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Recycling Of Waste Brass And Cast Iron Chips Through Metal Matrix Composite Material Production- Investigation Of Mechanical Properties

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ABSTRACT:*In this study, an alternative method to classical fusion process, which resembles the powder metallurgy process, was used in recycling of waste metal chips produced abundantly as a result of machining process. Firstly, ultrasonic cleaning process was carried out in order to grind andsift the waste metal chips and then remove thedirt and oxides from their surfaces.GGG-40 cast iron chips with three different rates(30%, 40% and 50%) by weight, were then reinforced into the brass matrix structure. Mixing process was applied for 15 minutes in order to distribute the components in the composite material structure homogeneously. The prepared matrix-reinforced particles were pressed under 730 MPa pressure at room temperature in a cylindrical mould and composite materials were produced after the sintering process at 942 ºC in atmosphere controlled furnace. Compression and hardness test measurements were conducted after the density-porosity measurements of the produced composite materials. For microstructural characterisation examinations of the composite materials, optical and scanning electron microscope (SEM) was used in experimental studies. Thus, the effect of reinforcement ratios on mechanical properties and microstructure of the composite material was investigated and the produced composite materials were compared with industrial brass CuZn31Si1 alloy.*

KEYWORDS –*Brass,Metal chips, Metal matrixcomposite, powdermetallurgy, recycling*

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I INTRODUCTION

In recent years, there has been a significant increase in the amount of waste chips produced from machining process as a result of the mechanisation needincreasing depending on rapid growth in the manufacturing sector. For this reason, recycling of metal chip wastes is of great importance nowadays due to raw material and energy cost problems. The efficient recycling of these waste metal chips is very important for both national economy and environmental reasons[1].The casting method which is one of the mostly used recycling methods in Turkey and in the world is in the form of re-melting and forming processes of metal chips. However, recycling the metal chips by melting is not an effective method because of the problems like high melting losses, high energy cost, high corrosion content and gas emission that affect the environment negatively. For this reason, studies for more effective recycling of metal chips have continued increasingly[2].

One of the methods that have emerged in recent years as alternative to traditional casting method is the recyclingof metal particles through compressing and sintering process as similar to powder metallurgy (PM).Yamanoğlu et al., investigated the effect of nickel addition into the copper and molybdenum alloy PM steels on wear and mechanical properties of the material. While the porosity ratio varies depending on the nickel density, hardness value of the material increases with the increasing nickel content[3]. Chen et al., investigated the mechanical properties with addition of Zn into W-Cu composite material produced at low temperature by using PM method.They emphasised that the Zn addition increased the material hardness and bending strength values of the composite material and thus Zn addition was effective in terms of mechanical properties of the material[4]. Hakan et al., investigated the effects of pressing and sintering on pore morphology and material hardness in AA 2014 aluminium alloy by using the powder metallurgy method. They stated that the increased sintering temperature increased porosity and made the pore shape irregular in the aluminiumalloy [5].By using powder metallurgy method, it is aimed to produce metal matrix composite (MMC) materialshaving the desired microstructure and mechanical properties in a very economical way due to the use of waste chips. Another advantage of this method compared to the conventional casting method is that it is possible to combine dissimilar metallic materials, which it is not possible to melt-alloy in the same pot, at macro level and to produce porous MMC material when necessary. Owing to the porous structure of the composite materials produced by using this method, it becomes possible to produce materials with superior tribological properties by means of the impact absorbing material and solid lubricants which can be included into that material[6, 7].Pepelnjak et al., investigated the recycling of waste AlMgSi1 aluminium chips produced from machining process by using solid state method. They stated that the shapes, dimensions, and especially fineness of the chips after the cold pressing process were important for the end product[8]. Karadağ produced composite materials after cold pressing and sintering by preparing waste steel and bronze chips, obtained as a result of machining process, in different rates. Thus, he expressed that composite materials had more tough and ductile values compared to industrially used mill CuSn10 bronze [9]. Aslanet al., produced MMC samples with hot pressing from waste bronze and cast iron chips obtained from machining process. They explained that the MMC samples were more strength and porous than pure CuSn10 bronze in terms of their microstructure and mechanical properties[10].

In the scope of this study, metal matrix composite materials were produced by mixing the chips of waste brass and cast iron with spherical graphite in three rates by weight. The mechanical properties of the produced MMC materials were investigated in accordance with ASTM (American Society for Testing and Materials) standards. In addition, the mechanical properties of composite materials were compared with each other and with the cast brass material which has widespread use in the industry.

II EXPERIMENTAL STUDIES

In this study, CuZn31Si1 brassand GGG-40 cast iron chips used as starting materials were obtained as a result of machining cylindrical samples, produced by casting method, on a lathe.Figure 1 shows the images of the obtained CuZn31Si1 brassand GGG-40 cast iron chips.

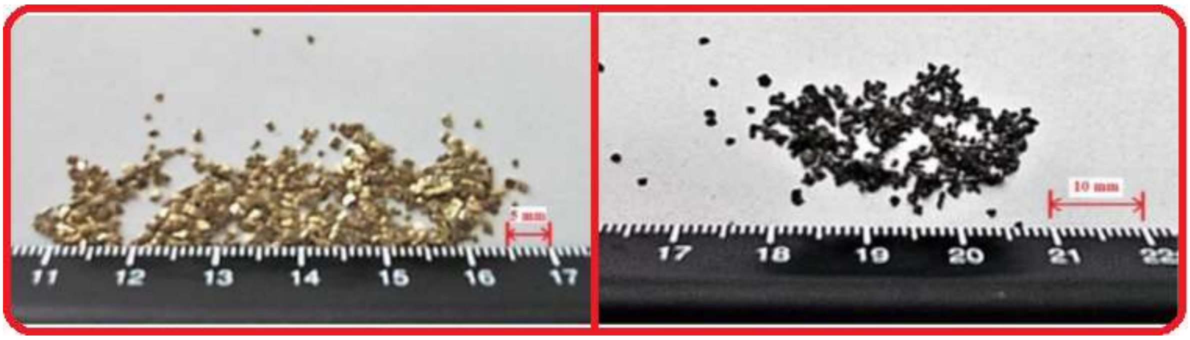


Figure 1.Images of starting chip materials; (a)CuZn31Si1-brassand(b)GGG-40 cast iron

It is known that the CuZn31Si1 starting material is used as a bearing element in the industry due to its tribological properties. The reason for choosing CuZn31Si1 material is its high load strength. The chip type of the material is continuous (Figure 1-a). It is known that GGG-40 material is used as a bearing elementin the industry since it has satisfactory tribological properties due to the graphite carrying solid lubricant property. The chip type of GGG-40 material is discontinuous (Figure 1-b).

