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Deformation and Densification Behaviour of Sintered Aluminium Alloy and Chromium Carbide Metal Matrix Preforms

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Abstract

This paper presents comprehensive experimental results focused on the deformation and densification behavior of sintered AA2618 - 2% Cr3C2 metal matrix preforms. The study specifically examines preforms with varying aspect ratios subjected to a cold upsetting process. To create the powder preforms, an initial theoretical density of 89% was achieved using a cylindrical die on a 600 kN hydraulic press. The sintering process was conducted in an electric muffle furnace, where the preforms were heated to a temperature of 530 °C for a duration of 90 minutes. This heat treatment is crucial for achieving the desired micro structural properties of the composite. Once sintering was complete, each compact was subjected to a carefully controlled incremental compressive load of 0.05 MN. This loading continued until a visible crack appeared on the free surface of the material, indicating the onset of failure. The choice of cold upsetting as the experimental method was driven by its effectiveness in evaluating the mechanical performance of composite preforms. Through this method, the study aims to gain valuable insights into the deformation characteristics and densification processes of the AA2618 - 2% Cr3C2 composites, contributing to a better understanding of their potential applications in various engineering fields. The findings revealed that the AA2618 - 2% Cr3C2 composite with an aspect ratio of 0.5 exhibited a higher relative density compared to composites with other aspect ratios. This increased relative density is significant as it correlates with improved formability stress index and, consequently, enhanced workability. In summary, the results suggest that the specific aspect ratio of 0.5 provides the best combination of density and workability for this composite material, making it a favorable choice for applications requiring superior mechanical performance.

Keywords: Powder metallurgy; 2% Cr_3C_2; metal matrix composites; cold upsetting; density; sintering

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INTRODUCTION

The main objective of hybrid metal matrix composites is to increase mechanical properties, which can be achieved by choosing light structural metals and making advancements in the reinforcements employed, even though the matrix can be formed of an alloy or a metal [1].Many high-performance composite materials are being developed with great interest as a result of the growing requirement for lightweight materials with specific qualities. Particles or whiskers with even tiny volume fractions are typically used as reinforcements, and they significantly increase the stiffness and strength of the composites [2].

Boron carbide [B4C] is the optimum reinforcement material for use with magnesium because to its low density, high hardness, fracture toughness, excellent elastic modulus, and exceptional wear resistance [3][4]. Owing to its superior qualities, it finds wide use in the nuclear, automotive, and aerospace industries, as well as in highly skilled applications including cutting and grinding tools, lightweight shields, quick breeders, abrasive grit, and nozzles[5][6][7].

The expense of magnesium matrix composites, which mostly consists of the price of the reinforcing particles and the production process, is delaying their acceptance in daily life [8]. Therefore, in order to fully utilise the potential of magnesium matrix composites with their wide range of reinforcing elements in advanced functional and structural materials, processing techniques and their features must be carefully considered. Only then can the appropriate fabrication approach be chosen for that specific composite material. Three well-known processing methods—powder metallurgy [P/M], squeeze casting, and stircasting—can be used to create magnesium matrix composites[9]. The P/M approach is appealing over others because the equally dispersed reinforced particles in the matrix controlled the microstructure and enhanced the mechanical and structural qualities[10].

Reducing the size of the particle reinforcement in Al–SiC composites by mechanical, machinability, and metallurgical tests shows that cyclic hardening prolongs the life in low cycle fatigue [11]. The composite materials' relative densities rise monotonically under pressure[12]. The choice of the weight percentage and particle size of the reinforcement determines the composite materials' cyclic stress response. An upsetting test on Al-SiC composites shows that the composites' formability is superior to that of pure aluminium. Because of their greater densification, composites with a lower aspect ratio have improved formability and stress index rates[13].

By examining the effects of different stresses related to relative density, Selvakumar et al. [14] demonstrate the workability of composites subjected to triaxial stress state conditions and came to the conclusion that an increase in the percentage of particle reinforcements increases the workability due to the increase in relative density. High workability shapes have a low aspect ratio and a high relative density. A variety of experiments, including tensile and hardness tests, were performed on the composites in order to examine their mechanical behaviour. The kind of reinforcement and how it is composed are important factors in composite material strain hardening [15].

EXPERIMENTAL DETAILS

In this experiment, powdered AA2618-2% Cr_3C_2 was employed. The required amount of powder and porcelain balls [10 mm to 15 mm in diameter] were put in the stainless-steel kettle in a 1:1 weight ratio and stirred for eighteen hours to form a homogenous blend. Subsequently, 16 mm diameter and heights of 16 mm, 12 mm and 8 mm green compacts formed. A 600KN hydraulic press was utilised to compact the powder blend, using the appropriate die and punch. These green compacts were subsequently sintered for ninety minutes at 530 ± 10°C and cooled in the furnace. The final preforms were machined to obtain height-to-diameter ratios of 0.5, 0.75, and 1.0. A 600KN hydraulic press was then used to cold upset forge the preforms in incremental steps of 0.05MN between flat dies. Dry friction conditions caused the deformation process to occur, and it was stopped when visible surface cracks appeared. A digital vernier calliper was used to measure the dimensions of each deformation step, including the deformed height and the contact and bulged diameters. The Archimedes principle was applied to density measurements.

