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The Recycling of Steel and Brass Chips to Produce Composite Materials via Cold Pressing and Sintering

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ABSTRACT
In this study a novel method of direct conversion of brass (CuZn30) and steel (S355JR) chips into finished product without melting is introduced as an alternative to melting process. CuZn30 Brass and S355JR steel chips were used as constituents of composite materials. The chips were cold pressed at room temperature and were subjected to liquid phase sinterization. Hardness, compression and three point bending tests were used to investigate the mechanical properties of the obtained composite materials and compared with cast CuZn30 brass. The produced composite materials are shown to have comparable mechanical properties with bulk brass. It is also shown that the proposed method can be considered as an alternative to conventional production methods such as melting, extrusion ect. with relatively low costs.

Keywords: *Recycling, Sintered brass-steel chips, Metallic composites*

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I. INTRODUCTION

Recycling of metals has been becoming an essential subject, lately due to the fact that the depleted resources, high energy consumption and harmful gases emission. In the industry, the majority of waste materials are the metal chips fell out during machining. In general recycling, the metal chips are melted and then casted. During this process, the materials are subjected to oxidation and degradation. Besides, melting process is low efficiency process which requires additional costs such as energy consumption cost of labor, harmful gas emission etc. However, waste chips can be converted into compacted composite materials without melting [1-4] in which metal chips are cut to form small particles which can be easily cold pressed and sintered. It is reported that this recycling procedure can be applied to iron, copper and aluminum alloys and cast iron [5-7].

In this study, as an alternative to melting method, a novel method of recycling has been introduced for production of brass / steel composite materials. The method of powder metallurgy requires very fine particles which are hard to obtain and expensive. The proposed method utilizes only waste metal chips which are cheap in comparison with metallic powders. So, this method is an economical and environmentalist approach for utilization of waste.

In this study, a metal matrix composite material was produced by the proposed method by using S355JR steel chips and the CuZn30 brass chips and the mechanical properties of produced composite were investigated. The composite material produced with two different brass content. After the production the compression strength and the bending strength are obtained and compared with those of industrial cast CuZn30 brass.

II. MATERIALS AND METHOD

The metal chips firstly sifted with a sieve with 800µm cells (20 mesh)(Fig.1 and 2). After that the chips were cleaned by acetone in order to get rid of oil debris on the surface. The chemical compositions of metallic chips are shown in Tables 1-2. The composite materials were produced with two different brass/steel content as shown in Table 3. The composite materials were named by using constituent's contents as in Table 3.

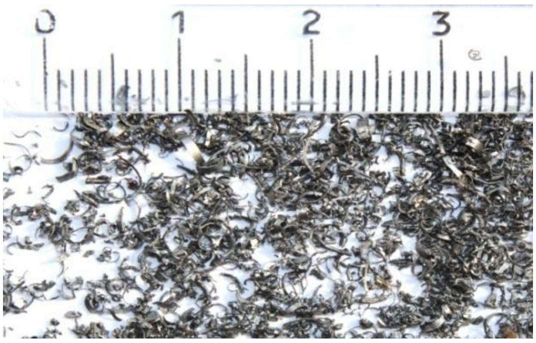

Figure 1. Saw chips of S355JR steel

Figure 2. Saw chips of CuZn30 brass

Table 1. Chemical composition of S355JR steel (by % weight)

Material	**C**	**Si**	**Mn**	**$P_{(max)}$**	**$S_{(max)}$**	**N**	**Fe**
S355JR	0.24	0.55	1.60	0.040	0.040	0.009	Remaining

Table 2. Chemical composition of CuZn30 brass (by % weight)

Material	**Cu**	**Zn**	**Pb_{max}**	**Fe_{max}**	**Ni**
CuZn30	69-71	31-29	0.05	0.05	0.20

Table 3. Weight percentage of composite material

Constituents (%)	**7030**	**5050**
CuZn30	70	50
S355JR	30	50

The metal chips were stirred by a mixer for 25 minutes in order to achieve adequate homogeneity. After the mixing the chips were pressed at ambient temperature. The pressing pressure was selected as 1GPa for compression specimens and 450 MPa for bending specimens so that the porosity ratio of the composite materials is obtained 20%. After that the raw samples were sintered at 940°C for 1h and then machined to standard dimensions by using conventional lathe and milling machine. The compression tests and three point bending tests were conducted in accordance with ASTM E9-89a and ASTM E290-97a respectively which proposes dimensions of 13mm diameter and 39 mm height for compression test and 13mmX13mmX70mm for three point bending specimens. (Fig. 3)