Table1. Sieve analyses of CuZn31Si1 brassand GGG-40 starting chips

Screen opening	CuZn31Si1 (%)	GGG-40 (%)
500-1000(μm)	70	70
250-500 (μm)	30	30

Table2.Chemical composition of CuZn31Si1 brassand GGG-40 materials (% by weight)

CuZn31Si1 (%)	Cu	Zn	Si	Pb	Ni	Fe	Sn
	66.70	balance	1.30	0.20	0.05	0.31	0.03
GGG-40 (%)	C	Mn	Si	Mg	S	P	Fe
	3.40	0.13	2.50	0.04	0.01	0.08	balance

In order to bring the starting metal chips into the desired size range, they were milled in disc mill and size distribution was determined by sieve analysis (Table 1). Additionally,Table 2 shows the chemical compositions of the starting chip materials used in the production of metal matrix composite materials. Ultrasonic cleaning process was performed to the brass and cast iron chips used as the starting material in the first stage of producing metal matrix composite materials in order to remove the oil, dirt, and oxide layers on their surfaces.Subsequently, the structure was prepared in the rates of 50 wt.% brass-50 wt.% cast iron, 60 wt.% brass-40 wt.% cast iron and 70 wt.% brass- 30 wt.% cast iron and the production of composite materials was performed in three rates. Table 3 shows the prepared mixture rates and the coding of the samples. The prepared starting mixtures were held in saturated boric acid-ethyl alcohol mixture for 1 hour and placed in the furnace at 80°C and the ethyl alcohol was evaporated.

Table 3. Mixturerates of the composite material and coding of the samples

Composition name	p50d50	p60d40	p70d30
CuZn31Si1 (%)	50	60	70
GGG-40 (%)	50	40	30

The amount of boric acid compound which precipitated/crystallized again on the metal chips was measured with the help of a sensitive scale and was determined to represent 1% of the total mixture by weight. Boric acid compound known to be used widely as flux in soldering process was used in this study for the same purpose [11]. In this way, the negative effect of the metal oxides found on the metal chip surfaces on sintering process was tried to be minimized. The metal components in the composition were then mixed in a cylindrical mixer to get a homogeneous distributionwithin the structure. After this process, the mixtures prepared in three different rates by weight were pressed under 730 MPa pressure at room temperature. The test samples were prepared in ASTM (E9-89a) standard dimensions (Ø13-h25 mm).Figure 2 showsthe production process of MMCmaterial after the pressing process and the prepared mixture.

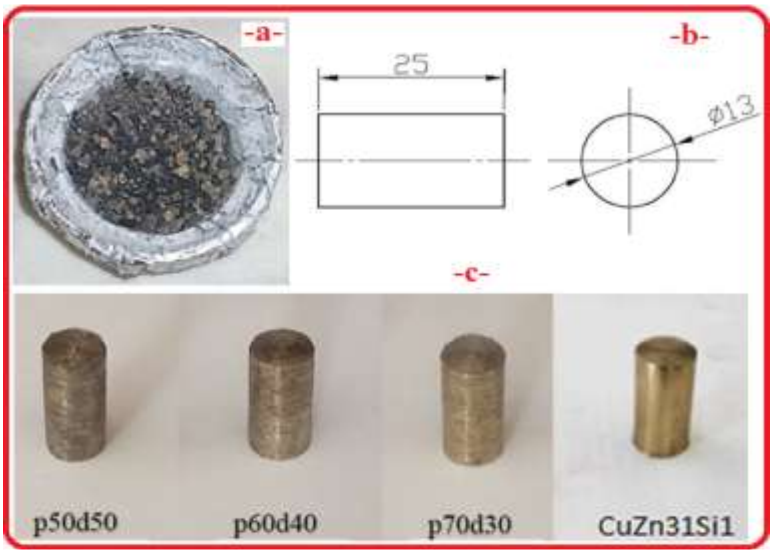


Figure 2. Production process ofcomposite material; (a)Powder mixtures, (b)Compression sample sizes, (c)Test samples after pressing

MMCmaterials after the pressing process were sintered in the atmosphere controlled furnace at a constant temperature of 942 °C for 45 minutes. The production parameters selected in pressing and sintering processes were optimised as a result of preliminary tests. Figure 3 shows Temperature-time diagram of the sintering process applied to the MMCmaterials after the pressing process.Having optimum values of porosity, which is a factor directly affecting the compression strength and mechanical properties of the produced composite materials, is a desirable feature.

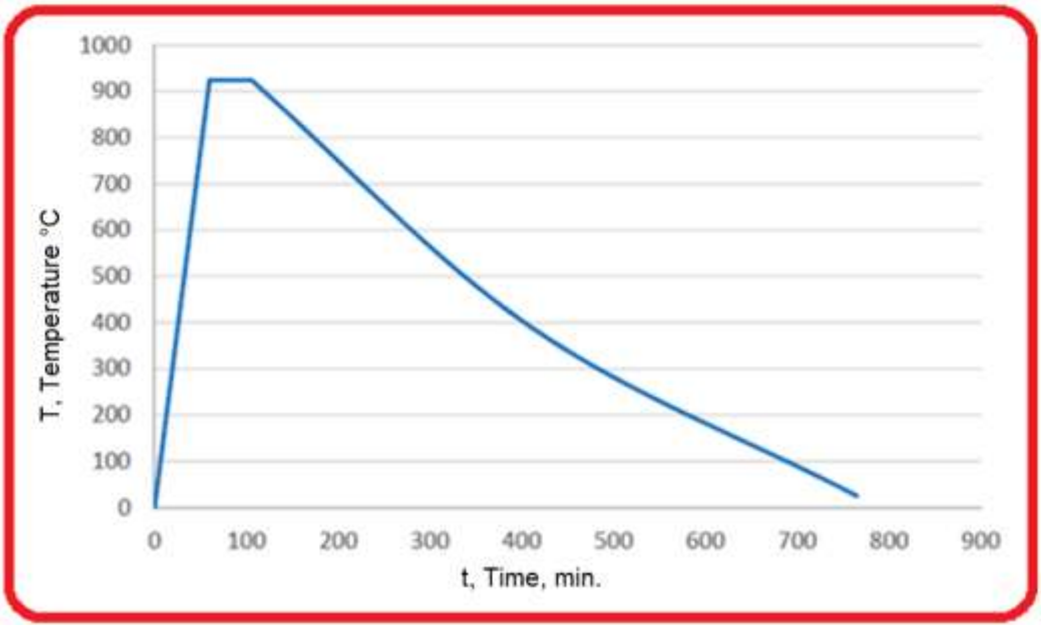


Figure 3. Temperature-time diagram of the process

For this reason, physical properties such as volume, density and percentage of porosity were determined. These values were found after both pressing and sintering and then compared with each other. After the general metallographic works including sanding (400-600-800-1000 mesh), polishing (1-3µm diamond solution) and etching (2% Nital) processes respectively, microstructure examinations of the MMCmaterials were carried out by using OLYMPUS - GX71 model optical microscope andHitachi-SU 1510 model Scanning Electron Microscope (SEM) devices. In the hardness measurements of MMC materials, Brinell hardness measurements were carried out using a 250 kgf load with 5-mm ball diameter. Compression tests of the MMC materials were conducted by using Shimadzu AG-X brand device with 100 kN capacity at 1.5 mm/minfeeding rate.

