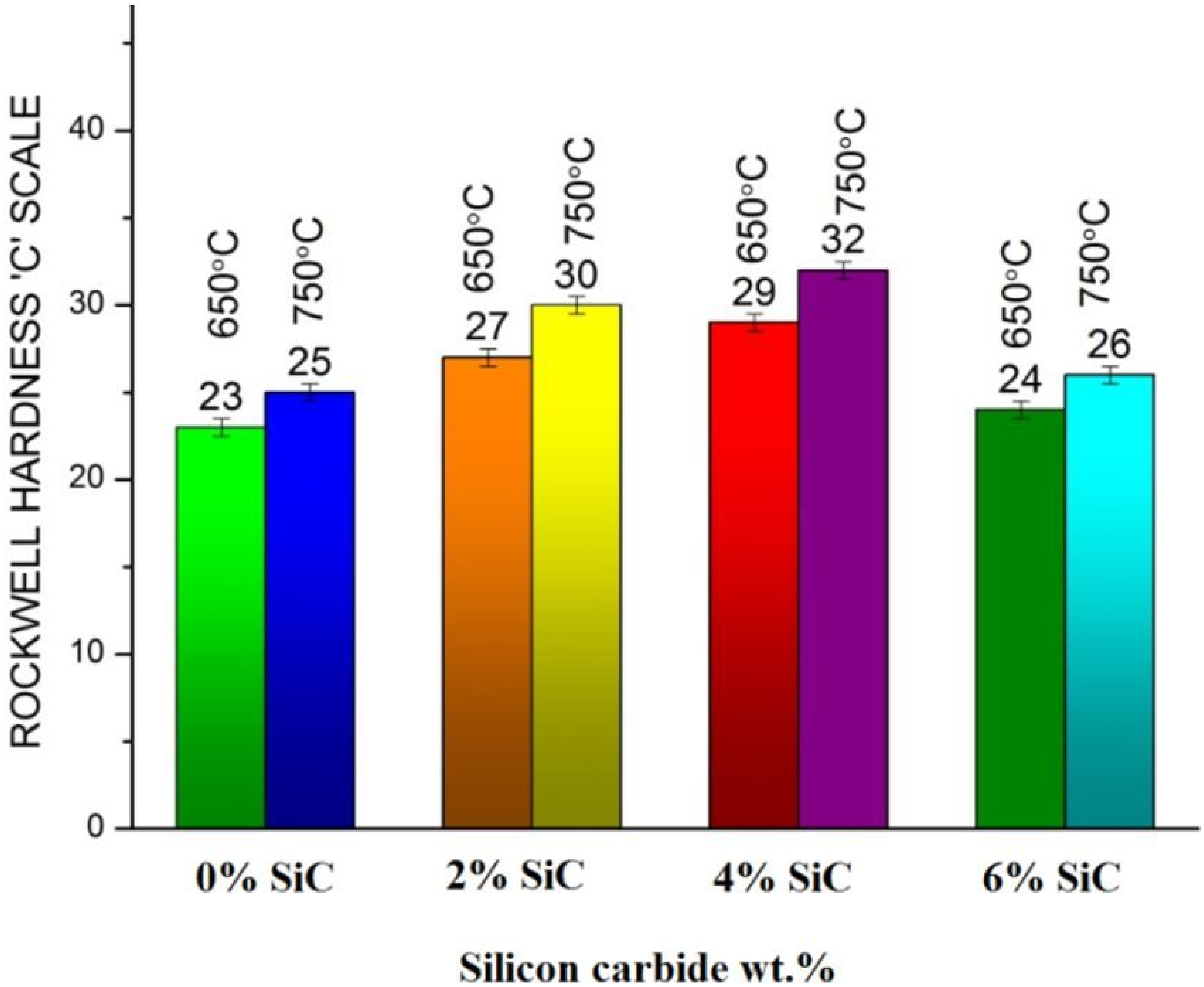

Figure 7

Effect of silicon carbide and sintering temperature in aluminium bronze matrix on hardness

