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Research Article

Investigation on Mechanical Behaviour of LM6 Aluminum Alloy Hybrid Composites Processed Using Stir Casting Process

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The stir casting process produces boron nitride (B_4N) and fly ash-based LM6 metal matrix composites. This hybrid composite was fabricated by varying fly ash from 3% to 15% with an increase of 3%. While the other reinforcement B_4N concentration was kept constant as 3%. The morphology of the metal matrix composite is analysed using a light optical microscope. The microstructure analysis shows the uniform distribution of hybrid reinforcement throughout the matrix, and only a few clusters are found in the matrix alloyed with 15% B_2N. Both pure and reinforced matrices are evaluated for the mechanical properties' evaluation. The result shows an increment in hardness from 70.4 VHN to 96.2 VHN. Similarly, the tensile strength of the composite material is improved from 151 MPa to 192 MPa. The reason for improving strength and hardness is the uniform distribution of hybrid reinforcement in the LM6 matrix.

1. Introduction

In 1960, graphite, boron, and ceramide fibres were utilised as reinforcement in the first matrix composites. Metal matrix composite (MMC) growth is fueled by the capacity to combine novel features and produce materials with superior mechanical qualities to those of conventional engineering materials. Strong high-temperature capacity, resistance to abrasion, and increased strength and stiffness are all features of MMC. In the last 20 years, the amount of scientific research on MMC has expanded by 150 percent, suggesting a significant increase in the number of enterprises using MMC. MMC made of intermittent and persistent reinforcement, such as constant fibre, whiskers, or particles, will provide physico-mechanical benefits in the homogenous alloy in the right metal matrix. The characteristics of the MMC cannot be changed by ingredients, size, form, size, proportion, orientation, or distribution of reinforcement. This allows the element to have a higher specific strength, a larger modular area, superior impact strength, control over the coefficient of thermal expansion, and higher temperature environments. These are cutting-edge materials that have considerable potential for use in gas turbine parts, automotive components, and elevated applications in aerospace, including missiles and shuttle vehicles, as well as other applications. The impact of graphite nanoparticles on the mechanical characteristics of MMC based on aluminum was examined by Alam et al. [1]. By adjusting the weight percentage of nanoparticulate beyond the predetermined limit, the toughness property of the graphite-based MMC was decreased. Using a stir casting technique, the mechanical characteristics of aluminum-born carbide MMC were evaluated. The composite's internal characteristics, flexural strength, and hardness were examined [2]. Ahamed et al.'s [3] review of the alternative method of MMC manufacturing. According to reports, the most common way to create MMC are through casting and powder metallurgy. Due to the better mix and simple control of process conditions, casting generated good moulds as compared to powder metallurgy.

The rutile-reinforced AA6061 aluminum alloy's mechanical and metallurgical characteristics were examined by Prabhu et al. [4]. This increases the mass proportion of rutile particles, which increases strength. The tribological and tensile characteristics of hybrid MMC were examined by Kumar et al. [5]. The durability and wear rate were both reduced by the addition of B4C and MoS2. The impact of heat treatment on the mechanical and wear properties of LM25 MMC was examined by Kumar et al. [6]. By using alloying components and using electromagnetic induction, the characteristics were enhanced. An aluminum TiC composite was described by Ravikumar and colleagues [7]. As TiC reinforcement was increased, composite density fell.

Additionally, the composite's stiffness and elasticity rose to a certain point and then dropped with additional reinforcement. Aluminum-silicon carbide MMC was produced via a stir casting technique by Soltani et al. [8]. A scanning electron microscope was used to examine the interactions between the reinforcement and matrix, ceramic particle percentage, and particle agglomeration. The impact of porosity and particle size on dry sliding wear on cast aluminum and aluminum oxide was examined by Hamid et al. [9]. As porosity in MMC increased, the coefficient of friction dropped. The Al-SiCp MMC's particle size, volume, and matrix strength were examined by Milan et al. [10]. The impact of particulate matter on structure and strength is dependent on matrix type.

From the work done thus far, it can be inferred that extensive research has been done on the impact of reinforcing particles on the tribological behaviour of MMC and hybrid MMC. However, there is still a paucity of information regarding how much TiB2 should weigh in LM6. As a result, a strategy has been made to examine how TiB2 and B4C's weight percentages affect the LM6 matrix.

