A Study On Effect of SiC And OFHC Cu-$Fe_{29}Ni_{17}Co$ Reinforcement With AA7075 On Microstructure, Mechanical And Wear Rate of Hybrid Composites

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Abstract

The silicon carbide (SiC) reinforcement with aluminium alloy 7xxx series has been found to be limited value as per the mechanical properties and wear behaviour of previous studies. In order to improve limited mechanical properties of hybrid aluminium metal matrix composites, the SiC and OFHC Cu-$Fe_{29}Ni_{17}Co$ reinforcement has been added with AA7075 alloy. Hence, the AA7075/SiC/Cu-Fe-Ni hybrid composites have been fabricated through a stir casting route under different weight percentages of SiC reinforcement. The mechanical properties such as hardness, compressive strength, tensile strength and wear rate have been investigated. The micro structure of hybrid composites found that the reinforcement particles in matrix alloy have been evenly spread. The silicon carbide and Cu-Fe-Ni alloy in aluminium solid solution has been found as well bonded interfacial reactions. The hardness, tensile strength, yield strength, compressive strength and wear rate were improved by 23.9 %, 48 %, 47 %, 15.3 % and 70 % for hybrid composite by adding 15 wt. %SiC and 15 wt. % Cu-Fe-Ni with AA7075 alloy, compared to matrix alloy.

Introduction

Aluminum alloy AA7075 (Al-Zn-Mg) is the basic aerospace, military and defense material for reducing the component weight and increasing the strength of components by addition of various reinforcements. Out of various ceramic reinforcements, Cu-Fe-Ni plays a major role for composites due to several desirable properties. Also, the interfacial reaction bonding between the SiC and Cu-Fe-Ni are good [1]. Hence, an AA7075/SiC/Cu-Fe-Ni hybrid composite is fabricated to study the microstructure, mechanical properties and wear rate of hybrid composite. On the addition of TiB_2 reinforcement with AA7075 alloy and found that the TiB_2 particles uniformly distributed in alloy and 9% wt. TiB_2 produced tensile strength of 295 MPa and hardness of 128 VHN [2]. Improvements in AA6061 properties were carried out by addition of fly ash particles in various percentages. The results found that composites showed the dendritic structure and produced the better hardness and strength [3]. Similarly, improvements in AA6061 properties were performed by addition of fly ash particles with SiC in various percentages. The results found that hybrid composites produced better properties [4]. The mechanical properties of AA6061 were improved by addition of SnO_2-coated $Al_{18}B_4O_{33}$ whiskers and found that yield strength and elongation percentage were improved [5]. The retrogression and re-aging treatment were also used to improve the Al–Zn–Mg–Cu alloy properties and it was identified by dense and coarse microstructure [6]. The aging process was also used to improve the yield strength and elongation percentage of Al-Zn-Mg-Cu aluminium alloy and it was identified by microstructure as elongated grains [7]. In another way, the cold water quenching, oil quenching and air quenching were used to improve 7085 aluminium alloy properties and found that alloy strength decreased with increasing the quenching rate [8]. The mechanical properties of Al-Mg-Si alloy were improved by addition of Al_2O_3 and rice husk ash. The results showed that 10 wt. % Al_2O_3 in hybrid composites produced the hardness of 80 VHN, UTS of 120 MPa, YS of 100 MPa and elongation of 13% [9]. Similarly, mechanical properties of Al-Mg-Si alloy were improved by addition of Al_2O_3 and SiC particles. The results showed that reinforced composites produced better wear resistance [10]. The