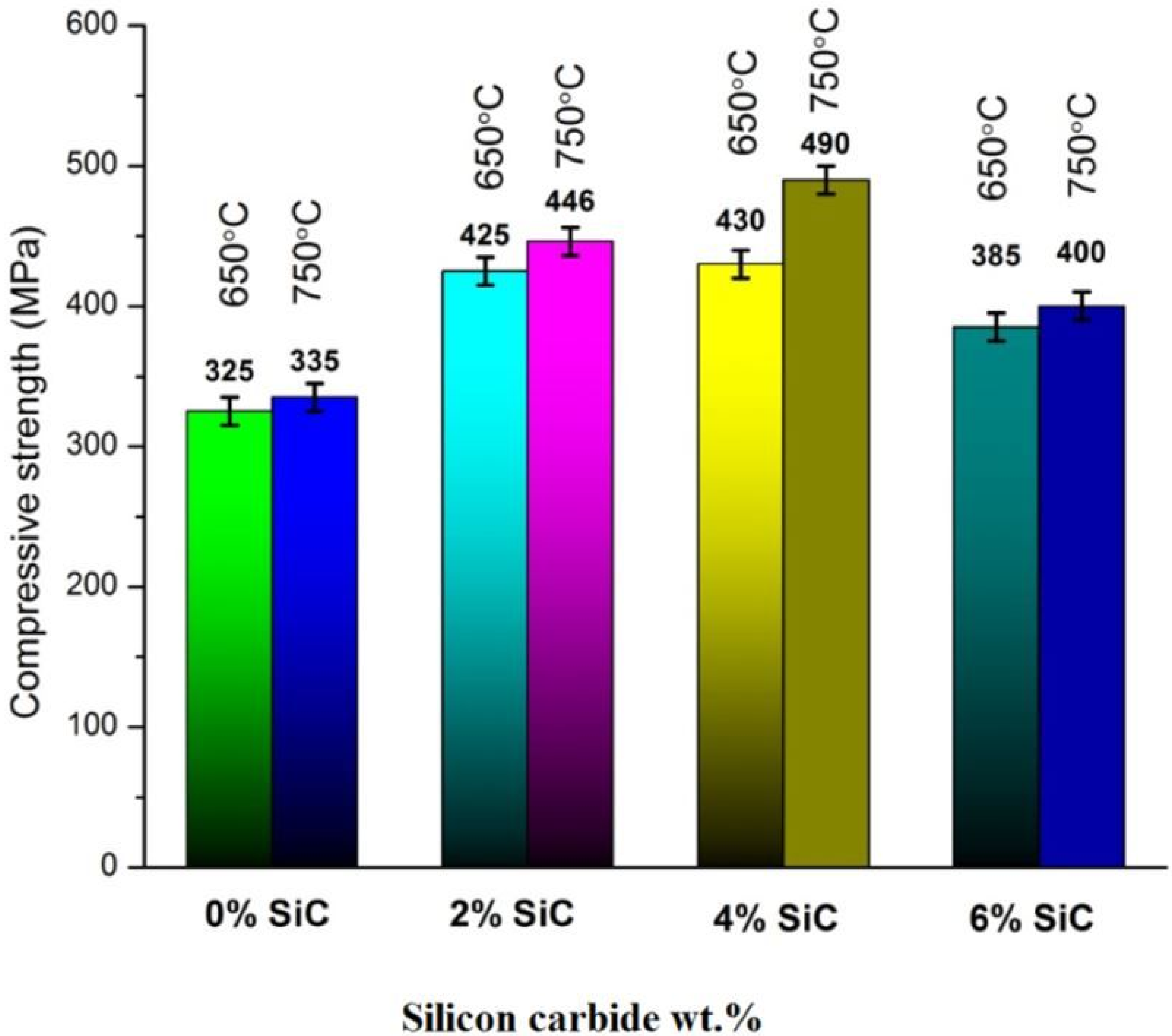

Figure 8

Effect of silicon carbide in aluminium bronze matrix on Compressive strength