III RESULTS AND DISCUSSION

Figure 4 showsSEM images of the mixtures, composed of cast iron and brass chips subjected to ultrasonic cleaning process and the boric acid particles added into these chips, before the pressing process. As shown inFigures 4a and b, some boric acid particles contained in the mixture were observed to stick onto the surface of starting chip materials. When the SEM images of CuZn31Si1 and GGG-40 starting chip materials given inFigure 4c and dwere examined, both brass and cast iron chips were observed to be involved in rectangular prism morphologies.It was observed that both brass and cast iron chips had brittle structure due to the cracks formed by the milling process both during and after the formation of the chips.

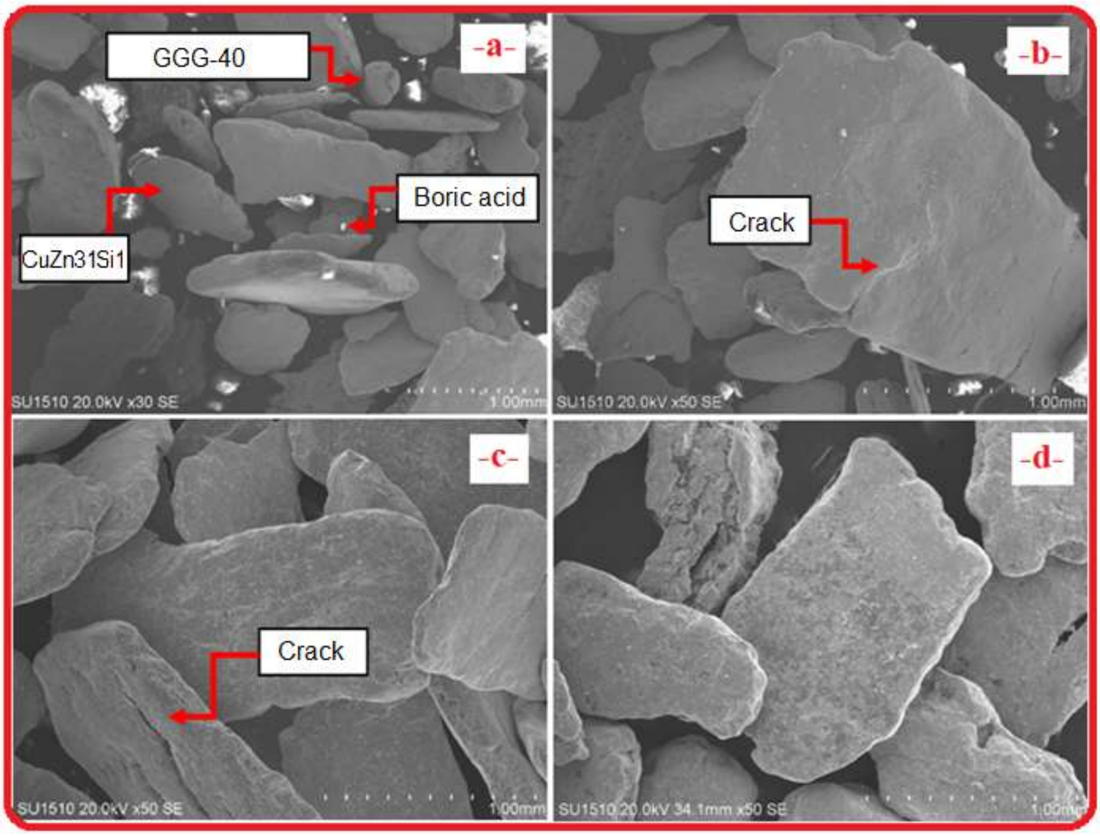


Figure 4. SEM images of the starting chip materials; (a)and(b)Matrix-reinforcement mixture, (c) CuZn31Si1, (d)GGG-40

In this study, the densities of the composite materials in three different rates were calculated before and after the theoretical sintering in order to find the porosity rates, which affect directly the mechanical properties and are a physical property, and the obtained values were given in Figure 5. It was found that the material with the highest experimental density was p70d30 and the material with the lowest density was p50d50 in the composite materials. Figure 6 showsthe total porosity percentages by volume of the composite materials found before and after the sintering process. Among the composite materials, it was found that the sample having the highest total porosity rate after the pressing processwas p50d50 with the rate of 28.51% and the sample with the lowest total porosity ratio was p70d30 with the rate of 21.3%. It was found that the material having the highest total porosity rate after the sintering process was p50d50 with the rate of 29.55% and the sample having the lowest total porosity rate is p70d30 with the rate of 23.29%. The densities of all the produced composite materials decreased after the sintering process compared to values obtained after the pressing process.

