Hindawi
Advances in Materials Science and Engineering
Volume 2022, Article ID 1684169, 8 pages
https://doi.org/10.1155/2022/1684169

Research Article

Investigation of Mechanical and Tribological Properties of AA6061/MWCNT/B_4C Hybrid Metal Matrix Composite

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Received 21 July 2022; Accepted 5 September 2022; Published 30 September 2022

Academic Editor: Pudhupalayam Muthukutti Gopal

Carbon nanotubes (CNTs) and graphene, in particular, have been the subject of many recent studies since their discovery in the early 2000s. Because of their unusual properties, carbon nanotubes (CNTs) have piqued the interest of scientists across a wide range of disciplines. An Al matrix was reinforced with powder metallurgy-fabricated B_4C and CNT composites. The nano-composite aluminium matrix was examined for tribological behaviour, density, stiffness, and compressive strength before and after hot isostatic pressing (HIP). Scanning electron microscopy and TEM were used to analyze the carbon nanotubes and their hybrid counterparts (SEM). The density of nanocomposites was reduced by 38% without HIP but by 45% after it was added to the mixture. Hardness was also increased by 40%, but following HIP, the hardness rose to 67%. Before and after HIP, the compression strength increased by 39% and 60%, respectively. HIP improves the wear rate by 45%, and B_4C and CNTs improve the coefficient of friction by 20% in all volume fractions but only by 48% in the case of nanocomposites.

1. Introduction

Composite materials have replaced monolithic substances in the minds of material scientists looking to improve mechanical qualities and develop high-tech equipment [1]. A clean interface separates the components of composite materials, which are made up of two or more chemically stable materials [2–4]. Due to their superior rigidity and strength, composites have replaced traditional materials [5]. Continuous fibres, discontinuous fibres, and particles can reinforce composites consisting of metal or polymer components [6, 7].

Among carbon nanotube's mechanical properties are stiffness and strength measurements in the 1000 GPa range and heat conductivity measurements in the 100 GPa range [8, 9]. Carbon nanotubes were used by [10] to strengthen magnesium alloy powder composites. They utilized a zwitterionic surfactant solution to evenly disperse the CNTs throughout the magnesium alloy. While CNTs have been proven to increase tensile and yield stress, they have also been demonstrated to reduce elongation. The researchers [4] investigated wet sliding wear on hybridized nanocomposites of AlSi–2.5wt% CNTs–10wt% SiCp. Hybrid nanocomposites can be used as reinforcement to increase wear resistance [11].

To make MWCNTs/Ti composites, they employed sorted coacervation and SPS (spark plasma sintering) (3 wt.%) [12]. MWCNT reinforcements and a dense structure worked together to reduce yield strength before a considerable increase in sintering temperature was reached [13, 14]. For this hypoeutectic AA356–Si alloy, [15] researchers studied its microstructure and dry sliding wear characteristics. Compared to monolithic alloys, A356/MWCNT alloys showed superior wear resistance [15]. In a CNT alloy composite, [16] used squeeze casting to examine Al and Mg. Nanostructures enable new features and capabilities that are more efficient or impossible with more extensive structures and machinery [17, 18].

HMMC with nano/microsized strengthening has only been studied in the literature for a modest amount [19–22]. The authors [23] examined the squeeze casting of Al/SiC/graphite hybrid MMCs. Compounds reinforced with boron carbide-reinforced graphite exhibited identical coefficients of thermal expansion, even after adding graphite to improve dimensional stability [24, 25]. Increased graphite content condensed the heat conduction of hybridized composites. Researchers [26] investigated the wear resistance of B_4C/Sic/Al hybrid composites. They initiate that the coefficients of friction of the mixtures gradually rise as the reinforcing weight percentage increases [27, 28].

There was a slight decrease in wear resistance with an increase in B_4C wt %, but the friction coefficient did not change [29]. The impact of hybridizing carbon nanotubes and B_4C on the mechanical properties of Al 6061 composites has not previously been studied using powder metallurgy [30]. Consequently, powder metallurgy was employed in the current investigation to generate the aluminium matrix reinforced with boron carbide and multiwalled carbon nanotubes [31]. Powder metallurgy has used a range of aluminium powders and CNT volume fractions to significant effect. For pre- and post-HIP, the tribological, density, stiffness, and compressive strength performance of the aluminium matrix nanocomposite were studied [32–34].