Al7075/8 wt. % Al_2O_3/5 wt. % graphite hybrid composites were produced with a hardness of 135 BHN, UTS of 235 MPa and ultimate compressive strength of 295 MPa [11]. A comparative study was made between AA6061 and AA7075 hybrid composite and found that the AA7075/10 wt.% B_4C/5 wt.% graphite hybrid composites produced the hardness of 120 BHN and UTS of 240 MPa and AA7075 hybrid composite exhibited better results compared to that of AA6061 [12]. The hardness and compressive strength composite were improved by using peak aged conditions and tests were carried out on Al–Li–SiC composites by varying percentage in SiC and found that 18 vol. % SiC particle in composites produced the hardness of 178 HV and compressive strength of 623 MPa [13]. On adding 20 wt. % SiCp with 2024 Al alloy, the hybrid composite hardness of 120 HV was achieved by natural aging [14]. In another way, by using the heat treatment process on A356/15 vol. % SiC, the composite had better wear resistance than without heat treatment on composite [15]. The hardness of aluminium/SiC/graphite hybrid composites was fabricated by using semi-solid powder densification method. The 55 VH hardness was obtained by using 2 wt. % Gr [16]. With the addition of SiC particles to the Al-Mg-Cu alloys, the wear properties of hybrid composites had improved and also found that the wear resistance of the composites much higher than that of the unreinforced alloys [17]. With an increase in SiCp from 0 to 30 wt. % with 7075 matrix alloy, composite hardness values were increased from 171 to 221 VH in 24 hr preheating [18]. Aging temperature was used to improve the mechanical properties. On increasing the aging temperature with 7075 Al alloys, the hardness and tensile strength were increased [19]. The 30 wt. % Al_2O_3 added with 2024 aluminium alloy composite produced the hardness of 135 BHN and tensile strength of 110 MPa [20]. The Al6061/6 wt. % SiC composite exhibited the tensile strength of 170 MPa and hardness of 94 BHN [21]. On increasing the graphite percentage with aluminium, the 6.017 % graphite reinforced aluminium composite resulted in a hardness of 334.9 MPa whereas 2.28 % graphite reinforced aluminium composite produced tensile strength of 88.365 MPa [22]. The 5 wt. % SiC and 5 wt. % TiB_2 particles added with AA7075 produced the hardness of 77 HV and 81 HV respectively. Similarly, the 5 wt. % SiC and 5 wt. % TiB_2 particles added with AA7075 produced the UTS of 175 MPa and 182 MPa respectively [23]. The stirring time was used to improve the mechanical properties. Hence, the SiC particulates added with Al7075 was studied and found that 20 min stirring time was used for obtaining the maximum strength [24]. In another work, a stirring temperature of 750°C and stirring speed of 700 rpm were used for improving the results of A356/SiC composite [25]. The 2.5 wt. % SiC nano particulates added to AA2219 produced the tensile strength of 66 % and hardness of 20% [26]. The carbon nano tube added to aluminium alloy also improved the mechanical properties of aluminium metal matrix composite [27]. The 6 wt. % SiC and 3 wt. % ZrO_2 reinforced with AA6061 showed a hardness value of 95.5 BHN and compressive strength of 255.47 MPa [28]. The 8 wt. % nano-SiC reinforced with aluminium alloy exhibited a hardness value of 55 HV, which was higher than that of micro-SiC reinforced with aluminium alloy (hardness: 51 HV) [29]. Based on the more work, it was found that the combinational effect of Al6061 added with SiC improved the tensile strength and compressive strength of hybrid composites [30]. Hence, a combination of Al6061/SiC composite is selected. The optimization and modelling were used to improve the mechanical properties of hybrid composites [31, 32, 33].