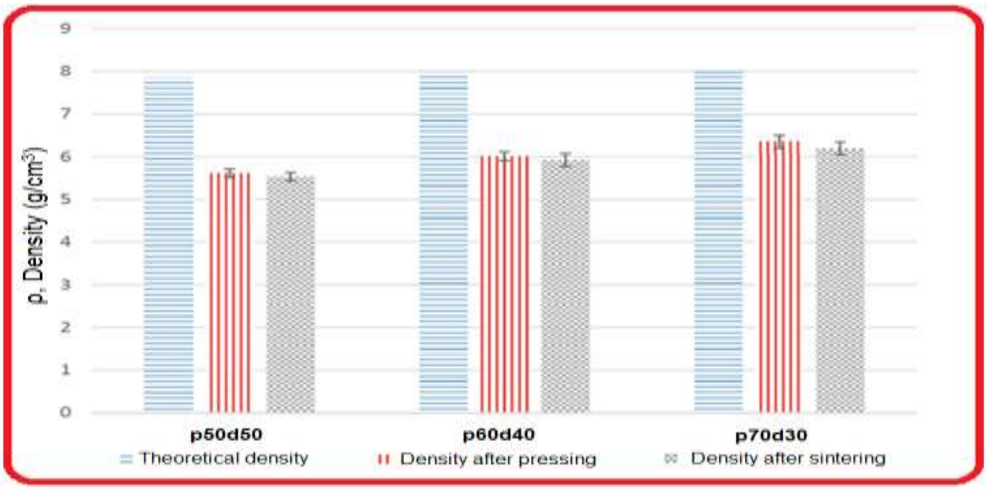


Figure 5.Density values of the produced composite materials

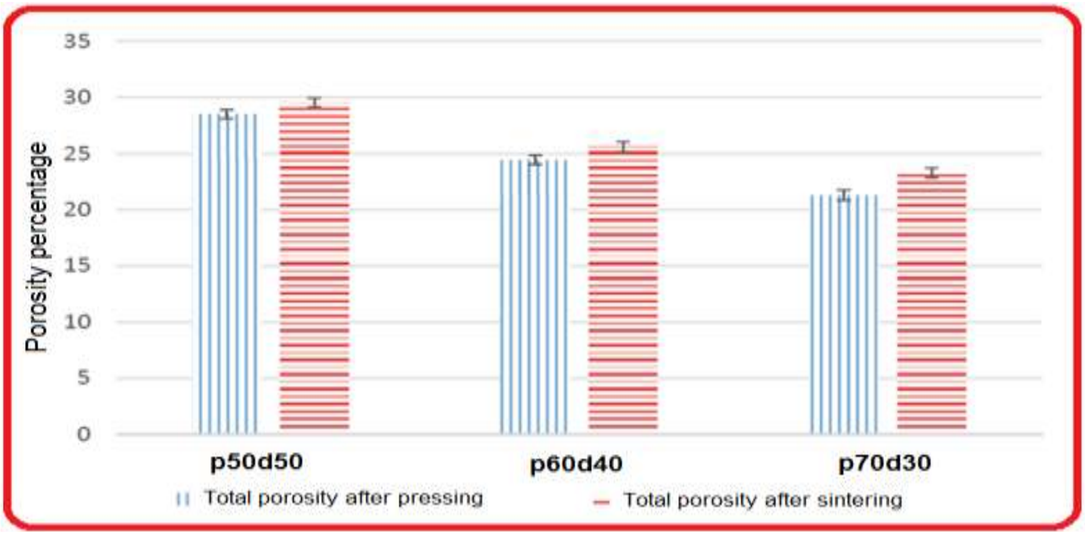


Figure 6.Total porosity values of the produced composite materials

The samplewith the highest increase in total porosity ratewas p70d30 with the rate of 9.34%. On the other hand, the sample with the lowest increase in total porosity rate was p50d50 sample with the rate of 3.64% (Figure 6). Swelling event can occur as a result of the separation of cast iron particles by the penetration of copper found inthe brass from the components forming the composite materials into those particles during the sintering process [12]. Thus, copper metals caused the separation of cast iron particles more in the composite samples with higher brass ratio. Thus, this led post-sintering porosity rate to increase more compared to the porosity ratio after the pressing.

Figure 7 shows the images of the fracture surfaces of the metal matrix composite materials after the compression test. As a result of the compression tests, all composite samples showed ductile behaviour and a fracture was observed in the direction of 45° which had the highest shear stress. In addition, barrelling was not observed in the samples during the compression test. Components initially found in the structure showed resistance to the force applied to the composite materials during the compression test. As the applied force increased, the plastic deformation started in the material when the sliding movement started in the brass component which was more ductile than the cast iron. In the meantime, the pores began to close and the majority of these pores were then closed as the force increased to high levels.

Figure 7.The fracture surfaces of the produced composite materials

When the applied load reached the maximum point, the cast iron particles in the structure which are harder and higher strength compared to brass were cracked and crushed, the sliding movement continued in brass component, which is more ductile than the cast iron, and finally the fracture occurred in the composite material in the direction of 45°which is the highest shear stress angle. Such occurrence of the fracture strengthened the idea that the pores and components in the structure were homogeneously distributed. After the applied compression test, the actual and engineering stress-deformation data of the produced metal matrix composite materials compared to CuZn31Si1 brass material are shown in Figure 8. According to the compression test results, it was observed that the actual stress-deformation values of all materials were higher than the engineering stress-deformation values as a result of the compression test(Figure 8).After the compression test applied to the materials(Figure 8), the material having the highest compressive strength (623 MPa) and the lowest unit deformation value (0.17%) compared to the composite materials was found as

CuZn31Si1. Among the composite materials, p70d30 material was determined to present the highest compressive strength as 180 MPa.