2. Material

The multi-walled carbon nanotubes (CNTs) employed in this study were synthesized using an electric arc discharge with 99%. The average diameter of MWCNTs is 10–12 nm, and the length is 1–20 m. Boron carbide (B_4C) has a Young's modulus of 300 GPa, a tensile strength of 150 GPa, and a density of 3.3 g/cm^3. This project uses an aluminium matrix with a purity of 99.36%. Nanotech Corporation provided the MWCNTs and B_4C. Table 1 lists the chemical compositions of various types of boron carbide (B_4C).

3. Experimentation

3.1. Manufacturing of B_4C/MWCNT Composites. The initial stage was to manufacture the samples by employing ball milling at 280 rpm for 30 hours on six samples of Al 6061 and hybridized strengthening (CNT and B_4C) with various attentiveness proportions, as indicated in Table 2.

The cylinder-shaped specimens, 12 mm long and 10 mm wide, were physically crushed using hydraulic pressing with a volume of 40,000 kg and a pressure of 500 MPa utilizing a double-action die. This was followed by 0.5 hours of degassing at 200°C and 2 hours of sintering at 600°C. The samples were kept in the oven until they reached room temperature for this experiment. Samples were then subjected to a HIP (Figure 4) for two hours at 600°C under 250 MPa. An hour of heating at 600°C at a pace of 20°C/min brought the process to a close.

3.2. Hardness Test. The mechanical properties of composite materials can be defined in part by their hardness. A Vickers hardness machine is used to conduct the hardness test (Figure 5). Six readings were collected along the polished specimen's cross-section with a Zwick/Roell model hardness tester to get the average result. ASTM −17 was used to conduct the tests on the specimens.

3.3. Compression and Density. We used SHIMADZU universal testing equipment to evaluate the samples to conduct a compressive strength test (UH-F500KN). In this investigation, the cross-head speed of the universal test machine employed was 3 mm/min, which is the area of the specimen. The temperature was set at 25°C for the experiment. According to ASTM D1217-15, Archimedes' rule was used to determine the density of the specimens [35]. Specimens were weighed in air and distilled water according to MPIF standard 42, 1998, and the density (D) was then calculated using the Archimedes methodology with water as the floating liquid.

$$D = \frac{\text{specimen de nsity}}{\text{water de nsity}} = \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}. \tag{1}$$

3.4. Tests on Wear. A pin-on-disc tribometer was employed to conduct wear tests on the sintered specimens (Figure 6). According to Figure 6, materials can be tested for friction and wear under various loads using the T.E. 79 multi-axis tribometer. The machine can execute ASTM G99 [36] tests in pin-on-disc mode. Cylinders of 12 mm and a diameter of 10 mm were employed in the experimentation.

4. Results and Discussions

Figure 1 depicts the XRD form of the CNT, as shown in the figure. According to the diffraction peaks, graphene sheets buckle together and form multiwalled nanotubes due to their concentric cylindrical structure. The reflection is seen as a sharp peak at 26.5 in the pattern [37].

Nanoadditive dispersion in aluminium was tested using SEM. The SEM was utilized for characterizing powder metallurgy-produced aluminium composites for microstructure and dispersion. A scanning electron microscope

Table 1: Chemical arrangement of Al 6061.

Elements	Silicon	Iron	Magnesium	Copper	Chromium	Zinc	Titanium	Manganese	Aluminium
wt %	0.7	0.6	0.9	0.30	0.25	0.20	0.10	0.05	Balance

Table 2: Al 6061 and hybridized reinforcement (MWCNT + B_4C) with variant mixtures.

