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Workability Behavior of Hybrid Copper Matrix Composites Synthesized by Powder Metallurgy Technique

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Copper based hybrid composite materials with 5wt.% of titanium dioxide and 0wt.%, 2wt.% and 4wt.% of graphite were produced using powder metallurgy technique. The presence and distribution of titanium dioxide and graphite reinforcements were examined in the copper matrix using scanning electron microscopic and energy dispersive spectroscopic analysis. To investigate the workability behavior of the sintered composite preforms, cold upset tests were conducted and various stresses and forming parameters were determined and using that various stress ratio parameters such as the true axial stress versus the true effective stress, the true hoop stress versus the true effective stress, the true hydrostatic stress versus the true effective stress and the true hoop stress versus the true hydrostatic stress were calculated and correlated with the true axial strain. From the studies, the workability of the composite is found to increase with increasing graphite content due to increase in lubricating affect by graphite addition.

Keywords: hybrid copper composite, Powder metallurgy, workability.

1. Introduction

In the field of automotive, aerospace, marine and defense industries [1] there is a prerequisite of innovation in material with enriched properties to use in diverse environments. Metal matrix composites have a wide range of scope to design and build materials with desired properties by reinforcing with hard and/or soft materials. Ceramic is one among the reinforcement which plays major role in the composite materials due to its outstanding mechanical properties, tremendous strength and better chemical stability even at elevated temperatures [2]. There are several modes of composite fabrication which includes solid phase or liquid phase processing and each has its own assets and faults in distribution of reinforcement and interfacial bonding of reinforcement with the matrix material. Powder metallurgy is one of the best and cost effective fabrication techniques which fabricate the required component at desired geometry with uniform distribution of reinforcement and ease of control in microstructure [3–6]. Further the properties of the material produced through powder metallurgy technique may be improved with the secondary processing and heat treatment [7]. Copper is the material which has extensive application due its remarkable properties such as electrical conductivity [8, 9], thermal conductivity [8, 9], ductility [9] and corrosion resistance [9]. Copper composites have exposed a superior combined properties of conductivities, mechanical and tribology [10]. Cu-Fe3Al composite was effectively fabricated at varying volume fractions of Fe3Al by powder metallurgy and investigated its wear behavior [11]. Mechanical and wear properties of copper tin composites with copper coated and uncoated lubricant of graphite and molybdenum disulfide was investigated [12] and found that the addition of copper coated lubricant shows an adverse effect on the material properties. Steel composite reinforced with TiC particles was produced through powder metallurgy and studied the workability of the produced composite during hot forging [13]. Workability of the copper composite produced by powder metallurgy with silicon carbide was studied and examined the different stress ratio parameter under trial stress state [14]. Hybrid copper composite with TiC and graphite was successfully fabricated and its tribological properties was investigated [15]. Al2024-SiCp composite was synthesized by powder metallurgy technique and investigated the workability behavior of the produced composite [16].

Copper composites with carbon nanotubes were fabricated and the tribological property of the composites were examined [17]. Aluminium composite with titanium carbide particles was synthesized through powder metallurgy route and explored it's forming behavior under triaxial stress state condition [18]. Hybrid aluminium composite with 5wt. % TiO_2 and 6wt. % graphite using powder metallurgy technique was produced and its forming behavior was studied [19]. Three copper based composite by precipitation, dispersion and multiple hardening using powder metallurgy was produced and the strengthening effects at room temperature and elevated temperature were studied [20]. The effect of copper addition on the mechanical properties of Ancorsteel 85 HP alloy was studied and reported that there is an increase in density and toughness [21]. Mechanically mixed the copper powder was mixed with aluminium silicon alloy, produced the composite by liquid phase hot pressing and observed that the addition of copper led to the formation of Al_2Cu, which enhanced the mechanical properties by precipitation and solid solution hardening [22]. With reference to the earlier findings discussed above, it was identified that there is research gap in the synthesis and workability studies of copper composites with TiO_2 and graphite as reinforcement. Therefore an attempt is made to produce a hybrid copper composite with 5wt.% TiO_2 and at varying weight percentage of graphite (0, 2 and 4) through powder metallurgy technique. To identify the reinforcement's presence and distribution the copper composite were subjected to scanning electron microscopic along with energy dispersive spectroscopy. Further the hybrid composites workability behavior is investigated during cold upset.