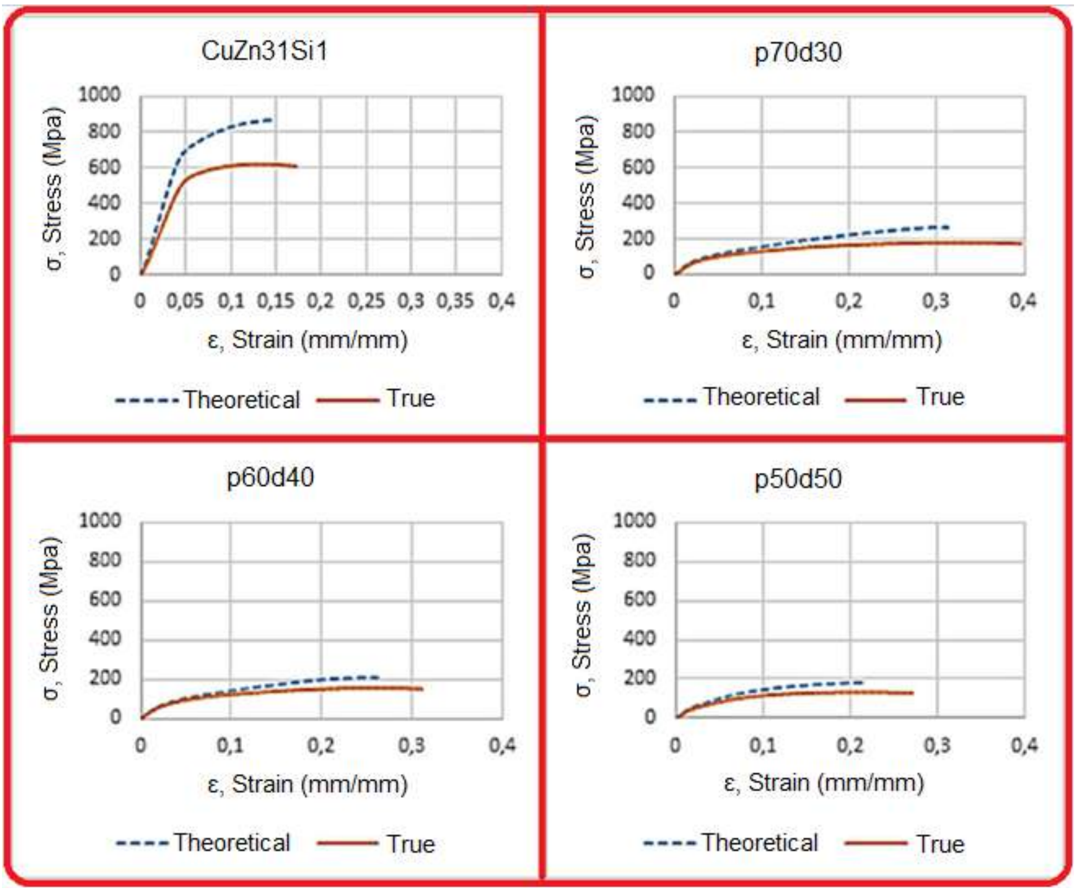


Figure 8.Compressive test results of the materials

It was determined that compressive strength of this material was as much as 28.9% of CuZn31Si1 material and the most ductile material among the composite materials was p70d30 (0.39%). The lowest compressive strength among the composite materials was determined as 134 MPa in p50d50 material. Compressive strength of P60d40 material with 155 MPa compressive strength was 24.8% of the compression strength and had 0.31% actual deformation value compared to CuZn31Si1. With the increase of CuZn31Si1 ratio in composite materials, compressive strength value and deformation values of the sample were found to increase. This was thought to be caused by the fact that the brass used as the filler material in the structure acted like a matrix as desired and an effective combination was obtained with the cast iron as the brass ratio increased in the mixture. After the compression test data obtained from Figure 8, the comparative yield strength values of the CuZn31Si1 brass and produced composite materials are given in Figure 9.According to the obtained results, the material having the highest yield strength was CuZn31Si1 with 429 MPa value. In p70d30, p60d40,and p50d50 metal matrix composite materials, decreasing yield strength values were determined as 95.9, 78.5,and 58.8 MPa, respectively.

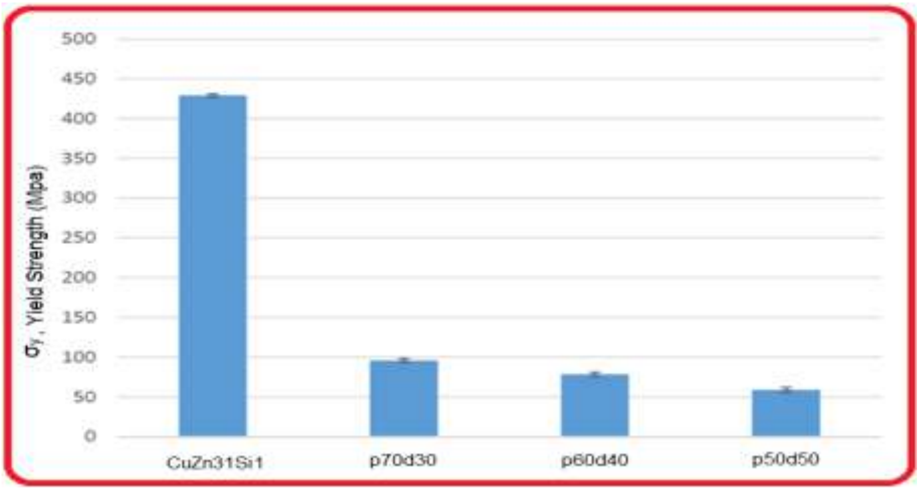


Figure 9.The yield strength values of the test samples

This can be stated as the increase of material yield strength of brass ratio increasing in the composite materials. In addition, it was also caused by the fact that the brass component involved as matrix format inside the composite body surrounded the cast iron particles better compared to the other rates and minimised the possibility of cast iron particles to be adjacent to each other. The resilience value refers to the energy stored during the elastic deformation of the material [13]. Figure 10 shows the resilience value obtained in the compression test and it was found that CuZn31Si1 matrix component produced by casting method had the highest resilience value with the value of 7.65 J/mm^3. The highest resilience among the composite materials was found in p70d30 material with the value of 2.64 J/mm^{3}and this value was found to be 34.7% of CuZn31Si1 material. The resilience results obtained from compression test showed that the resilience value decreased as the cast iron ratio in the composite materials increased. This can be explained by the fact that the cast iron particles are more strongly surrounded by the matrix by increasing ratio brass in matrix form in the structure. The fact that all cast iron particles in the structure of p50d50 material having the richest cast iron component cannot be surrounded by the matrix, thus the weakest ring of the composite material, namely cost iron particles in contact with each other was thought to cause a decrease in resilience values as in other mechanical properties.

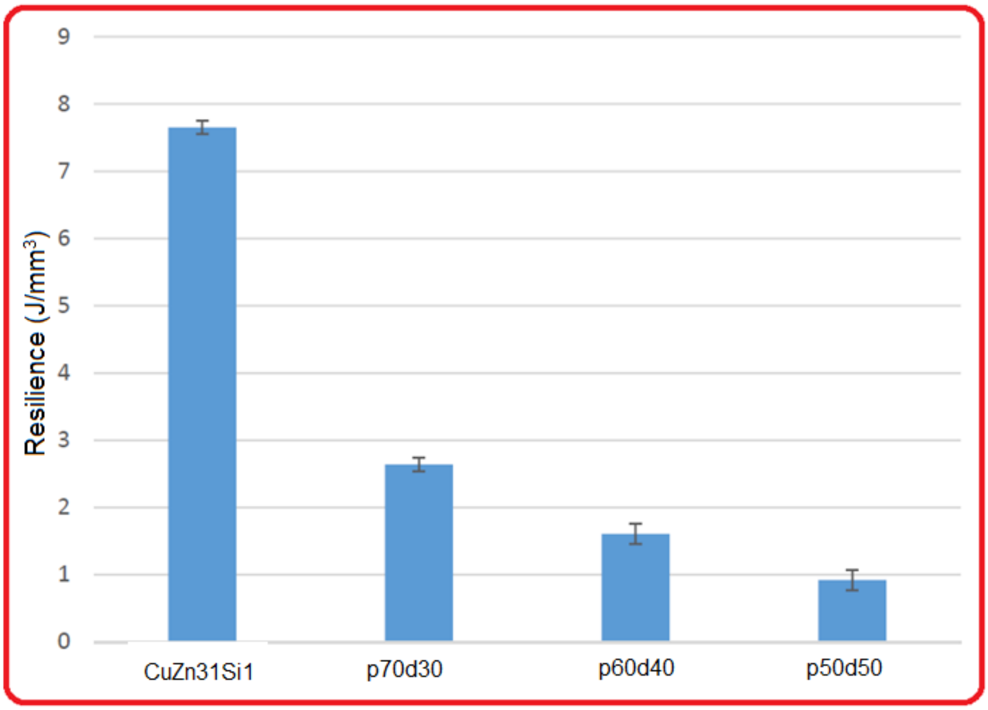


Figure 10.Resilience values of the materials

Figure 11 showstoughness values of the samples as a result of the compression test. The higher the compressive strength and deformation capability of a material are, the higher its toughness is. It was determined that the material obtained as a result of the compression test and having the highest toughness value was CuZn31Si1 material with the value of 88.1 J/mm^3. It was determined that the material having the highest toughness among the composite materials was p70d30 material with the value of 58.54 J/mm^3. As the brass ratio in the composite sample increased, the toughness of the material increased. This was associated with the fact that the increase in brass ratio, which is matrix material provides an effective joining by surrounding the cast iron particles in the structure more. In addition, it is also caused by the fact that as the load applied during the compression test increased, the pores were closed and as the ratio of brass component found as matrix in the structure increased, shearing movement of the cast iron particles in the matrix increased and thus the sample with higher brass ratio had higher deformation value. Toughness/resilience ratios of MMC materials subjected to compression test were higher than CuZn31Si1 sample. This indicated that the pores of the composite materials rapidly passed through the elastic zone, but generally absorbed more energy in the plastic zone. The elasticity modulus of the samples was found as a result of the determination of slope of the linear line in the elastic zone in actual compression stress-actual unit deformation curve and Figure 12 showsthe obtained values. It was found that the sample having the highest elasticity modulus was CuZn31Si1 with the value of 120.4 GPa.