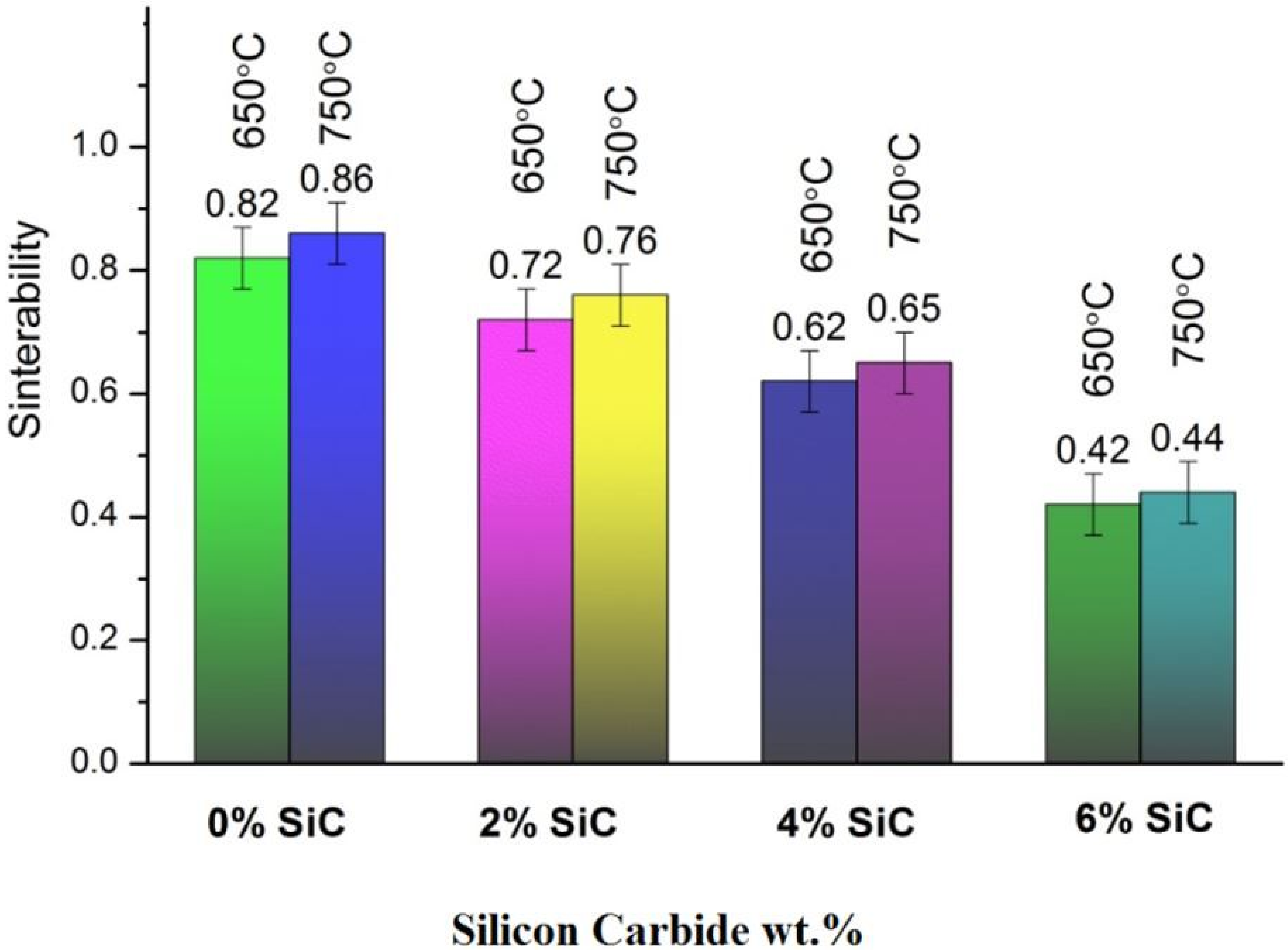

Figure 9

Effect of silicon carbide and sintering temperature in aluminium bronze matrix Compressive strength