2. Experimental Work

The current study uses the stir casting process to create MMC from LM6 and two reinforcing particles, such as B4N and fly ash. Small blocks of LM6 were used to supply the resistance furnace, and these blocks were subsequently heated to 850°C [11, 12]. The B4N and fly ash reinforcement particles were added gradually to the furnace once it had achieved the proper temperature using a handy funnel. While introducing B4N and fly ash to the LM6 matrix, the stirrer was being turned. Figure 1 depicts the stir casting experimental setup. The liquid metal was fully mixed with the ceramic particles. Additionally, after being removed from the furnace, molten metal was poured into an appropriate mould. The current study uses the stir casting process to create MMC from LM6 and two reinforcing particles, such as B4N and fly ash. Small blocks of LM6 were used to supply the resistance furnace, and these blocks were subsequently heated to 850°C [11, 12]. The B4N (30 μm)and fly ash(40 μm) reinforcement particles were added gradually to the furnace once it had achieved the proper temperature using a handy funnel. While introducing B4N and fly ash to the LM6 matrix, the stirrer was being turned. Figure 1 depicts the stir casting experimental setup. The liquid metal was fully mixed with the ceramic particles. Additionally, after being removed from the furnace, molten metal was poured into an appropriate mould. The tensile samples were prepared as per ASTM E8-M04. Additionally, the Izod impact test (ASTM D:256) was performed on an Izod impact machine to gauge MMC's ability to absorb energy. For microstructure analysis, the samples were cut from the composite materials and polished with suitable sandpaper for a mirror-like image. Finally, a fracture pattern analysis was performed using a scanning electron microscope (Make: JEOL and Model: 5610LV). Table 1 presents the chemical composition (Wt. %) of LM6 aluminum alloy, and Table 2 shows the mechanical properties of the LM6 base material. Table 3 shows the mechanical properties of reinforcement.

3. Results and Discussions

3.1. Microstructure Analysis. A low magnification optical microscope was used to study the LM6 alloy as well as composites with reinforcement added in Figure 2. The microstructure of the LM 6 cast aluminum revealed a homogenous distribution of the dendritic network structure of aluminum. This structure is a result of the casting being supercooled during phase transformation. EDS analysis is used to determine the distribution of different components within the cast. The EDS test revealed distinct peaks of different elements in the LM 6 alloy. Magnesium, silicon, zinc, and copper were found to be present. In all four situations, the distribution of fly ash with weight percentages of 3 percent, 6%, percent of total, 12%, and 15% indicates uniform dispersion and a little aggregation of B_4C. The grey area is the aluminum matrix, which is surrounded by black dots, which are referred to as reinforcement. As the weight percentage increases from 3% to 15%, microstructural observations reveal a nonuniform distribution of B_4C in the aluminum matrix, as well as some agglomeration. The density mismatch between the aluminum matrix and the reinforcement is one of the causes of nonhomogeneous dispersion in the matrix. On the contrary, foreign particle production and solidification shrinkage were detected. There was an air gap between agglomerated particles in certain places. This can happen when liquid molten metal (LM6) comes into direct contact with reinforcement (B_4C).

Figure 1: Photograph of stir casting machine.

Table 1: Chemical composition (Wt. %) of LM6 aluminum alloy.