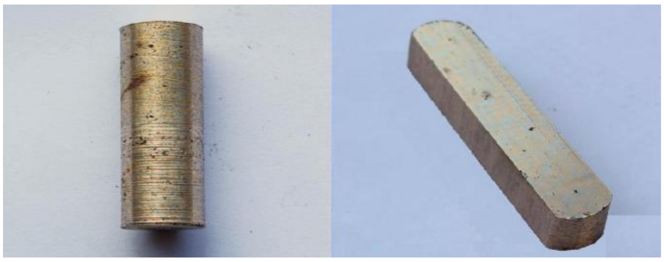

Figure 3. Specimens for compression and three point bending tests

2.1 Test set up and Procedure

- ***Compression test***

The compression tests were repeated three times for consistency and force-displacement curves were obtained for all specimens. This data were utilized for obtaining true stress and strain values by using

$$\sigma_{true} = \frac{4Fh'}{\pi d_0^2 h_0}, \ \varepsilon_{true} = \ln \frac{h_0}{h'}$$

where h_0, d_0, F and h' represents initial height, initial diameter, applied force and instantaneous height respectively.

- ***Three point bending test***

The bending tests were done in accordance with ASTM (E290-97a) standard which stipulates 55 mm span width and diameter of support of 8 mm. The bending force was applied on the surface where the compressive force was applied during production. During the tests the force –displacement variation were recorded and the variations were obtained in graphical form.

- ***Surface hardness***

After the production, the hardness of composite materials has been measured by using Brinell Test. A steel sphere with diameter of 5mm was indented under 250 Kgf. The reason why that diameter has been selected is for representing both the constituents and pores at the same region and obtaining the material's more accurately.

III. RESULTS

The mechanical properties of composite materials are seen in Table 4 and the true stress-true strain curves are seen in Fig.4.

It is seen in Table 4 that the 5050 composites showed the lowest Young modulus and both composites have showed Young module which are approximately 50% lower than cast brass.

As seen in this figure the cast brass showed the highest strength. It is concluded that the pores within composite materials create stress concentration and lower the strength levels for both 7030 and 5050 composites under compression. A similar behavior is observed for yield strengths.

It is also seen in Fig.4 that the composite materials show true strain at fracture considerably higher than that of cast brass. It is concluded that the porous structure of the composite can greatly increase the strain during compression test. This situation has led to an increase of 50 % for 5050 composites and 60% for 7030 composites.

It is seen in Table 4 that the toughness values of composites are lower than that of cast brass. It is concluded that this situation generally arises form porous structure of composites which creates stress concentration and results in decreased strength. However the 7030 composites show relatively high toughness due to increased brass content which can create an envelope over steel chips and result in increased ductility.

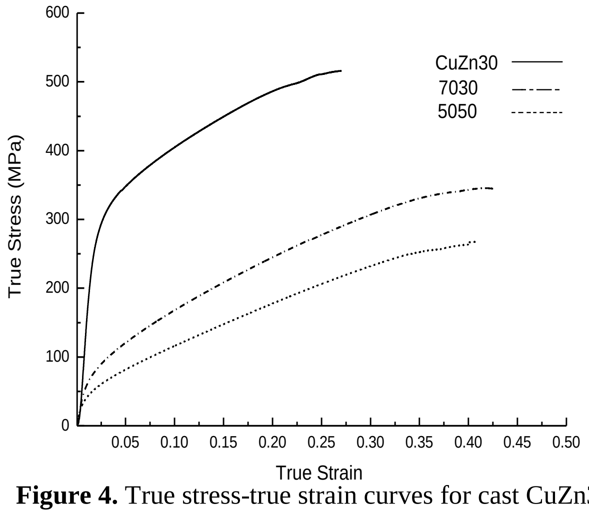

Figure 4. True stress-true strain curves for cast CuZn30

Table 4. Mechanical properties of Composite materials (Tested under compression loading)

Samples	Young's Modulus *(GPa)*	Yield Strength *(MPa)*	Comp. Strength *(MPa)*	Strain at fracture *(%)*	Toughness *(J/m^3)*
70-30	49.6	73.21	343.1	43	102.6
50-50	41.3	39.2	267.4	41	70.1
CuZn30	111	249.3	516.1	27	111.2

Fig. 5 shows the force-displacement variation for three point bending loading. It is seen in this figure that the composites showed lower resistance to bending loads than that of cast brass. It is also seen that the composites showed approximately the same resistance to bending loads. It s concluded that this behavior arises from the fact that when the composites subjected to bending, the deformation concentrates at tensile side and pores within composites plays an important role. These pores also restrict the deformation and result in low displacement as seen in Fig. 5.