RESULTS AND DISCUSSION

The relationship between the relative density [R] and the formability stress index [β] under tri-axial stress conditions during the upsetting of AA2618–2%Cr_3C_2 preforms with various aspect ratios is shown in Figure 1. The formability stress index rises in tandem with each measured aspect ratio's relative density. Previous investigations[16][17] have noticed that this correlation arises from the closure or reduction in pore size that happens as the relative density rises due to increasing deformation.

In the case of preforms with an aspect ratio of 0.5 and an initial relative density of 0.90, the formability stress index maximum of 2.98. These situations result in uniform densification because the height of the porous bed diminishes and a higher relative density is found throughout the preform height. On the other hand, formability stress index values for preforms with greater aspect ratios and lower beginning relative densities are closer to the minimum. Their increased pore content and larger porous bed height are the reasons for this. Compared to preforms with smaller aspect ratios, the relative density increases less sharply as deformation increases. These results closely match those of other studies [18][19].

A parabolic curve fitting method was used to examine the link between the formability stress index and relative density over a range of aspect ratios. Table 1 displays the values of the associated regression coefficients for each aspect ratio for which polynomial equations were developed. Interestingly, for relative density, the R-squared [R^2] values hold true for all aspect ratios.

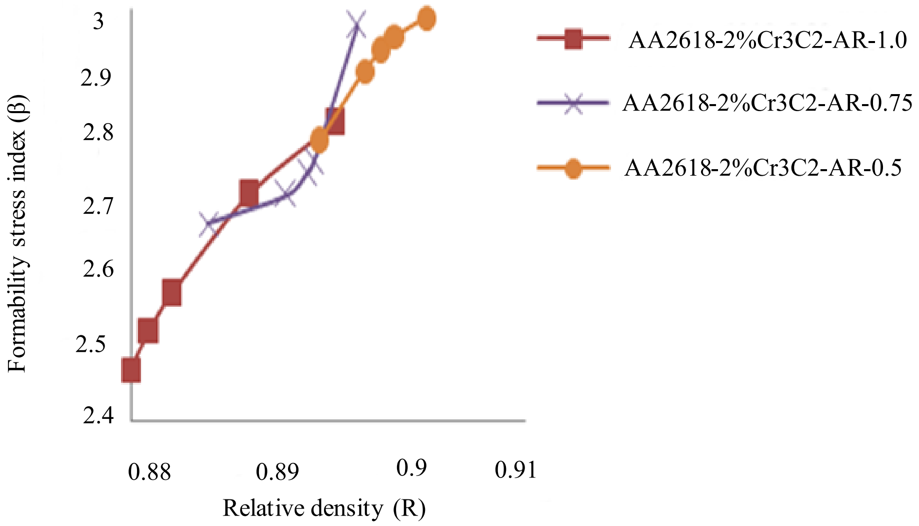

Figure 1. Relative density Vs formability stress index.

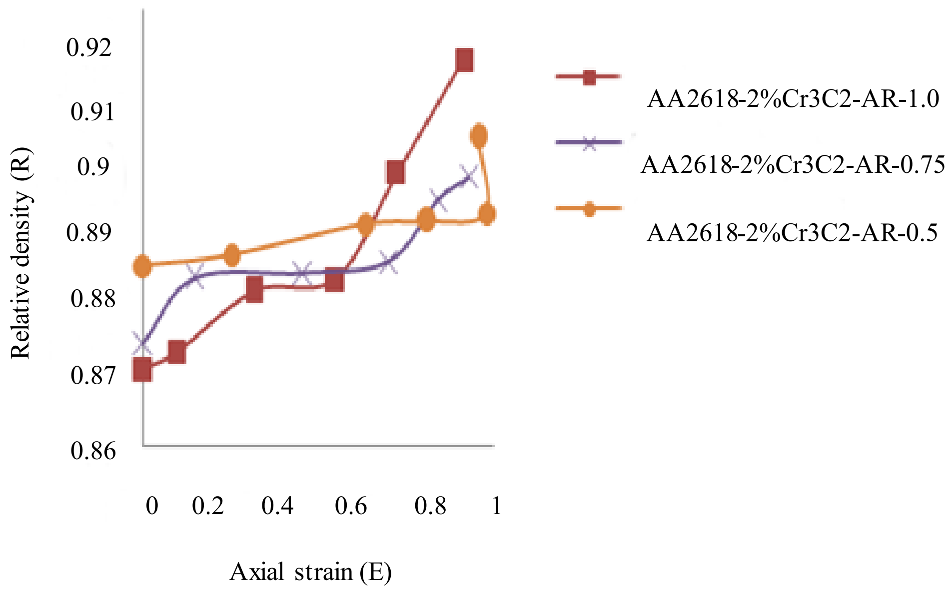

Figure 2. Axial strain Vs relative density.