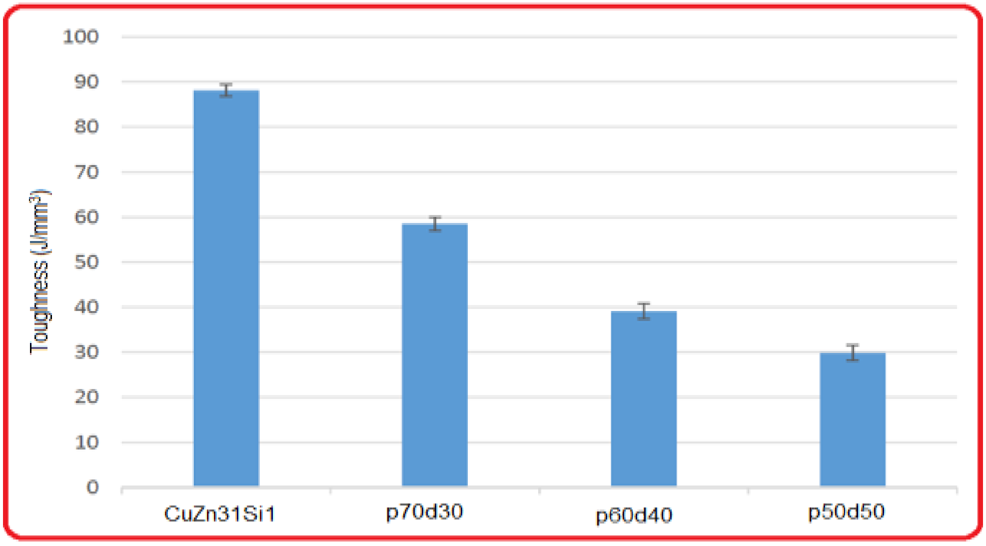


Figure 11.Toughness values of the materials

The elasticity value closest to this sample belonged to p70d30 composite sample with the value of 40.5 GPa and young's modulus of this sample was found to be almost 33.6% of the young's modulus of CuZn31Si1 material. Elasticity value of p60d40 sample was Ep60d40=34,5 GPa and the sample having the lowest young's modulus value was p50d50 with the value of 30.4 GPa.The obtained results indicated that young's modulus of the sample decreased as the cast iron ratio in the composite mixture increased.

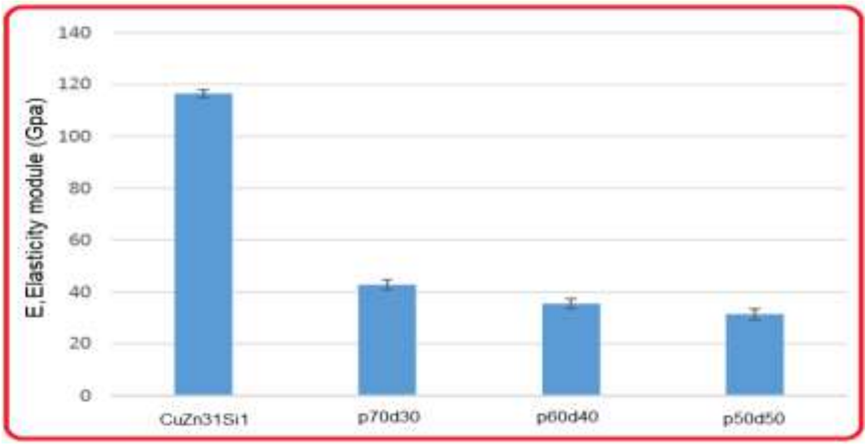


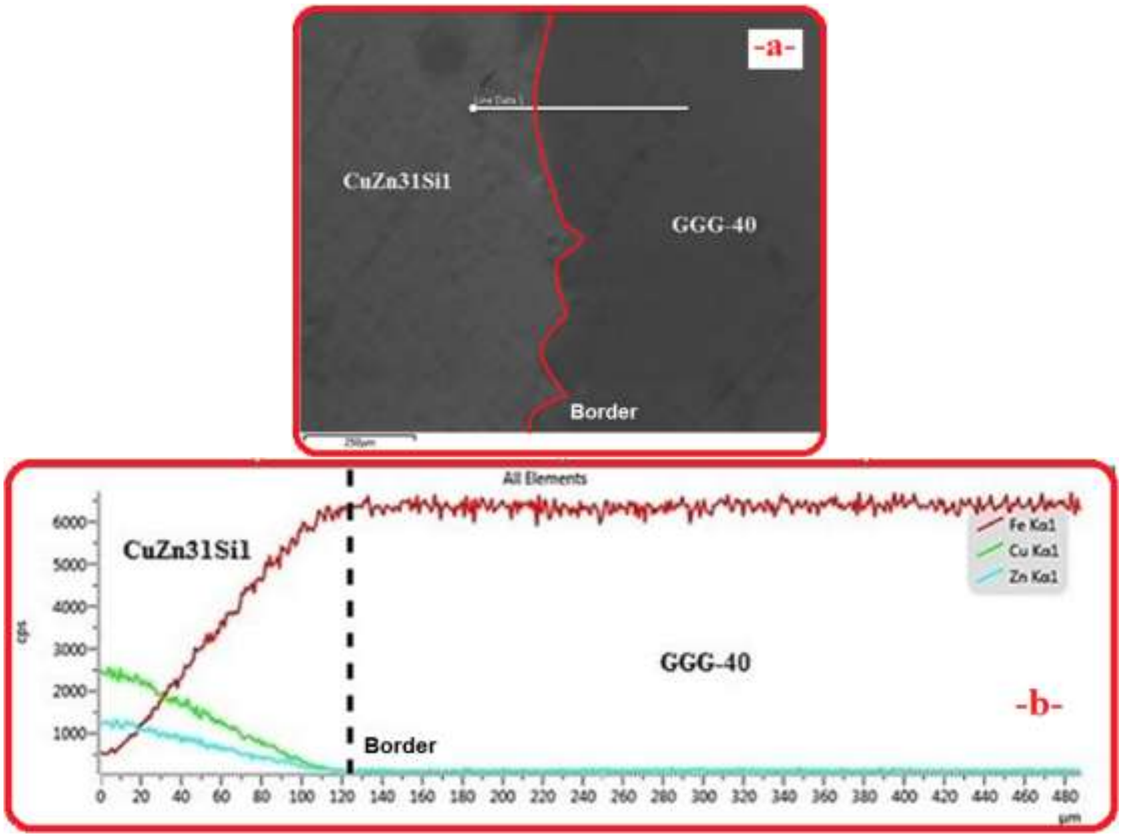
Figure 12.Elasticity modulus of the materials

Table 4 showsBrinell hardness results (BSD) of the produced metal matrix composite materials, matrix (CuZn31Si1) and reinforcement (GGG-40) components located in the composite body. After the applied hardness test, the highest hardness of 59 HB and the lowest hardness of 37 HB in the produced composite materials were determined in p50d50 and p70d30 materials, respectively. This resultwas thought to be caused by the fact that cast iron hardness was higher than the brass material and p50d50 material had the highest spherical graphite cast iron rate among the composite materials.