2. Experimental details

Copper powder of 150 μm with 99% of purity was chosen as the matrix material, TiO_2 and graphite powder of 10 μm with 99% of purity was taken as reinforcements to fabricate the hybrid copper composite material with 5wt.% TiO_2 and at different weight percentages of graphite (0, 2 and 4) using powder metallurgy techniques. In order to obtain the required composite composition, copper, TiO_2 and graphite powders were weighed accurately using 0.0001 g accurate digital weighing balance and then the mix were blended in a ball mill for 15 hrs at 300rpm using a ball to powder ratio of 10:1. After the blending process, the powders were compacted in a hydraulic press using a punch and die setup with zinc stearate as die wall lubricant. Green compacts were further sintered at 900^{o}C temperature for a duration of 2 hours under argon environment in a muffle furnace and then it is allowed to cool in the furnace. Samples were prepared from the sintered preforms for metallurgical characterization through scanning electron microscopic analysis along with energy dispersive spectroscopy analysis. During the pilot experiments, reduction of hardness was observed beyond 10wt.% TiO_2 addition and also agglomeration of graphite particles were observed beyond 6wt.% addition of graphite. Hence the hybrid copper composite for the workability study were constrained to Cu-5wt.% TiO_2-0wt.% Gr, Cu-5wt.% TiO_2-2wt.%Gr, and Cu-5wt.% TiO_2-4wt.%Gr.

Initially the dimensions of the sintered hybrid copper composite preforms were measured, and cold upsetted with 20 kN compressive load was applied in an incremental manner using flat fine polished dies till the appearance of crack on the surface. At the end of the each incremental loading, the dimensions such as bottom contact diameter (D_{BC}), top contact diameter (D_{TC}), bulged diameter (D_B) and height (H_d) of the upset preforms were documented to quantify the deformation. With all the measured values, relating the plasticity theory as explained elsewhere [13, 14, 19, 23, and 24], the various stresses and forming parameters were determined. From that the stress ratio parameters such as the true axial stress versus the true effective stress (σ_z/σ_{eff}), the true hoop stress versus the true effective stress ($\sigma_\theta/\sigma_{eff}$), the true hydrostatic stress versus the true effective stress (σ_m/σ_{eff}) and the true hoop stress versus the true hydrostatic stress (σ_θ/σ_m) were calculated and correlated with the true axial strain (ε_z).

3. Results and discussion

3.1. *Scanning electron microscopic analysis*

Fig. 1(a)–(c) shows the scanning electron microscopic image of hybrid copper composite with 5wt.% TiO_2 and varying graphite content. The microscopic image clearly visualizes and differentiates the matrix phase and reinforcement phase and also shows the even distribution of reinforcements in the copper matrix. From the energy dispersive spectroscopic analysis it is observed that in all three compositions, the presence of TiO_2 is found equal whereas the intensity for graphite are found to be increasing with increase in graphite content of 2 and 4 weight percentages as shown in Fig. 2 (a)–(c).

3.2. *Workability behavior*

Workability of a material highly depends on the ductility and its process parameters [46], which can be evaluated using the stress ratio parameters. Fig. 3–6 depicts the relationship of the stress ratio parameters (σ_z/σ_{eff}), ($\sigma_\theta/\sigma_{eff}$) with the true axial strain (ε_z) for Cu hybrid sintered composites during cold upsetting. Fig. 3 shows that stress ratio parameter (σ_z/σ_{eff}) increases with increase in graphite particles in the hybrid copper composite. Among the various composites tested the higher stress ratio parameter (σ_z/σ_{eff}) is observed for Cu-5% TiO_2-2% Gr composite and this may be due to the addition of 2wt.% of soft graphite particles which promotes densification in the axial direction and hence the axial stress (σ_z) is relatively more than that of the effective stress (σ_{eff}). But for higher content of graphite such as 4wt.% , the material gets self–lubricated and due to which the axial stress (σ_z) is relatively less than that of the effective stress (σ_{eff}) thereby the stress ratio parameter (σ_z/σ_{eff}) for 2wt.% is higher than that of 4wt.%.