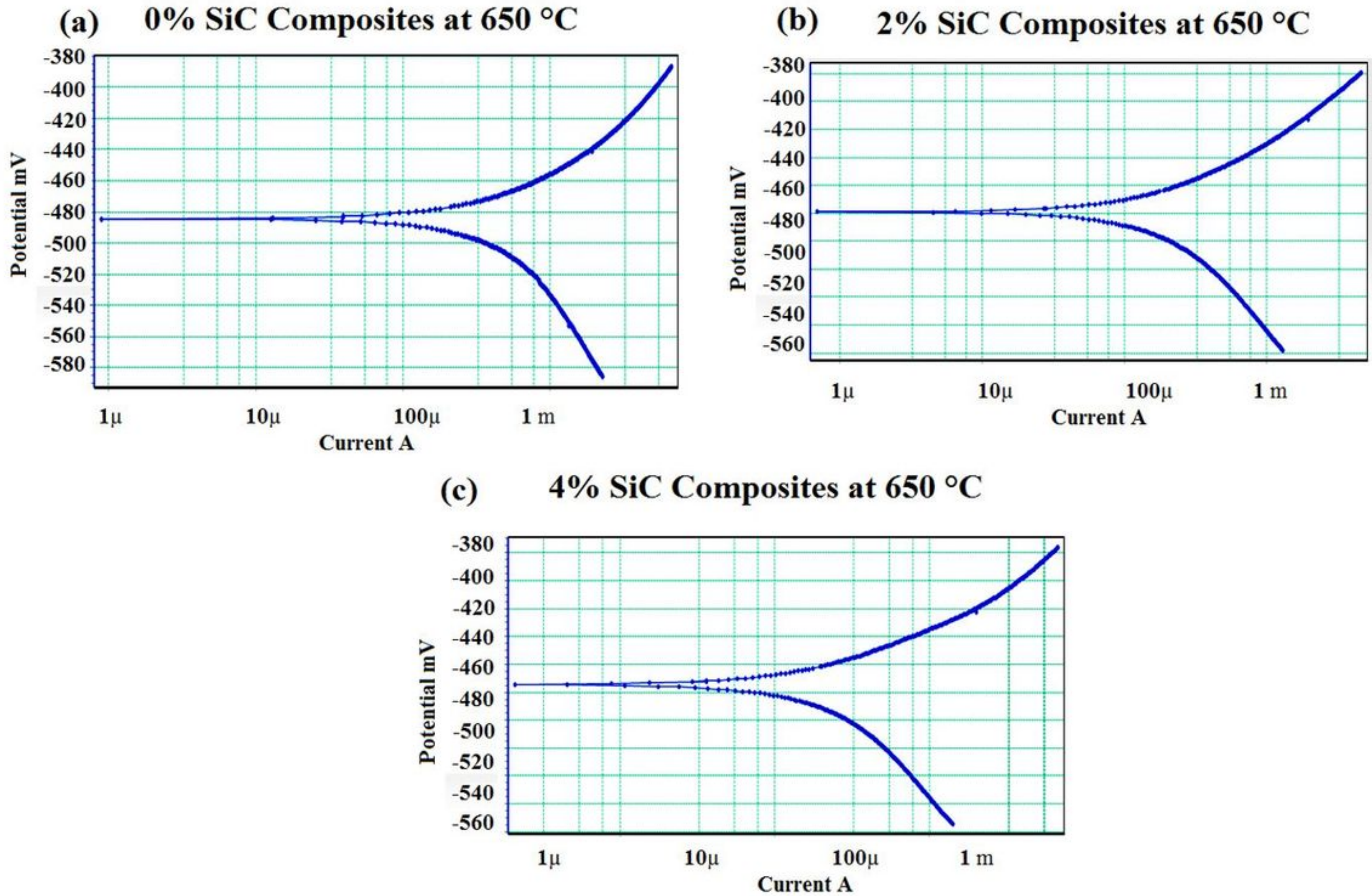

Figure 10

Polarization curves for composites sintered at 6500C (a) Cu-20%Al-4%Ni-0%SiC (b) Cu-20%Al-4%Ni-2%SiC (c) Cu-20%Al-4%Ni-4%SiC