Specimen	Composition
1	Al 6061
2	Al 6061 + 10% B_4C
3	Al 6061 + 10% B_4C + 1% CNT
4	Al 6061 + 10% B_4C + 1.5% CNT
5	Al 6061 + 10% B_4C + 2% CNT
6	Al 6061 + 10% B_4C + 2.5% CNT

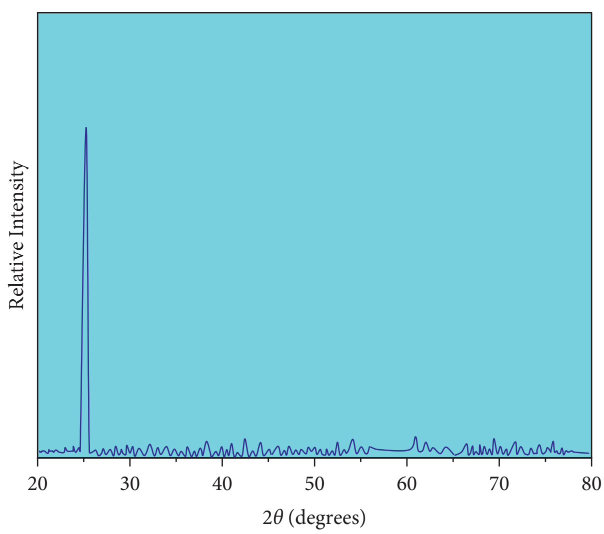

Figure 1: XRD form of CNTs.

(SEM) image of Al 6061 can be seen in Figures 2(a). Figure 2(b) shows a scanning electron microscope image of Al 6061 in the presence of boron carbide. Table 1 displays the oxidation states of aluminium and MWCNTs at various molar concentrations, as seen in Figure 2. (1, 1.5, 2, and 2.5 % wt.). Figure 2(b) shows that the Al 6061 contains a small amount of boron carbide (10wt. %). The compressive strength of the composites can be improved with the help of the B_4C [38].

Boron carbide and its various concentrations have been studied using the Energy Dispersive X-ray (EDX). As shown in Figure 3, the EDX of Al 6061 looks like this. Figure 3(b), on another end, shows that the atomic contribution of element O is 8% due to the inclusion of B_4C in the matrix. A carbon nanotube composite was used to add the element of C to Figures 3(c)–3(f). Each of these graphs has a different percentage of C: 5, 12, 21, and 37%. Boron carbide, which promotes interfacial attachment and increases the mechanical characteristics of hybridized composites, was shown to have been formed by the high carbon peak [39].

4.1. Comparison of Density before and after HIP. By comparing the densities before and after hot isostatic pressing, the actual density of hybrid composites was calculated. When compared with aluminium alloy and B_4C, the concentration of multiwalled carbon nanotubes was increased by decreasing the density, as shown in Figure 4. On the other hand, the actual density of the composite before HIP is less than the density of hybrid composites after HIP. It also clearly reveals that the ideal percentage of MWCNT was 2% by giving the best value of density.

4.2. Actual Density before and after Hot Isostatic Pressing. Figure 5 shows the experimental results of AA 6061/B_4C/MWCNT composites in the Vickers hardness test. It clearly shows that raising the volume fraction of MWCNT results in a higher value for hardness after HIP and before HIP which gives the best optimum result of about 2.5% volume fraction. The high hardness value and hard B_4C/MWCNT particles mat attribute to the strengthening effect. It is shown in the table that the maximum hardness value before hot isostatic pressing is 42.31 HV at 2.5% of multiwalled carbon nanotube and after hot isostatic pressing is 50.1 HV at 2.5% of MWCNT. The low hardness value before hot isostatic pressing is 37.39 HV at 1% of multiwalled carbon nanotube and 46.12 HV at 1% of MWCNT after HIP, respectively.

4.3. Variation of Reinforcement Particles in Volume Fractions. Table 3 shows compression test results for AA6061/boron carbide/multiwalled carbon nanotube nanocomposites before and after hot isostatic pressing. By increasing MWCNT, the value of the compression stroke decreases, as shown in Table 3. In all scenarios, the compression value attained after HIP is comparable to that of the value attained before HIP. The before and after compressed specimens are ductile materials meant for AA6061/B_4C/MWCNT.

4.4. Effect of Reinforcement Particles on the Friction Coefficient and Wear of Hybrid Composites. After 15 minutes at 250 rpm and 20 N of force applied, the coefficient of friction for the powder metal was calculated by calculating the pin on the disc setup. Figure 6 illustrates the COF of produced hybrid composites. From Figure 6, by adding B_4C to aluminium the COF of hybrid composites was reduced. Also, with the addition of various concentrations of MWCNT to B_4C and aluminium, the COF shows high improvement after HIP [40, 41]. In the case of with and without HIP, the COF for nanocomposites is raised by 39% and 48%, respectively. Whereas with HIP, wear rates were improved by 45% at all volume concentrations, and with B_4C and CNT, wear rates were improved by 20% at all volume fractions. Figure 7 shows the wear rates before and after hot isostatic pressing.