In the present study, the stress ratio parameter decreases for the increase in true axial strain which is due to the rate of increase in true effective stress (σ_{eff}) which is higher than that of increase in true axial strain (ε_z). Due to similar reasons the stress ratio parameter ($\sigma_\theta\ /\sigma_{eff}$) and ($\sigma_m\ /\sigma_{eff}$) as shown in Figs. 4 and 5 represents similar trend which is observed in Fig. 3.

Fig. 6 represents the variation of stress ratio parameter (σ_θ/σ_m) with true axial strain (ε_z) during cold upsetting of copper hybrid composites. In the early conditions of axial strain the composite without graphite exhibits lower stress ratio parameter (σ_θ/σ_m) as the pore size is relatively larger which leads to lower hoop stress whereas the composite with higher graphite content having very fine pores leads to higher hoop stresses. Later after deformation the larger pores get closed and decreased in size which makes the stress ratio parameter (σ_θ/σ_m) uniform for all the composites tested.

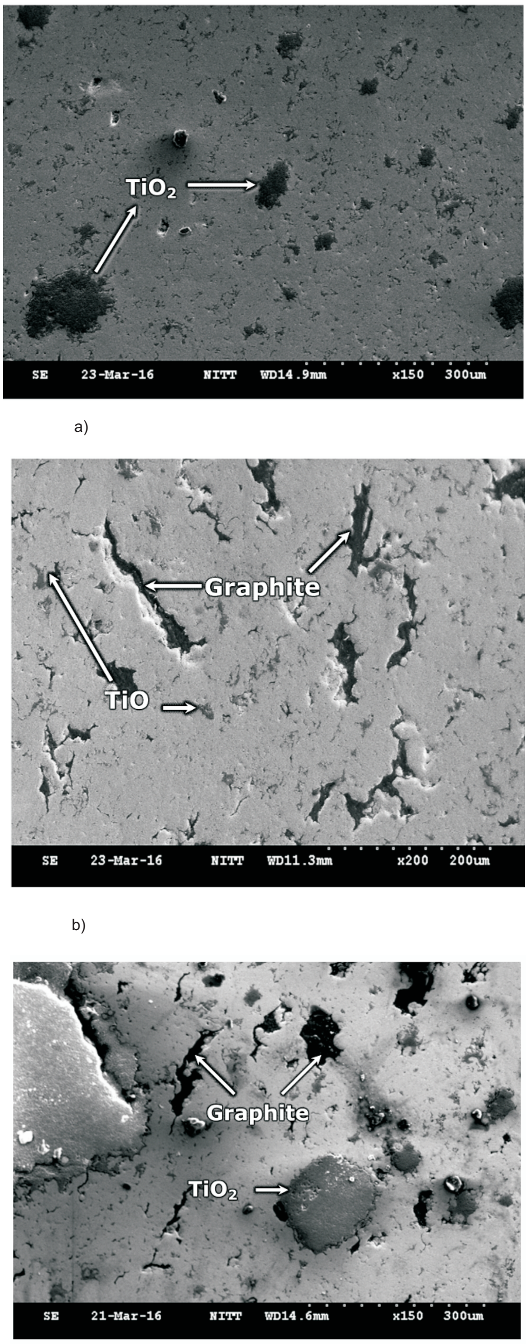
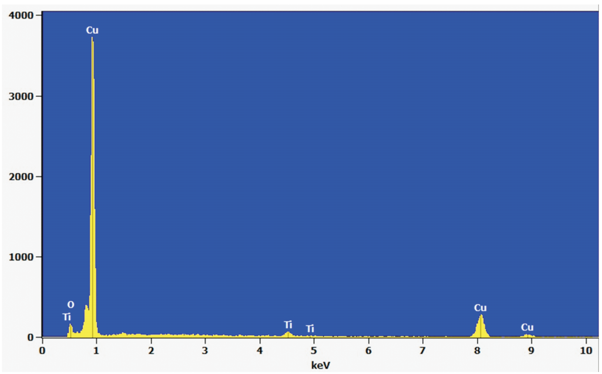
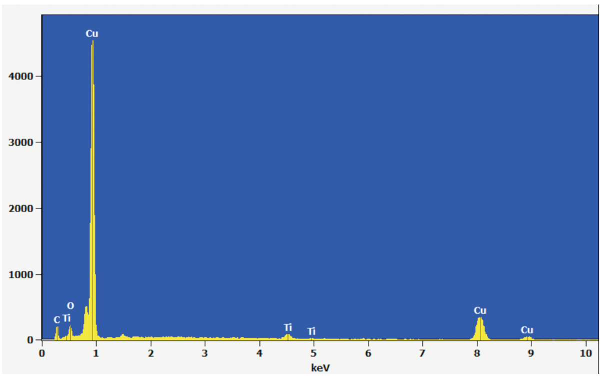