Table 1. Curve fitting results-formability stress index [β] vs. axial strain [ε_z].

Relation ship	Aspect ratio	Initial relative density [R]	Polynomial equation	Regression co-efficient R2
β vs. ε_z	1	0.88	$y = -835.5x^2 + 1506.x - 675.9$	$R^2 = 0.999$
	0.75	0.89	$y = 3925.x^2 - 6974.x + 3100.$	$R^2 = 0.991$
	0.5	0.89	$y = -1664.x^2 + 3012.x - 1360.$	$R^2 = 0.999$

Figure 2 shows the relationship between axial strain [ε] and relative density [R] for AA2618 – Cr3C2 powder preforms with different aspect ratios during the cold upsetting process. Because of the closure of pores, relative density increases consistently with increasing axial strain across all aspect ratios.

It was shown that preforms with lower aspect ratios and higher starting relative densities likely to produce cracks at much higher strain levels within the range of aspect ratios investigated. Their reduced pore content is the reason for this behaviour. This insight aligns with results from other research [20][21][22].

Polynomial curve fitting was used to measure the connection between relative density and axial strain across various aspect ratios. For every aspect ratio, polynomial equations were created, and Table 2 lists the corresponding regression coefficient values. Remarkably, for preforms with lower aspect ratios and larger beginning relative densities, the R-squared [R^2] value continuously stays high [reaching 0.996], suggesting a strong link between these variables.

Table 2. Curve fitting results- Relative density [R] vs. axial strain [ε].

Relation ship	Aspect ratio	Initial Relative density [R]	Polynomial equation	Regression co-efficient R2
R vs. ε	1	0.88	$y = 0.046x^2 + 0.002x + 0.872$	$R^2 = 0.972$
	0.75	0.89	$y = 0.012x^2 + 0.008x + 0.877$	$R^2 = 0.973$
	0.5	0.89	$y = 0.011x^2 + 0.000x + 0.885$	$R^2 = 0.996$

The stress ratio [σ_θ/σ_z] and beginning relative density [R] of AA2618-2%Cr_3C_2 preforms with different aspect ratios are shown in Figure 3. The parameter for the stress ratio [σ_θ] increases with an increase in relative density. Aspect ratio has little impact on the stress ratio parameter [R = 0.85] at lower initial perform density. An aspect ratio and stress ratio [σ_θ/σ_z] correlate when initial preform densities are higher. A larger stress ratio is shown by the smaller aspect ratio as the initial preform density increases. This discovery aligns with previous research findings [20][23].At a larger stress ratio, cracking happens when the original preform density or aspect ratio increases.

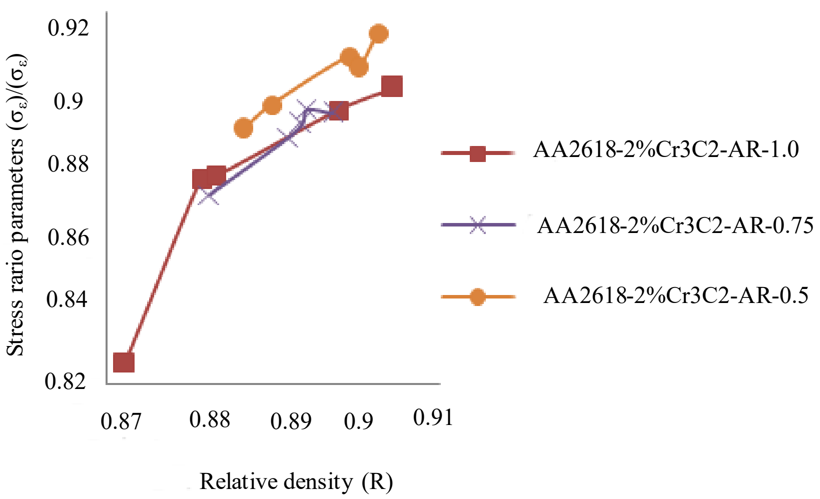

Figure 3. Relative density Vs stress ratio parameters.