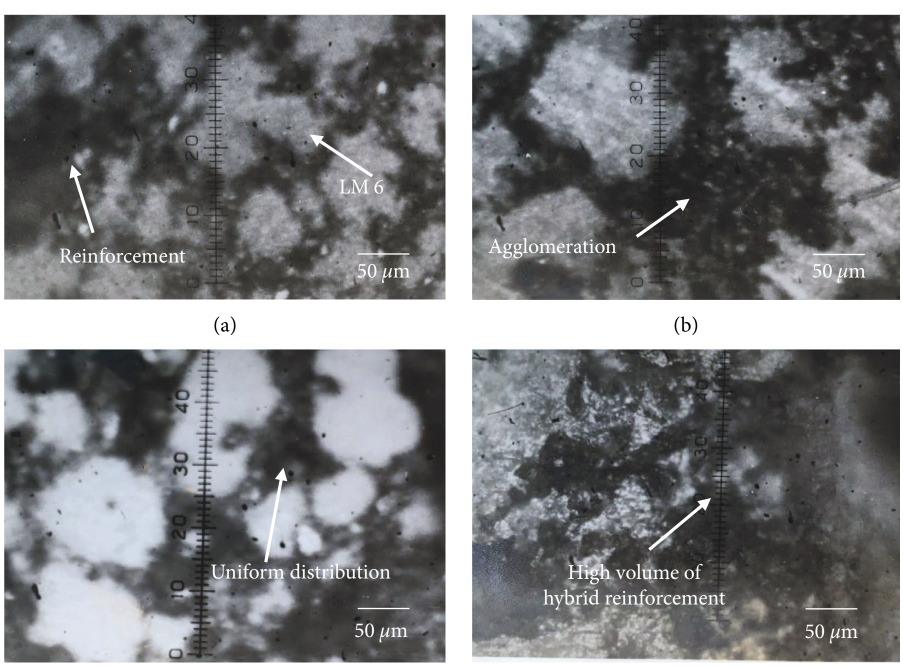
Si	Fe	Pb	Mn	Cu	Mg	Zn	Ni	Ti	Sn	Al
6	0.3	0.09	0.18	0.10	0.41	0.07	0.08	0.091	0.03	Bal.

Table 2: Mechanical properties of LM 6 base material.

Condition	Hardness "VHN"	Elongation	Yield strength "MPa"	Ultimate tensile strength "MPa"	Density "gms/cm^3"
LM6	58	7.8	128	223	2.7

Table 3: Mechanical properties of reinforcement.

Sl. No	Properties	B_4N	Fly ash
1.	Density	2.45 gm/cm^3	4.42 gm/cm^3
2.	Tensile strength	448 MPa	



(a) (b) (c) (d)

Figure 2: Effect of reinforcement on microstructure of (a) LM6-33, (b) LM6-36, (c) LM6-39, and (d) LM6-312.