To summarize, improvement in mechanical properties of aluminium metal matrix composite is a difficult process due to the selection of reinforcement particles. The AA7075/SiC/Cu-Fe-Ni hybrid metal matrix composites has not yet been presented in the addition of 15% Cu-Fe-Ni to AA7075/ xSiC (x = 0, 5, 10 and 15% wt.). Previously, the effects of microstructure on mechanical properties of CuNiSi alloys have been studied [34]. In this work, the primary aim is to explore the microstructure, mechanical properties and wear rate of various combinations of AA7075/SiC/Cu-Fe-Ni hybrid composites. More works showed that the addition of SiC reinforcement with aluminium matrix materials is enhancing the microstructure and mechanical properties of aluminium hybrid composites [4, 10, 14, 23, 25, 28]. However, it has been found that few works have been carried out to find the effect of adding SiC and Cu-Fe-Ni alloy with AA7075 hybrid composites. Hence a study has been performed to develop AA7075/SiC/Cu-Fe-Ni hybrid composites by stir casting root under various weight percentages of SiC reinforcement to obtain the mechanical properties. The microstructure, hardness, tensile strength, compressive strength and wear rate of AA7075/SiC/Cu-Fe-Ni hybrid composites are the finding and discussed in this work.

Materials And Methods

2.1 Fabrication of hybrid composites and testing methods

Aluminium alloy (AA7075) has been considered as the matrix. The chemical composition of the matrix is shown in Table 1. Silicon carbide xSiC (x = 5 %, 10 % and 15 % in weight) and Cu-Fe-Ni alloy (15% Wt. Cu-Fe-Ni alloy) have been used as reinforcement. The material properties are shown in Table 2. The 55 μm particle size of SiC and 92 μm particle size of Cu have been selected for fabricating hybrid composites. As per stir casting root, the hybrid composites, AA7075/0%SiC/15% Cu-Fe-Ni, AA7075/5%SiC/15% Cu-Fe-Ni, AA7075/10%SiC/15% Cu-Fe-Ni and AA7075/15%SiC/15% Cu-Fe-Ni have been prepared [34]. The microstructures of hybrid composites have been studied by using the optical microscopy. The hardness tests have been conducted on hybrid composite as per ASTM E10-07 standards. Brinell hardness has been found by using a 10 mm ball indenter with 500 kg load applied in the duration of 30 s. The experiments have been conducted at room temperature and hardness is measured at five positions of composition and average value is taken for further analysis. According to the ASTM E08-8 standard, the universal testing machine is used to evaluate ultimate tensile strength (UTS) in MPa and yield strength (YS) in MPa. Prior to tests, composite samples have been polished by using 1200 grit to remove the machining scratches and surface defects. The wear tests have been conducted in the 30 N, 60 N and 90 N load and sliding speed of 0.2 m/s, 0.4 m/s and 0.6 m/s. On using ASTM E9-09 standards, the compression test has been conducted on these composite samples using a computerized universal testing machine. The ultimate compressive strength is conducted at room temperature and 2 mm/min cross head speed. The wear rate of hybrid composites has been found by using pin-on-disc method. The parameters, 60 N load, 0.4 m/s sliding velocity, 1000 m sliding distance and room temperature are constantly used to conduct the experiments [11].

Table 1
Chemical composition of AA7075

Element	AA	Zn	Mg	Cu	Others
Wt. %	90	5.6	2.5	1.6	Bal.

Table 2
Materials properties

Materials	AA7075	SiC	Cu
Melting point (°C)	477	2730	1085
Thermal conductivity (W/m.K)	130–150	490	386
Density (g/cm^3)	2.81	4.36e-9	8.96
Elastic modulus (GPa)	71.7	410	110 to 138 kMpa
Poisson's ratio	0.33	0.14	0.34
Hardness (HB500)	87	280	89
Tensile (T)/Compressive strength (C) (MPa)	510–538 (T)	3900 (C)	210 (T)