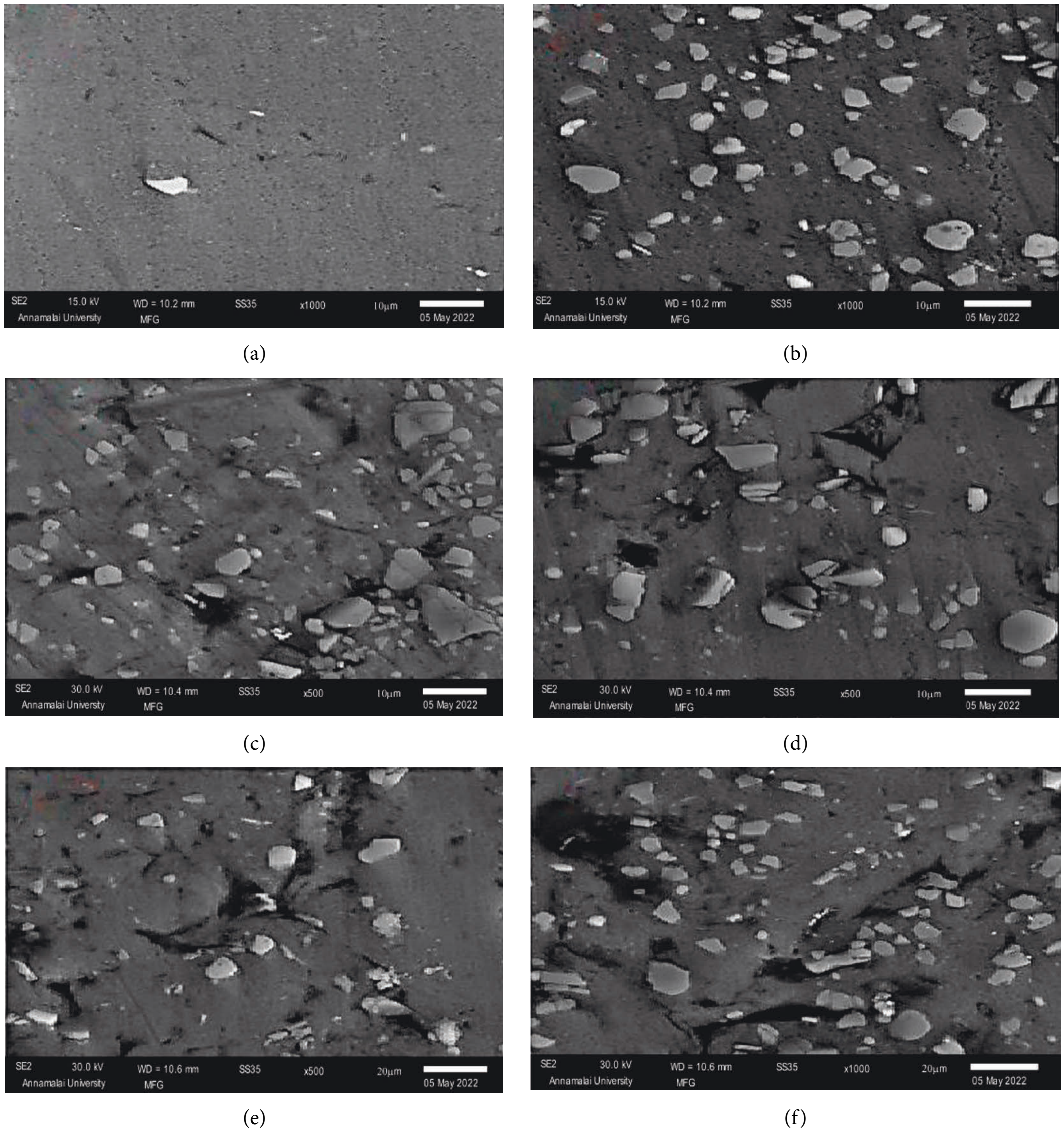

Figure 2: SEM images of (a) Al 6061, (b) Al 6061 + 10% B_4C, (c) Al 6061 + 10% B_4C + 1% CNT, (d) Al 6061 + 10% B_4C + 1.5% CNT, (e) Al 6061 + 10% B_4C + 2% CNT, and (f) Al 6061 + 10% B_4C + 2.5% CNT.