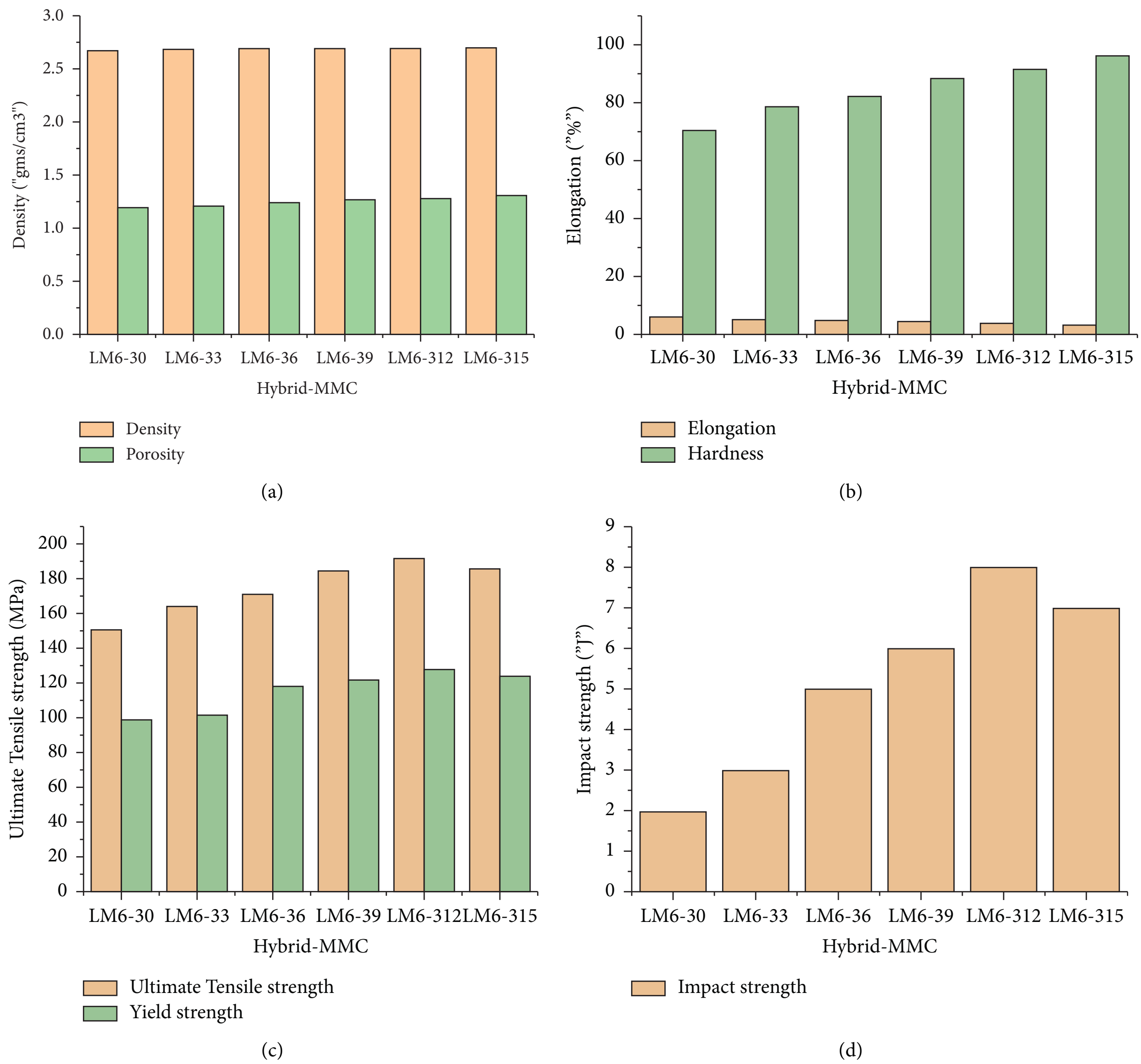


FIGURE 3: (a) Effect of reinforcement in (a) porosity and density, (b) hardness and elongation, (c) yield strength and strength of hybrid composite, and (d) impact strength of hybrid MMC.

Figure 3(a) depicts the variance in porosity and density of MMC. It is assumed that the entire casting was done at 850 degrees Celsius. According to the findings, increasing the weight % of reinforcement improves the MMC's weight and porosity. Numerous studies have shown that the porosity and specific weight of MMC can be improved by increasing the weight percent of reinforcement [13–18]. This is as a result of MMC's expanding reinforcement. It can increase places for heterogeneous pore nucleation and increase porosity by elevating the surface of the gas layer surrounding the particles.

3.2. Hardness Property. Different assessment processes, including tensile and hardness tests, were used to examine the material behaviour of LM6 MMC. Hardness distribution on reinforced castings was measured using a Vickers microhardness tester with a constant load of 0.5 N and a holding period of 30 sec. The hardness values for each condition are recorded at five different places. Figure 3(b) displays the hardness characteristics of various hybrid MMC combinations. This increased the hardness by increasing the fly ash weight percent. MMC's hardness might be increased by the uniform size and distribution of ceramic particles, as well as the volume percentage of reinforcement [19]. Another factor is grain formation in MMC during the solidification process [20]. However, depending on the type of ceramic reinforcement utilised, the MMC's hardness attribute differed significantly.