Results And Discussion

3.1 Microstructure

The AA7075/SiC/Cu-Fe-Ni composites were polished with emery paper grit size of 1200 followed by polishing with alumina suspension on velvet cloth prior to study of microstructure. Second, the composite samples were polished with 0.5 μm diamond paste to achieve the mirror finish. The composite mechanical properties were highly associated with a microstructure, basic matrix properties, and reinforcement particle size and shape and reinforcement distribution in the matrix alloy [35]. The fabricated samples were inspected to learn the reinforcement distribution in the matrix alloy through an optical microscope. All composites microstructure showed the aluminium solid solution and inter-dendritic structure of Al-Cu eutectic. The major portion of microstructure of cast AA7075 showed the α-Al dendritic network structure [36]. This was formed due to the super-cooling in solidification, with minor impurities and cracks present. The microstructure of all composites revealed small impurities with a non-uniform distribution of Cu-Fe-Ni particles along with clustering of SiC and Cu-Fe-Ni particles present at some locations. The surface morphology of the composites decided the addition of dissimilar density percentage of reinforcement in matrix. The low density of SiC particles as compared to that of AA7075 causes the SiC particles to float in aluminium melt resulting in non-uniform distribution [37]. More percentage additive in reinforcement particles resulted in minimal effect in distribution and minimum particles accumulation observed as shown in Fig. 1. The few reinforcement particles had distributed in slight uniform in the matrix due to the stirring effect. However, the reinforcement particles had also accumulated at some location of the casting. In the solidification process, the solidification time and temperature of molten composite materials were greatly affecting the heat rejection due to various latent heat materials, resulting in increased temperature of particle clusters, which delays the solidification velocity. The composite etched surface shows clearly the position of the reinforcement particles more preferential in the grain boundary cavity. The interfacial reaction observed between the reinforcement and matrix was a good with larger grain and few un-dissolved Al (Cu, Fe) in aluminium solid solution matrix alloy, which were uniformly distributed in the matrix [38]. This was the reason for increasing the mechanical properties of hybrid composites.

3.2 Hardness

The hardness tests were performed on a Brinell hardness machine. The effect of SiC and Cu-Fe-Ni on the hardness of composite observed in the hardness test was made, which are shown in Fig. 2 and Table 3. It was found that the hardness of the AA7075/SiC/Cu-Fe-Ni hybrid composites increased with the addition of SiC, which was higher, that of matrix alloy. Hardness of all the combinations of hybrid composites was significantly greater than that of the matrix alloy due to the hard nature of SiC and Cu-Fe-Ni particles. Compared to other reinforcements, in addition of graphite particles to the aluminium, the hardness was decreased [39]. To solve this problem, the Al_2O_3 ceramic particle was added in matrix alloy and it acted as the obstacles in the movement of dislocation [40, 41]. In order to improve the hardness of aluminium alloy and free movement of ceramic particles, SiC and Cu-Fe-Ni particles were added to matrix alloy. The particles in the matrix alloy provided protection and good interfacial bond strength to the soft matrix. The previous works found that addition of ceramic produces a significant improvement in the matrix hardness. The higher hardness values for the hybrid composites containing 15 wt. % of SiC was due to the presence of hard SiC and Cu-Fe-Ni particles and the elongated grains also reasoned. The present result was a good agreement with the previous result of work [28]. The 8 wt. % Al_2O_3 and 5 wt. Gr added to AA7075 alloy produced the hardness of 135 BHN, which was lower than the present result of 15 wt. % SiC and 15 wt. % Cu-Fe-Ni added to AA7075 alloy [11]. Similarly, the 10 wt. % B_4C and 5 wt. % Gr added to AA7075 alloy produced the hardness of 120 BHN, which was lower than that of present result of 15 wt. % SiC and 15 wt. % Cu-Fe-Ni added to AA7075 alloy [12]. The 30 wt. % Al_2O_3 added to AA2024 alloy produced the hardness of 135 BHN, which was lower than that of the present result [20]. The 6 wt. % SiC added to AA6061 alloy produced the hardness of 94 BHN, which was very lower than that of the present result [20]. This was due to the difference in matrix alloy and reinforcement particle properties.