Table 4.Hardness values of the test samples

Samples	CuZn31Si1	p50d50	p60d40	p70d30	GGG-40
Brinell Hardnes	148±1,1	59±1,7	45±1,7	37±1,7	175±1,1

Figure 13 showsthe results of EDX spectra and XRD analysis applied to p50d50 material in metal matrix composite materials.According to the EDX analysis SEM image of p50d50 material given in Figure 13-a, the right side of the boundary was GGG 40 component and its left side wasCuZn31Si1 component. It was found that as we went to the right side from the boundary, the iron ratio by weight increased and the copper and zinc ratio was negligible on the right side of the boundary. It was found that as we went from the boundary to the left side, the ratio of copper and zinc by weight increased but the iron ratio decreased(Figure 13-b). In other words, it was found that iron was diffused into the CuZn31Si1 brass but the diffusion of zinc and copper into GGG-40 cast iron was negligible. This can be expressed as the lack of dissolution of copper element withface-centred cubic structure and zinc with simple hexagonal structure since they were in iron alloy having a body-centred cubic structure namely in different crystal lattices [14, 15]. According to the XRD analysis of p50d50 material given in Figure 13-c, no intermetallic compound formation was observed between the cast iron and brass metals forming the composite structure.



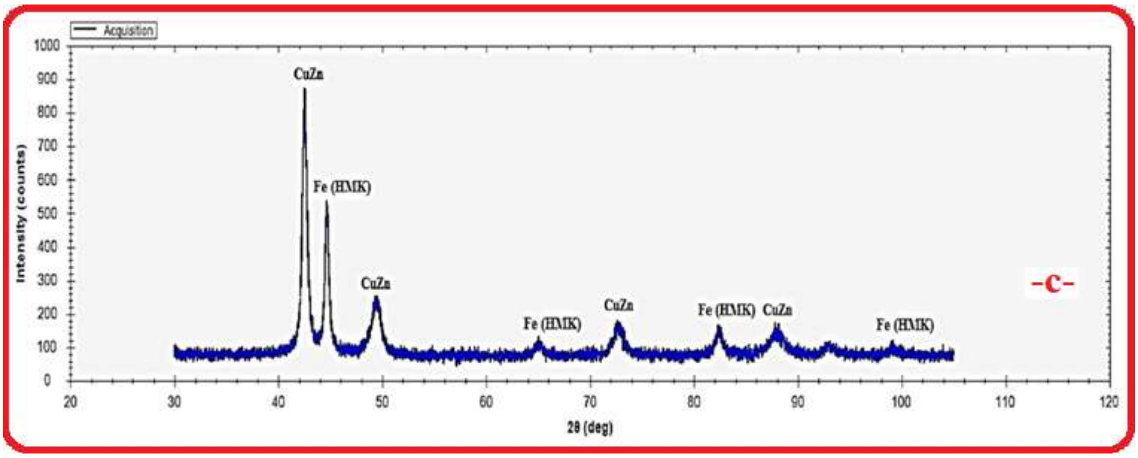


Figure 13.The p50d50 sample's
a) EDX spectrum-EDXimage, c) EDX graph and d)XRD analysis

Figure 14 showsoptical microscope microstructure images obtained in terms of microstructural characterisation of the composite materials produced with three different mixture ratios (p50d50, p60d40 and p70d30). It can be asserted that the maximum pore formation took place in the microstructure of p50d50 material. The compressibility of materials with a higher brass ratio was higher during the pressing process. The p70D30 material had a less porous microstructure than the other samples since the brass melting during the sintering process filled the pores in the structure at higher rate.

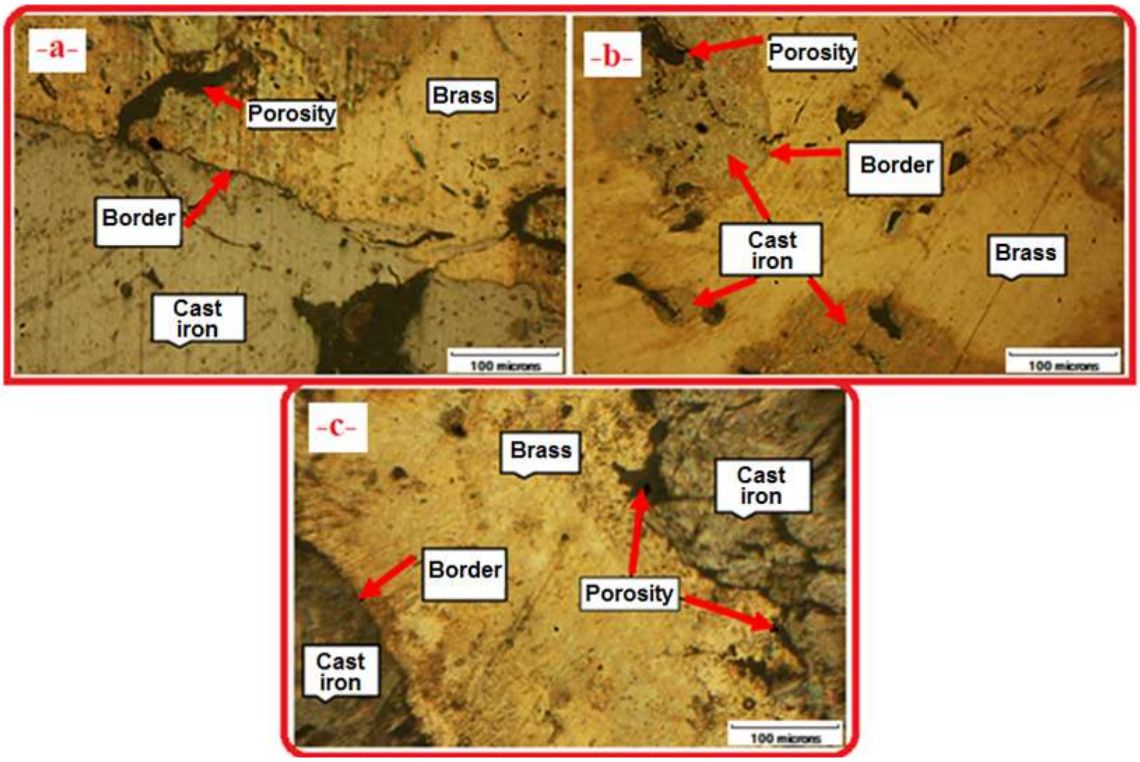


Figure 14.Microstructural images of produced composite materials;
(a) p50d50, (b) p60d40, (c) p70d30

In the microstructure images shown in Figure 14, brass and cast iron components and joining boundaries were observed.In some places of the composite structure, it was observed that the melt brass could not fill the pores due to the chip geometry and pores were formed in the structure. When these pores were examined in terms of tribological properties of the composite material, it was found that even though they increased the oil absorption capability of the material, these irregular and large pores in terms of their structure affected all other mechanical properties of the material negatively.