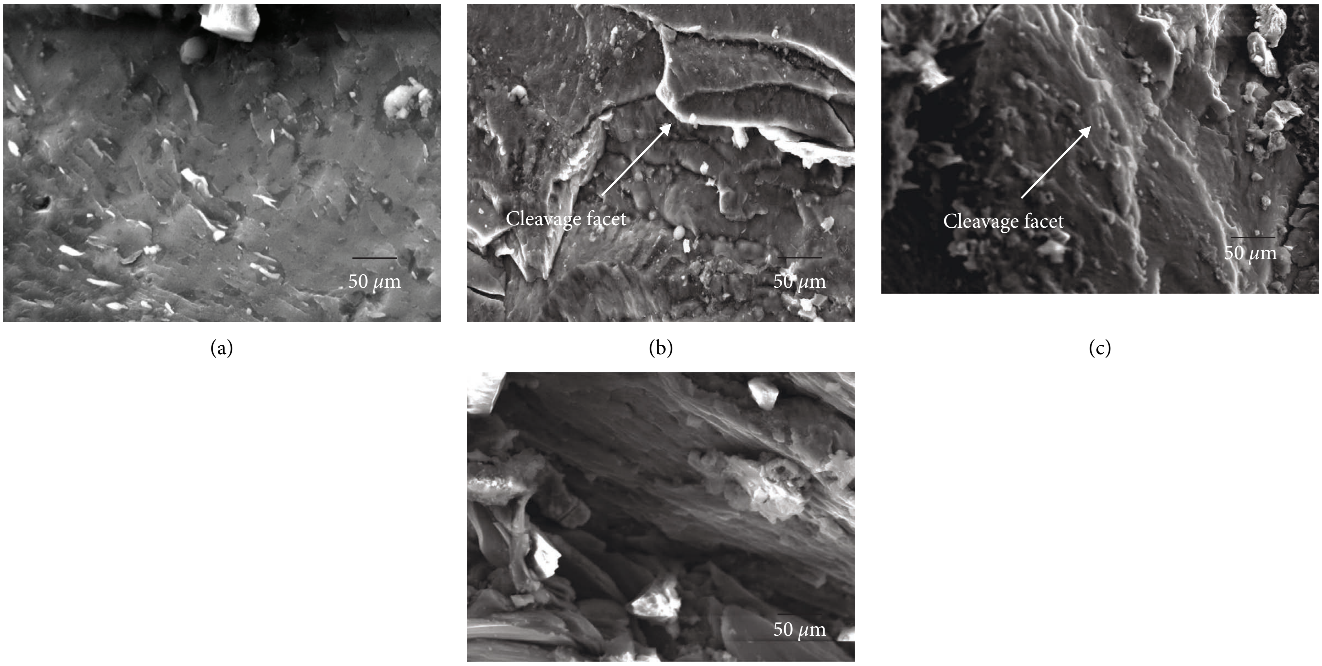
3.3. Tensile Properties. Table 4 presents mechanical properties of hybrid metal matrix (LM6 + B4N + fly ash) composites. Figure 3(c) demonstrates the variations in tensile strength of the MMC. Overall, using LM6-315 fly ash as a reinforcement allows Al to attain a high-level strength when compared to other proportions. As a result of increasing the reinforcing volume percentage, the microporosities in the

Table 4: Mechanical properties of hybrid metal matrix (LM6 + B_4N + fly ash) composite.

Sl. No	Condition	Designation	Density "gm/cm^3"	Porosity "%"	Hardness "VHN"	Impact Strength "J"	Elongation	Yield strength	UTS "MPa"
1	LM6 + 3 Wt.% of fly ash	LM6-30	2.670	1.20	70.3	2	6	98	150
2	LM6 + 3 Wt.% of B_4N + 3 Wt.% of fly ash	LM6-33	2.685	1.21	78.7	3	5	101	163
3	LM6 + 3 Wt.% of B_4N + 6 Wt.% of fly ash	LM6-36	2.688	1.24	82.1	5	4.8	117	170
4	LM6 + 3 Wt.% of B_4N + 9 Wt.% of fly ash	LM6-39	2.690	1.27	88.3	6	4.5	121	184
5	LM6 + 3 Wt.% of B_4N + 12 Wt.% of fly ash	LM6-312	2.693	1.28	91.4	8	3.8	127	191
6	LM6 + 3 Wt.% of B_4N + 15 Wt.% of fly ash	LM6-315	2.697	1.31	96.1	7	3.1	123	185