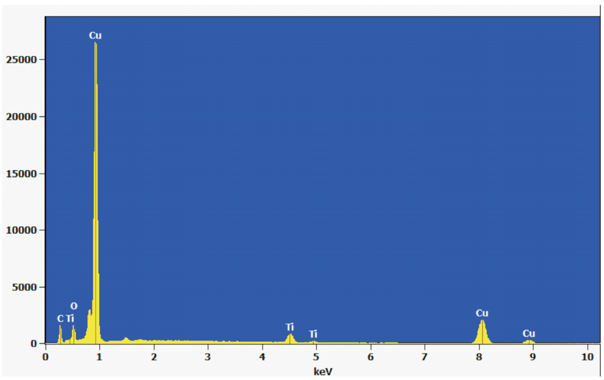
Figure 1 Scanning electron microscopic images of (a) Cu-5wt.% TiO_2-0wt.% Gr, (b) Cu-5wt.% TiO_2-2wt.% Gr, and (c) Cu-5wt.% TiO_2-4wt.% Gr



(a)



(b)



(c)

Figure 2 EDS spectral analysis for hybrid copper composite a) Cu-5wt.% TiO_2-0wt.% Gr, b) Cu-5wt.% TiO_2-2wt.% Gr, and c) Cu-5wt.% TiO_2-4wt.% Gr

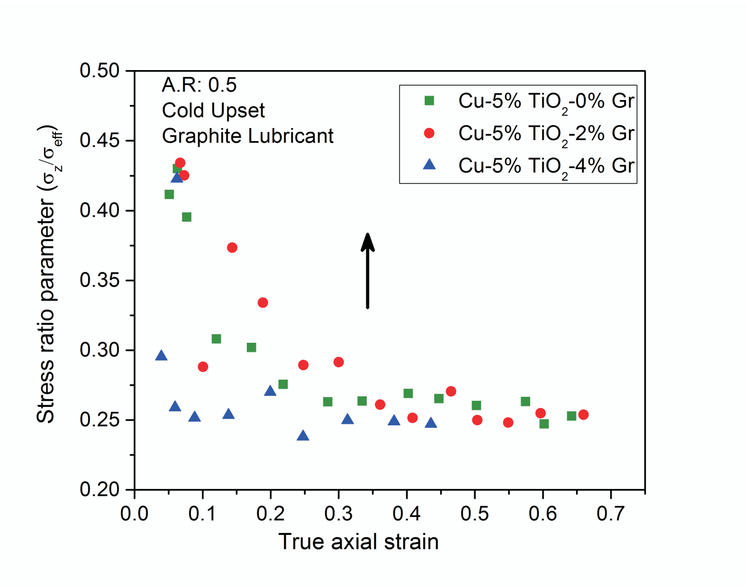


Figure 3 Stress ratio parameter (σ_z/σ_{eff}) versus True axial strain (ε_z)