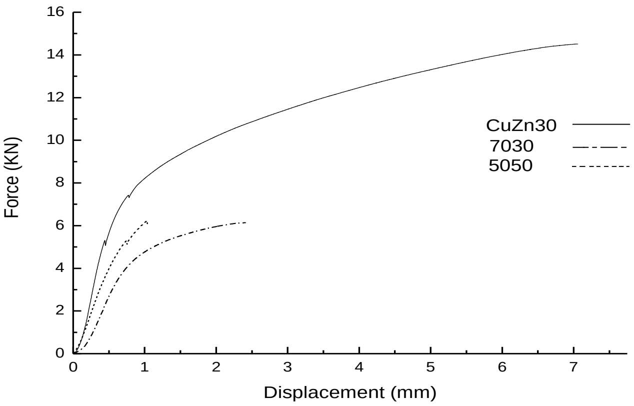

Figure 5. Force-displacement curves for cast CuZn30 brass and composite materials under three point bending.

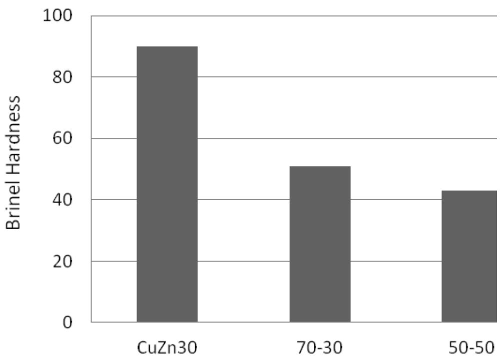

Figure 6. Variation of surface hardness

Figure 6 shows surface hardness of bulk brass and composite materials. As seen in this figure the bulk brass is harder than that of composite materials as expected. This is mainly due to the pore content of composite materials which is approximately 22%.

As seen fig.6. the material become softer with increasing steel content. This is mainly due to the fact that increasing steel content decreases the amount of brass which act as matrix material resulting in lack of adhesion between steel particles and reduces the resistance to plastic deformation at the surface.

Figures 7-8 shows the microstructures of composite materials after three points bending test. It is seen in these figures that during liquid phase sinterization the brass chips are partially melt and creates an envelope around the steel chips. This situation leads a good bonding between steel and brass chips and lead to structural integrity.

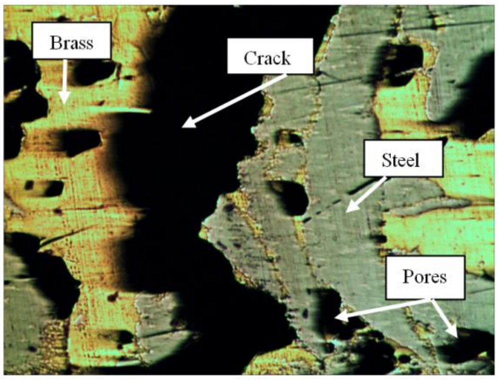

Figure 7. Microstructure of 5050 composite after three points bending test

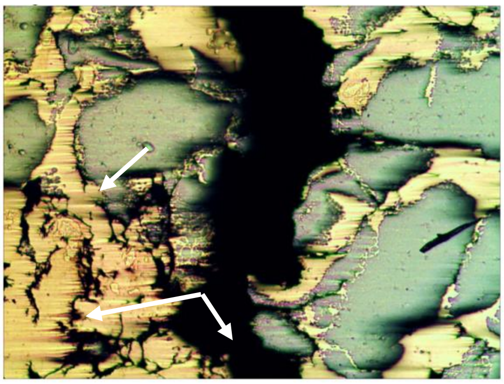

Figure 8. Microstructure of 7030 composite after three points bending test

IV. CONCLUSIONS AND FUTURE WORKS

In the paper the method of direct conversion of brass and steel chips, into finished product without melting, as an alternative way to conventional method is described. The proposed method is cheap, green and alternative to conventional methods. After the production the materials were subjected to compression, three points bending and hardness tests. Finally the fracture surfaces were evaluated by optical microscopy.

It is concluded that the brass constituent creates a positive effect on ductility when tested under compression. Mainly due to the fact that the shear motion as a result of compression generally occurs on brass particles which easily slips. On the other hand the pores with in material restrict the shear motion of the material when tested under three points bending test.

It is concluded that the mechanical properties of the composite materials mainly depends on mechanical response of brass constituents and adhesion between brass and steel particles.

It is observed that the produced composite materials have mechanical properties which are comparable with cast brass.

The authors are planning to conduct new research to determine if those materials can be considered as both bearing and friction materials.

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