composite rise, resulting in less stress movement. There could be faults in the ceramic particle locations, such as increased dislocation volume (Figure 3(a)). Increases in dislocation volume and other faults in ceramic particle regions could result from the significant difference in thermal expansion between the reinforcements and aluminum matrix. The debonding of the Al/reinforcement contact may cause the strength of composite materials with additional reinforcements to decrease. Some properties, including considerable grain alteration, the existence of hard particles in the matrix, and dislocation generation are factors, as per the Orowan strengthening mechanisms [21, 22]. Because of mismatches in many parameters between the aluminum and ceramic particles, there is a direct and indirect load transfer from the soft matrix to the hard ceramic phase. The improved strength in MMC is a result of the even distribution of ceramic particles throughout the aluminum matrix and the good compaction between the reinforcement and the matrix. Additionally, the anchoring action of the fine and uniformly distributed reinforcing spices in the grain border limits the dislocation of grains under tensile load. One of the causes of the strength increase could be this phenomenon. The direct mechanism, which depends on the transfer of load from the matrix to the rough particles at the interface. As shown in Figures 3(a)–3(c), adding more ceramic than 12% results in inferior mechanical properties, which may be connected to increased microporosities and agglomerations in composites [23, 24]. The results of this study indicate that composite strength is decreased when the B4C concentration is over the optimum range. This might be caused by greater porosity and increased particle aggregation. The strength may also be impacted by the size of the interface and the quantity of reinforcement. Numerous factors may reduce the strength of MMC produced at various weight percentages. Due to the thermal stress fluctuation between the reinforcement and the matrix, there is a likelihood that increased displacement density inside the matrix will result in the formation of local stresses. This may also contribute to weak strength. Rajamanickam and Uvaraja reported the assessment of mechanical properties of LM13 aluminum alloy hybrid metal matrix composites using the stir casting route and obtained the same results [25].

3.4. Impact Property. The impact strength of the different combinations of the LM6 hybrid composite is presented in Table 4. The test results reveal that the impact strength of hybrid MMC increases with an increasing fly ash weight percentage of 3% to 9%. On the other hand, the impact strength decreased by increasing fly ash further (9%). The strength drops at LM6-312 may be due to the formation of more porosity and agglomeration of B_4C particles in the LM6 matrix. From the test results (Figure 3(d)), it is inferred that the hybrid composite with 12% fly ash yielded a higher impact strength of 8 J than its counterpart. Moreover, the impact strength of 15% alloyed with fly ash reveals lower strength than the 12% fly ash MMC. This may happen due to the high level of porosity. The fractography of impact test samples, as shown in Figure 4 shows that the fracture mode is categorized into two types brittle and ductile. The formation of this fracture is purely dependent on the distribution of strengthening precipitates' size and shape, followed by reinforcement and grain size. The fractography does provide helpful information about the role of reinforcement in tensile strength. The fracture mode was ductile from the SEM fractography (impact test), except for the low weight percentage of reinforcement (LM6-33, LM6-36, and LM6-39) in the matrix. This may be due to insufficient reinforcement in the materials and the inadequate strengthening formation precipitates. The primary factor for this fracture mode is the differences in a strain carrying capacity between matrix/reinforcement and variation in thermal expansion between precipitates among LM6 aluminum alloy. On the other hand, the mixed fracture mode was observed in LM6-312. Hence, this sample exhibits higher impact strength than the other samples due to straight ridges and dimples. This could imply that the large stretch zone was present at the crack's tip, which indicates the considerable strain energy stored in the matrix. Another critical factor is the level of porosity, which could affect the



(a) (b) (c) (d)

FIGURE 4: SEM fractography at different weight of (a) LM6-33, (b) LM6-36, (c) LM6-39, and (d) LM6-312.

strength property of MMC. By continuous straining action in MMC, the dislocation between pores is very fast under impact loading. Hence, this may be the reason the LM6-315 possesses lower impact energy than other castings.

4. Conclusions

The hybrid composite is fabricated with the stir casting technique. It was used for mixing different proportions of reinforcement at 850°C. From the investigation, the following points are drawn:

(1) Aluminum with B_4N/fly ash-based MMC was successfully produced using the stir casting process. The weight percentage of fly ash varied from 3%–15% with an increment of 3%.

(2) A small amount of B_4C agglomerated at Wt.% 15 is observed. Of the different proportions of fly ash, the maximum hardness of 96.2 VHN blended with Wt.% 15 is observed.

(3) The strength of MMC increases with increasing Wt.% of fly ash 2 of 3% to 12%. Further decreasing the strength by increasing the weight percentage of TiB_2 reinforcement to 15%.

(4) The strength drops at the 15 Wt.% of fly ash may be due the large amount of porosity and agglomeration of reinforcement in the aluminum matrix.

(5) The thermal mismatch stress between the ceramic and alumnium matrix has the potential to enhance the density dislocation in the matrix, which could produce local stress.

(6) LM6-312 sample yields higher load-carrying capacity and impact strength. The reason for the superior strength is due to the low volume percentage of porosity, the formation of favourable strengthening precipitates, and dense distribution of ceramic particles.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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