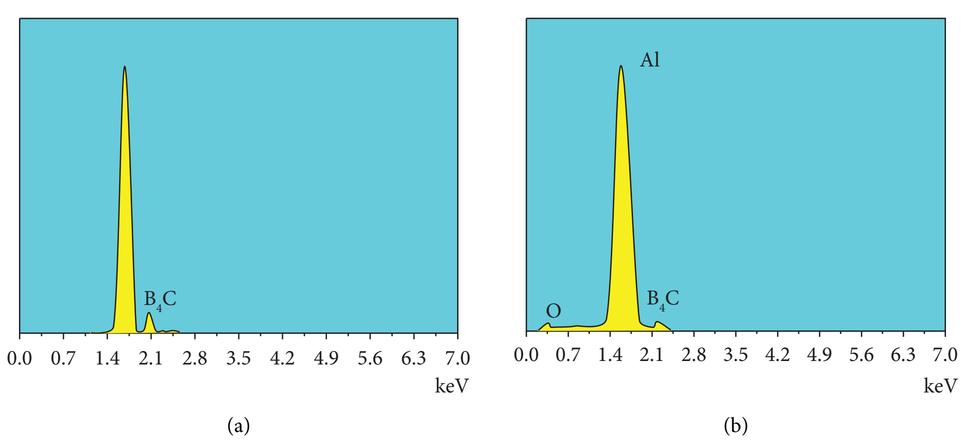

Figure 3: Continued.