Table 3
Hardness of hybrid Composites

AA7075- Weight % of SiC and Cu-Fe-Ni	Hardness (BHN)
AA7075	106.51
AA7075/5%SiC/15% Cu-Fe-Ni	119.42
AA7075/10%SiC/15% Cu-Fe-Ni	125.85
AA7075/15%SiC/15% Cu-Fe-Ni	139.99

3.3 Tensile strength

Tensile tests of hybrid composites were conducted at room temperature using a universal testing machine (UTM) by following procedure of ASTM Standard. There were three sets of tests performed to avoid the measurement error and the mean value was computed and considered for analysis further. The influence of reinforcement particles such as SiC and Cu-Fe-Ni particles on yield strength and Ultimate Tensile Strength (UTS) of hybrid composite has shown in Fig. 3. It found that the UTS and YS of aluminum hybrid composites increased with increase in reinforcement. Increment in the UTS and yield strength was owing to the interfacial bonding between the hard reinforcement particles and the soft aluminium matrix. The mechanical properties of hybrid composites were dependent on the microstructure and mechanical properties of the reinforcement particles due to the strong interface, resulting in high elastic strength and modulus [42]. It was also observed that the UTS of hybrid composites was increased up to 48% as that of yield strength increases 47% when compared with AA7075 alloy. Similarly, the percentage elongation of hybrid composites was decreased up to 2.9% with increase in percentage of SiC and Cu particles reinforcement in the matrix alloy as shown in Fig. 4. This was owing to the addition of ceramic reinforcement such as SiC and Cu-Fe-Ni particles which enhances the plastic deformation and reduces the elastic deformation of hybrid composites [39]. However, the presence of SiC and Cu-Fe-Ni reinforcements in the matrix was higher tensile strength comparatively with AA7075 alloy. Compared to previous hybrid composite results, the reinforcement of Al_2O_3 and rice husk ash added to Al-Mg-Si exhibited the UTS of 120 MPa and YS of 100 MPa, which were lower than that of AA7075/15% SiC/15% Cu-Fe-Ni reinforcement [9]. The 8 wt. % Al_2O_3 and 5 wt. % Gr added to AA7075 alloy produced the UTS of 235 MPa, which was lower than that of the present result [11]. The 10 wt. % B_4C and 5 wt. % Gr added to AA7075 alloy produced the UTS of 240 MPa, which was lower than that of the present result [12]. The improvement was observed due to the grain refinement.

3.4 Compressive strength

The compression tests were conducted using UTM with ASTM standard at room temperature, which the results are shown in Fig. 5. It was found that the compressive strength was increased with increase in weight percentage of reinforcement particles to matrix alloy. However the presence of SiC and 15% Cu-Fe-Ni were higher compressive strength comparatively with AA7075 alloy. It was also found that the compressive strength and tensile strength of hybrid composite were linearly increased with increasing the reinforcement particles due to the consistent interfacing and uniformly distributed reinforcement with matrix alloy. Moreover, the addition of stiffer reinforcement particles in matrix alloy behaves as obstacles, resulting in restricting the dislocation motion and plastic flow [43]. The surface morphology of fractured surfaces of hybrid composites is shown in Fig. 6. This was developed due to compressive load. The crack propagation in the compressed surface was reduced with the presence of the particle's reinforcement in hybrid composites due to the constrained material flow. However, the compressive strength of hybrid composites was comparatively higher than that of AA7075 alloy. This was obtained due to the consistent distribution of reinforcement particles in matrix alloy, resulting in grain refinement. Compared with other results, the reinforcement of 8 wt. % Al_2O_3 and 5 wt. % Gr to Al7075 showed the compressive strength of

295 MPa, which was lower than that of AA7075/15% SiC/15% Cu-Fe-Ni hybrid composite [11]. The 18 vol. % SiC added with Al-Li showed the compressive strength of 623 MPa, which was higher than that of AA7075/15% SiC/15% Cu-Fe-Ni hybrid composite [13]. The higher value was due to the stiff reinforcement with matrix alloy. The 6 wt. % SiC and 3 wt. % ZrO_2 added with Al6061 revealed the compressive strength of 255.47 MPa, which was lower than that of AA7075/15% SiC/15% Cu-Fe-Ni hybrid composite [28]. The improvement was detected by the grain refinement.