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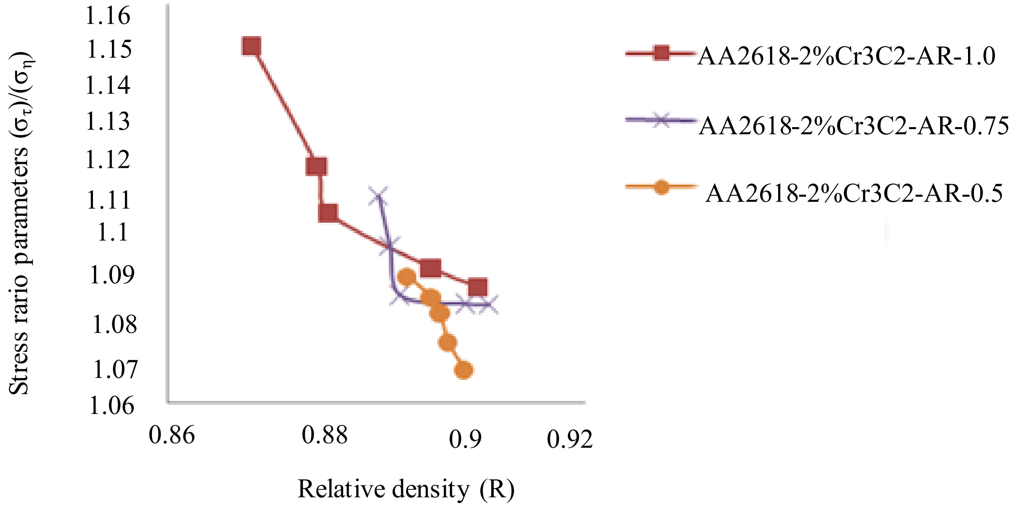

Figure 4. Relative density Vs stress ratio parameters.

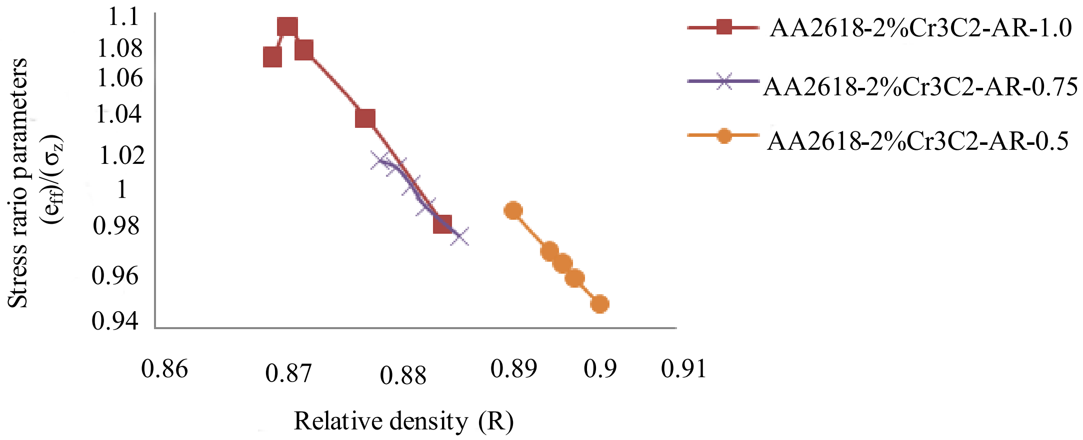

Figure 5. Relative density Vs stress ratio parameters.

As seen in Figure 4, Using the parabolic curve fitting technique of the second order polynomial equation, the stress ratio parameters [σ_θ/σ_z and σ_{eff}/σ_z] for the 2% Cr_3C_2 particle-containing composites of the AA2618 alloy have been plotted against the relative density [R], as seen in Figures 4-5. As the relative density [R] increases, the mean stress [σ_m] and hoop stress [σ_θ] rised, but not the effective stress [σ_{eff}]. The resistance against deformation rises when the load is gradually increased because less volume is needed to seal the pores during cold upsetting. Consequently, bulging occurs when σ_θ & σ_m expand. The increase in relative density[R] is due to the stress ratio parameters [$\sigma_\theta/\sigma_{eff}$ & σ_m/σ_{eff}].

CONCLUSION

The experimental investigation of formability and strain hardening index of AA2618 – 2% Cr_3C_2 have been studied using cold deformation test and the following conclusions are made:

- The formability stress index increases with axial strain, regardless of initial relative density. Because of the uniform densification, AA2618 - 2%Cr_3C_2 preforms with a smaller aspect ratio and higher initial relative density have a higher formability stress index value of 2.98.
- It is discovered that when comparing lower initial relative density to higher initial relative density, the rate of change of increase in the formability stress index value with regarding to relative density is higher.
- Stress ratio parameters [σ_θ/ σ_z & σ_z/σ_{eff}] for AA2618-2%Cr_3C_2composite are higher than the other due to the better densification and low porosity and the stress ratio parameter [σ_z/σ_{eff}] decreases for the composites because of the mean stress [σ_m] combined with low porosity.

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