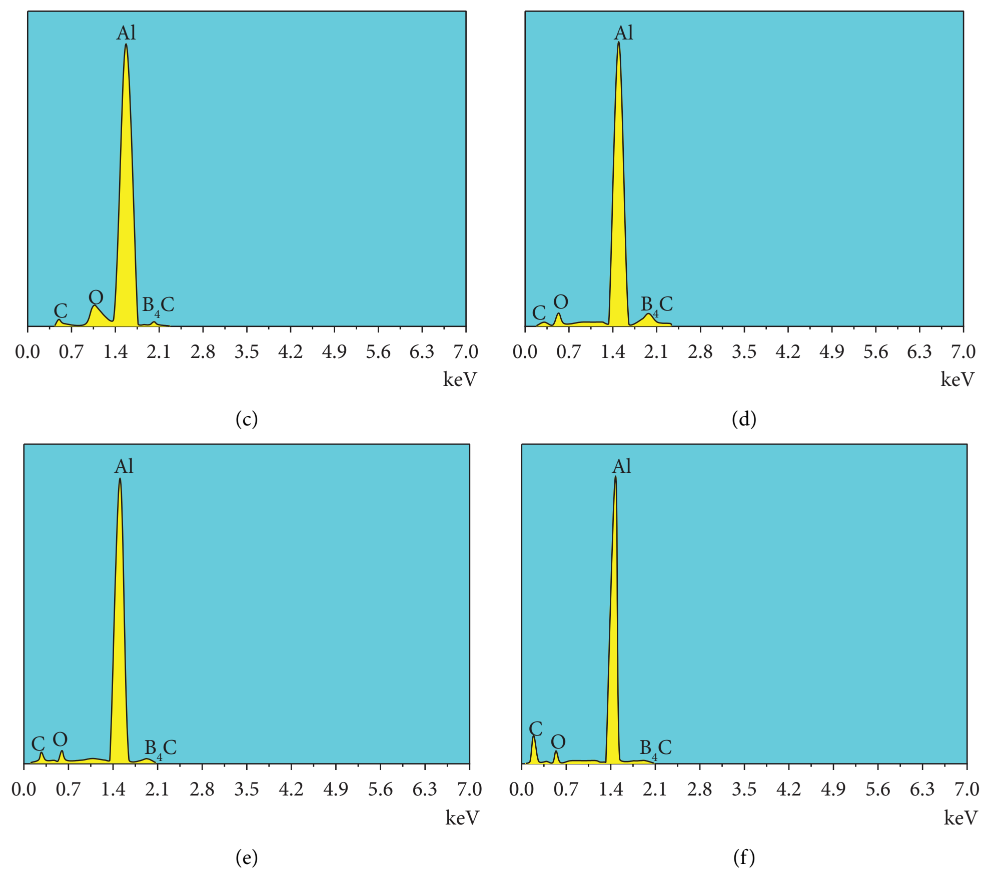

Figure 3: EDX of (a) Al 6061, (b) Al 6061 + 10%B_4C, (c) Al 6061 + 10% B_4C + 1% CNT, (d) Al 6061 + 10% B_4C + 1.5% CNT, (e) Al 6061 + 10% B_4C + 2% CNT, and (f) Al 6061 + 10% B_4C + 2.5% CNT.

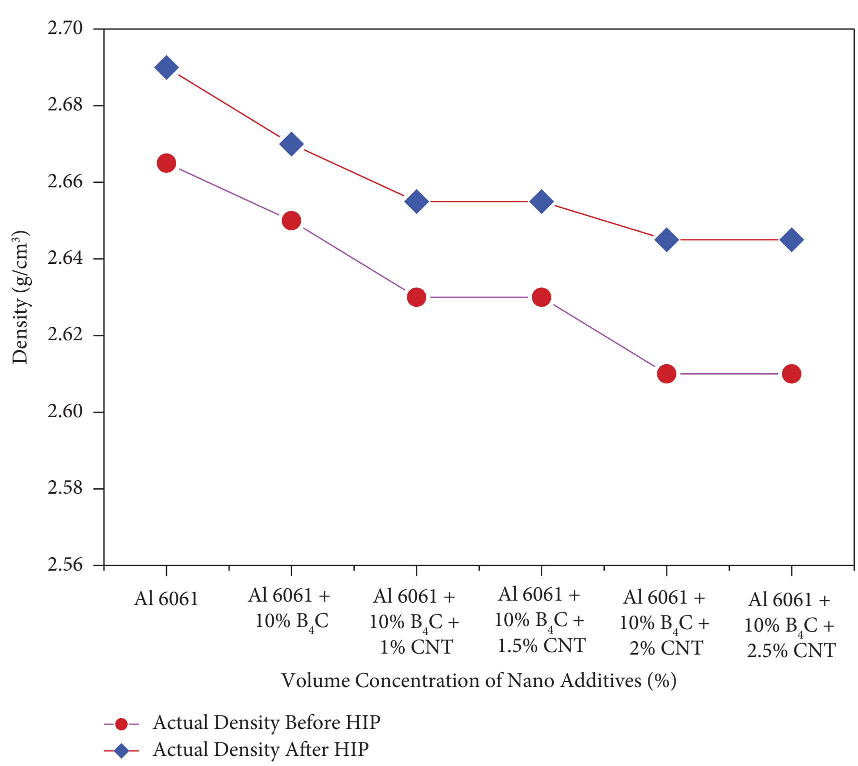

Figure 4: Before and after measurements of actual densities HIP.

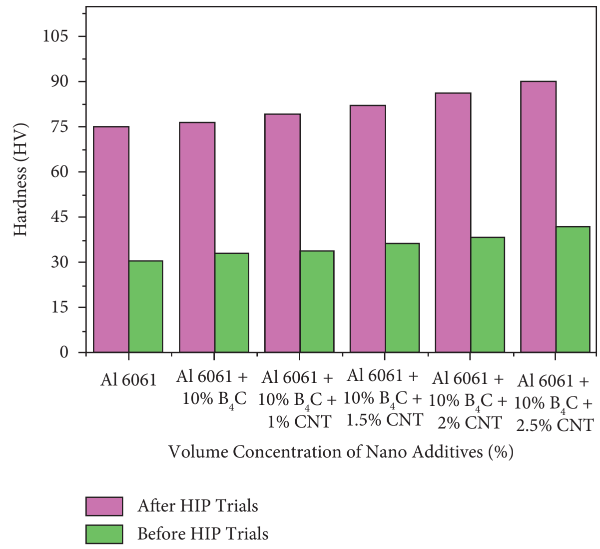

Figure 5: Hardness before and after hot isostatic pressing.