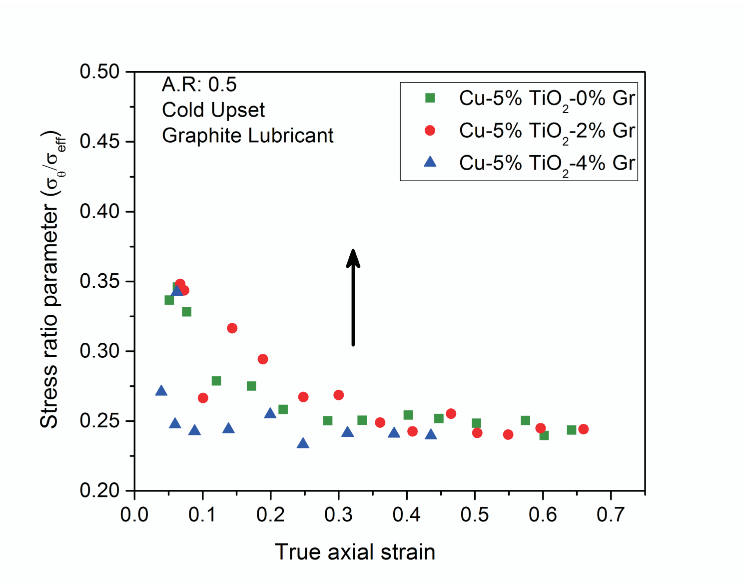


Figure 4 Stress ratio parameter $(\sigma_\theta/\sigma_{eff})$ versus True axial strain (ε_z)

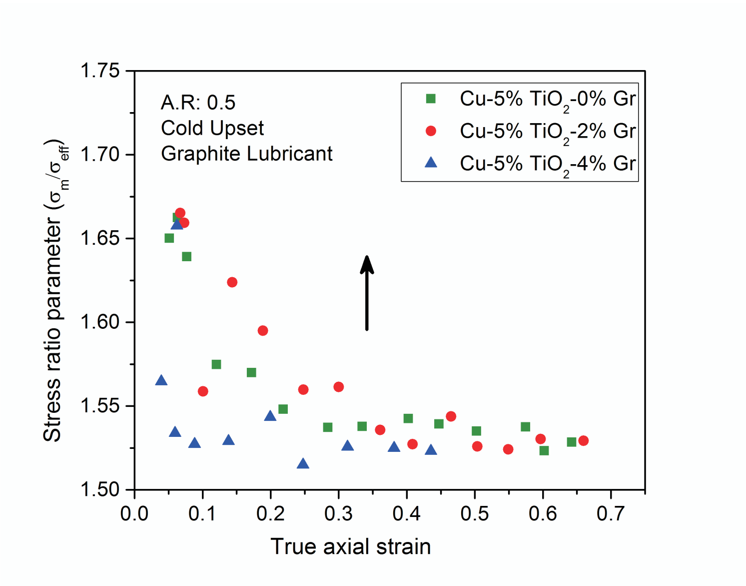


Figure 5 Stress ratio parameter (σ_m/σ_{eff}) versus True axial strain (ε_z)

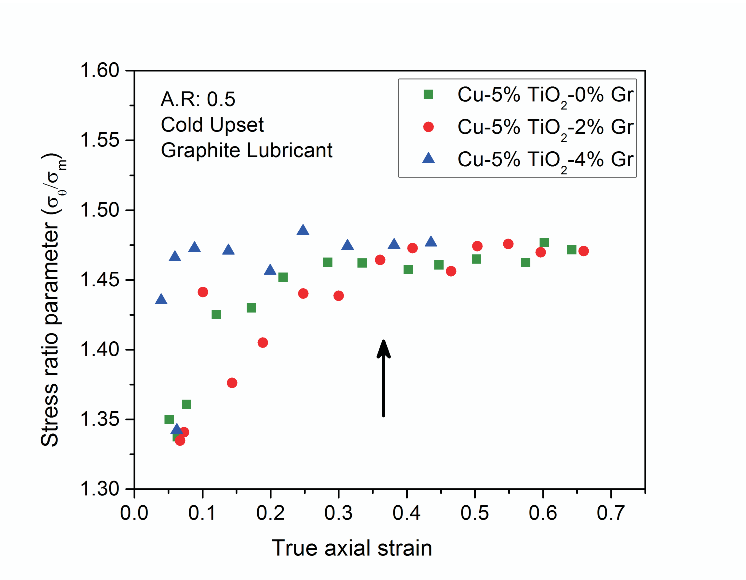


Figure 6 Stress ratio parameter (σ_θ/σ_m) versus True axial strain (ε_z)

4. Conclusions

Hybrid copper composites with 5 weight percentage of TiO_2 and varying weight percentage of graphite namely 0, 2 and 4% was successfully synthesized through powder metallurgy technique and following are the conclusions drawn based on the characterization and formability studies. Scanning electron microscopic analysis with Energy Dispersive Spectroscopy shows the presence and uniform distribution of TiO_2 and Graphite reinforcements. Workability of the composite is found to increase with increasing graphite content due to lubricating property of graphite.

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