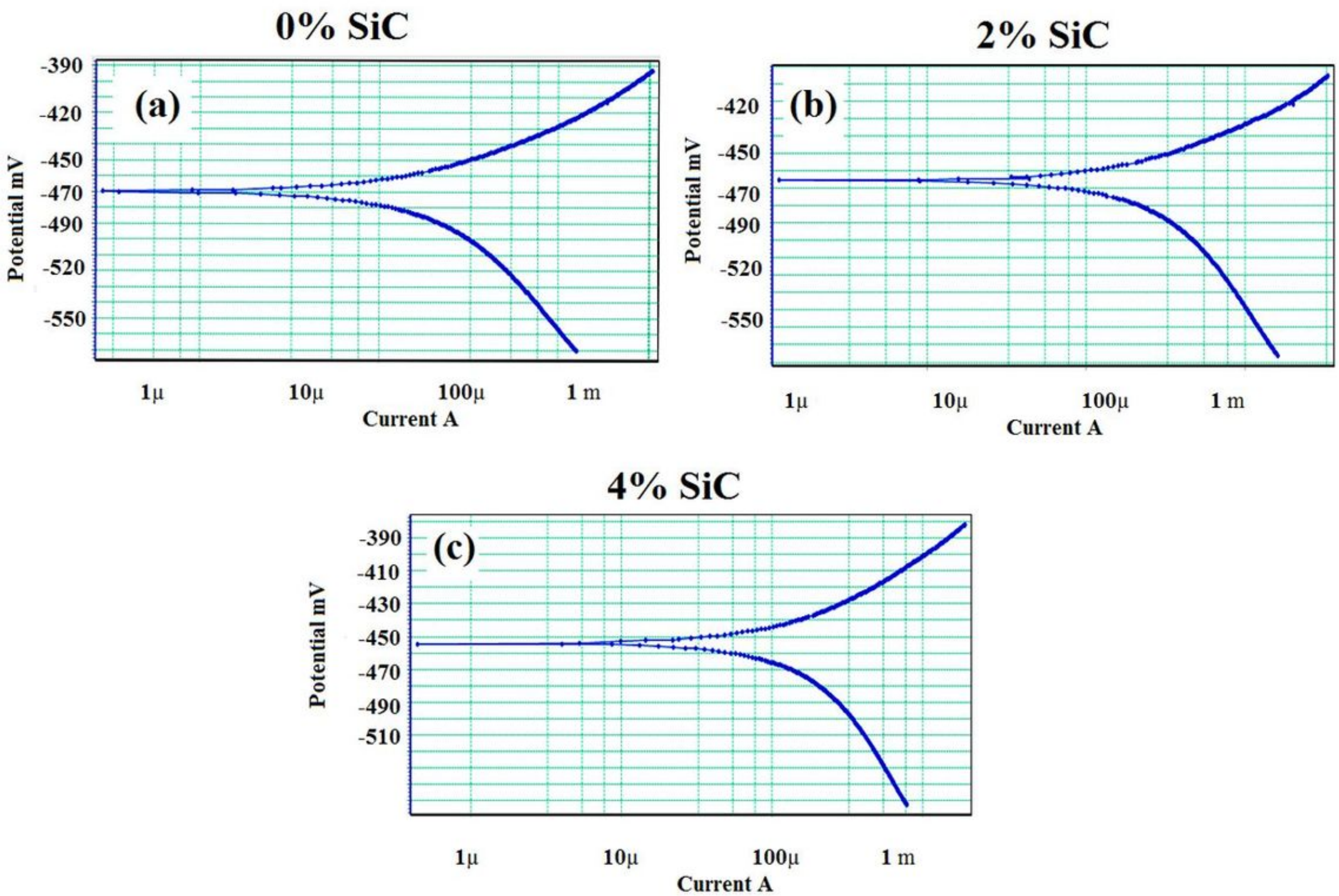

Figure 11

Polarization curves for composites sintered at 7500C (a) Cu-20%Al-4%Ni-0%SiC (b) Cu-20%Al-4%Ni-2%SiC (c) Cu-20%Al-4%Ni-4%SiC