Table 3: Pre-HIP and post-HIP compressive stroke of AMC with varied CNT wt %.

Specimen	Stroke pre-HIP (mm)	Stroke post-HIP (mm)
Al 6061	5.723	4.4
Al 6061 + B_4C	5.341	3.9
Al 6061 + 10% B_4C + 1% CNT	5.234	3.5
Al 6061 + 10% B_4C + 1.5% CNT	4.82	2.9
Al 6061 + 10% B_4C + 2% CNT	4.787	2.7
Al 6061 + 10% B_4C + 2.5% CNT	3.599	2.4

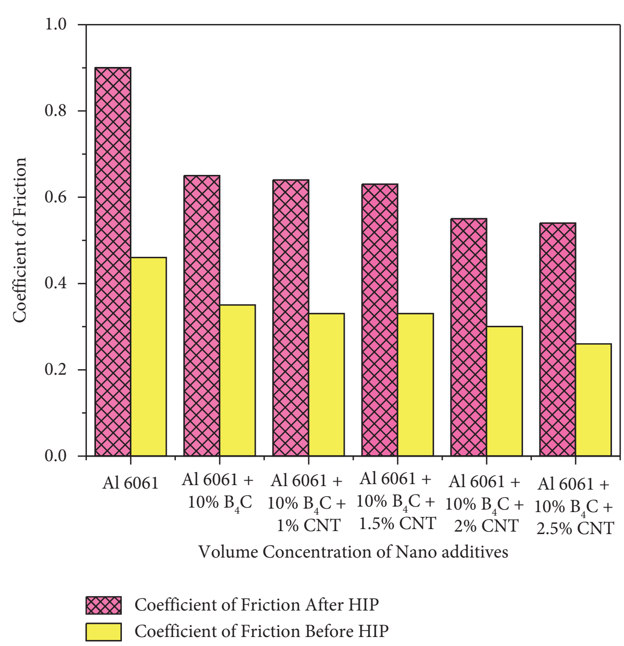

Figure 6: The friction coefficient of before and after HIP.

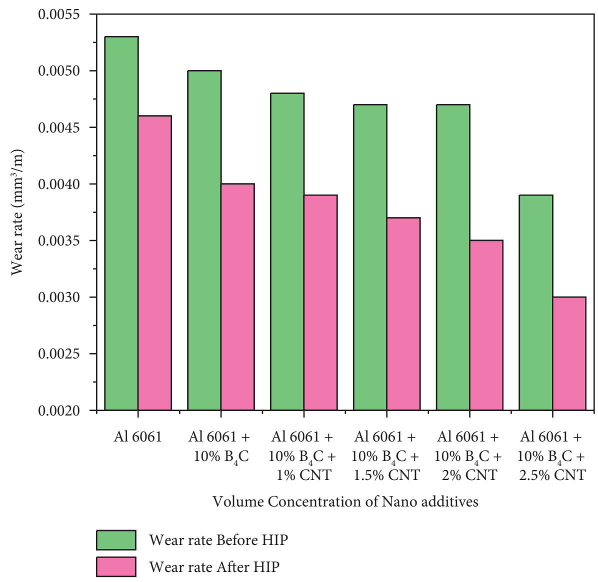

Figure 7: Before and after HIP wear rates.

5. Conclusion

By using a powder metallurgy process, AA6061 with hybrid composites was fabricated and characterized by compression, tribology, hardness, and density tests before and after HIP. Based on morphological and test results, the tribological and mechanical characteristics were enhanced, and multiwalled carbon nanotubes and boron carbide were dispersed uniformly and homogeneously in AA6061. The self-lubricating effect of B_4C and the creation of a carbon coating on the surface increases the tribological and mechanical characteristics of hybridized composites compared to AA6061. In all the experimental results, the best percent of multiwalled carbon nanotube was 2.5wt%. The excess B_4C and MWCNT were added to the composites, which inimically affect the composites due to the lack of wettability of the matrix. The tribological and mechanical characteristics of hybrid composites were increased by 39%, 45%, and 65%, respectively. Qualities of the composites like friction, wear, hardness, and compression strength were enhanced by hot isostatic pressing. As a result, HIP showed more effectiveness in composites without heat treatment due to sealed pores in the samples.

Data Availability

All required data are available within the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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