Another factorthat affected the mechanical properties of metal matrix composite materials was the metal oxide compounds on metal chips that could not be completely removed. These stable hard oxide compounds with relatively high melting temperatures preventedthe structure components to stick-interlock at desired level by not only reducing the compressibility of the particles in the mould during compression but also causing a decrease or interruption of the contact surfaces between the components especially during the sinterization [12]. As a result, the mechanical properties of the composite materials decreased. Figure 15 a-c shows the elements and their distributions in the iron and copper alloys in the structure of composite material.

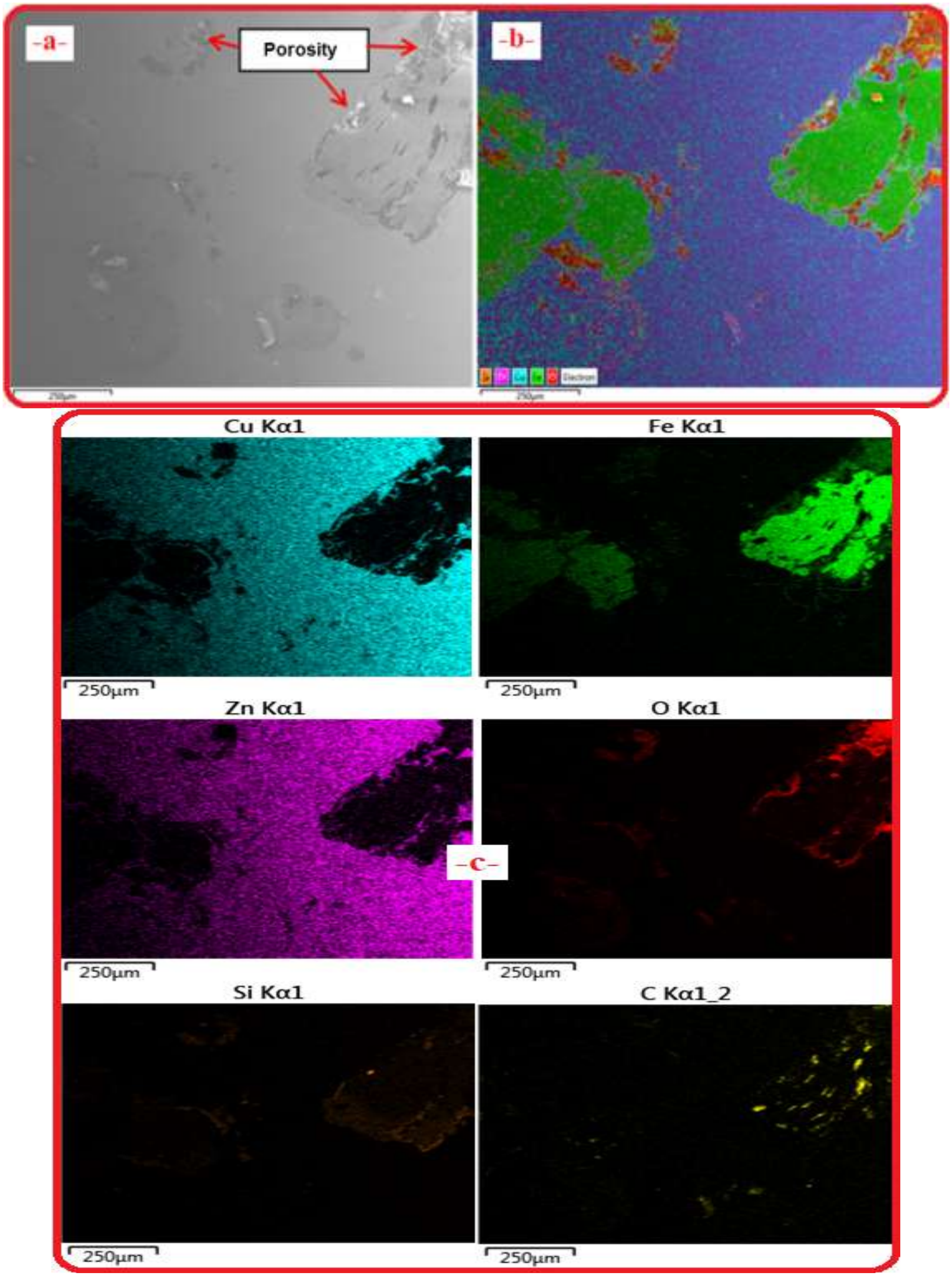


Figure 15.SEM and EDX analysis element mapping of the produced composite materials; (a)General SEM image,(b)Distribution of all elements in the zone,(c)Elemental distributions

It can be seen in the images that the copper was melt and partially entered and filled the capillary pores and between the iron chips but pores preserved their presence in many joining regions. Figure 15-cshows regions rich in oxygen element (red coloured) concentrated in the joining regions/interfaces and especially in the pores of the chips which were the component of composite material. The presence and location of metal oxide compounds which discontinued the contact between the particles and weakened the mechanical properties of the composite materials in these regions were clearly observed.

IV CONCLUSIONS

In terms of their role in the production process of recycling, metal matrix composite material production was conducted with powder metallurgy method using cast iron and brass material chips. The results of the experimental studies are presented below;

It was determined that as the brass ratio increased in metal matrix composite materials, the compressibility increased and total porosity ratio after sintering increased with the increase in cast iron ratio. The highest and lowest total porosity rates of MMCmaterials after sintering were determined as 29.55% and 23.29% in p50d50 and p70d30 materials. It was determined that the compression strength of CuZn31Si1 material was higher than the produced composite materials. The highest compressive strength was found in p70d30 material with the value of 180 MPa. The resilience and toughness of the industrial CuZn31Si1 alloy were higher compared toMMCmaterials. The highest resilience and toughness values in composite materials were found as 2.64 J/mm^3 and 58.5 J/mm^3, respectively in p70d30.It was determined that the hardness of MMCmaterials increased with increasing matrix cast iron ratio. In MMCmaterials, the highest hardness value was measured as 59 HB in p50d50 material.

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