3.5 Wear rate

The wear rates of the AA7075/15% SiC/15% Cu-Fe-Ni hybrid composites are shown in Figs. 7 and 8. The wear rate was decreased with the addition of SiC and reaches a minimum at 5 wt. % SiC/15 wt. % Cu-Fe-Ni, which was 70% lesser than that of the AA 7075 alloy, whereas the wear behaviour of hybrid composite was decreased with increasing in sliding speed. Increasing in sliding distance was the temperature of sliding surface increased, resulting in heavy deformation in surface [44]. However, decrement in wear rate of hybrid composite was relative to the AA 7075, it was reasoned to beneficial effect of SiC addition in reducing the worn out surface due to thin lubricating carbide film formation in the tribo surface. On increasing the addition of SiC with AA7075 was above 5 % produced the adverse effect in wear rate. This was due to the crack initiations and propagation in the metal interface. The wear rate was increased with increasing in all applied load. The AA7075/5% SiC/15% Cu-Fe-Ni hybrid composite was produced the minimum wear rate. The SiC particles behaved as load bearing elements in the hybrid composites, resulting in forming of more stable lubricating film on the tribo surface. Decrement in wear rate with SiC content was attributed due to the collective effect of SiC and Cu-Fe-Ni particles produced more resistance tribo layer formation in contact surface [45]. The carbide and oxide tribo film produced the minimize the degree of shear stress, which was transferred to sliding material below the sliding contact area, which produces in less plastic deformation in subsurface zone and reducing in wear rate in hybrid composites. Compared with wear rate of other hybrid composites, the Al/10 wt. % SiC/ 5 wt. Gr had the minimum wear rate of 1.2 mm^3/m by using sliding distance of 50 m and applied load of 15 N [46], which was higher than that of present work. The AZ91D/5 wt. % SiC/ 5 wt. Gr produced the minimum wear rate of 0.0147 mm^3/m by using a sliding distance of 500 m and an applied load of 10 N [47]. The AA7050/4 wt. % SiC exhibited the minimum wear rate of 0.00239 mm^3/m by using sliding distance of 1800 m and applied load of 20 N [48], which was lower than that of present work. This was achieved due to the presence of SiC in alloy.

Conclusions

The AA7075/SiC/Cu-Fe-Ni hybrid composites have been fabricated with dissimilar weight percentage of SiC reinforcement with a constant 15 % wt. Cu-Fe-Ni under stir casting method and the mechanical properties has been analyzed. From the experimental results compared with previous results, the closing statements have been made.

- The above addition of 15 % wt. Cu-Fe-Ni reinforcement presence in the matrix alloy has significantly decreased mechanical properties of hybrid composites.
- The well bonded interfacial reaction has observed between the reinforcement and matrix.
- The elongated grain and few undissolved Al (Cu, Fe) in aluminium solid solution matrix alloy have been found.
- The mechanical properties of hybrid composites are comparatively higher than that of AA7075 alloy due to the stiffer reinforcement particles addition in the matrix alloy.
- The hardness, tensile strength, yield strength and compressive strength are directly proportional with addition of SiC and Cu-Fe-Ni reinforcement to AA7075 alloy and indirectly proportional for percentage of elongation.
- The 5 % wt. Cu-Fe-Ni reinforcement presence in the matrix alloy has produced minimum wear rate.

Declarations

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Conflict of Interest:

The authors declare that they have no conflict of interest.

Contributions:

Ramasubbu Narasimmalu: Conceptualization, Methodology, Writing Reviewing discussion and Editing, Computation, Methodology, Software, Writing discussion, Conceptualization and analysis, Writing-review, writing manuscript, Methodology, Software, and writing – discussion Ramabalan Sundaresan: review manuscript language.

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The available data and material had been used and discussed in the manuscript.

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All persons named as authors in this manuscript have participated in the planning, design and performance of the research, and in the interpretation of the results.

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Figures

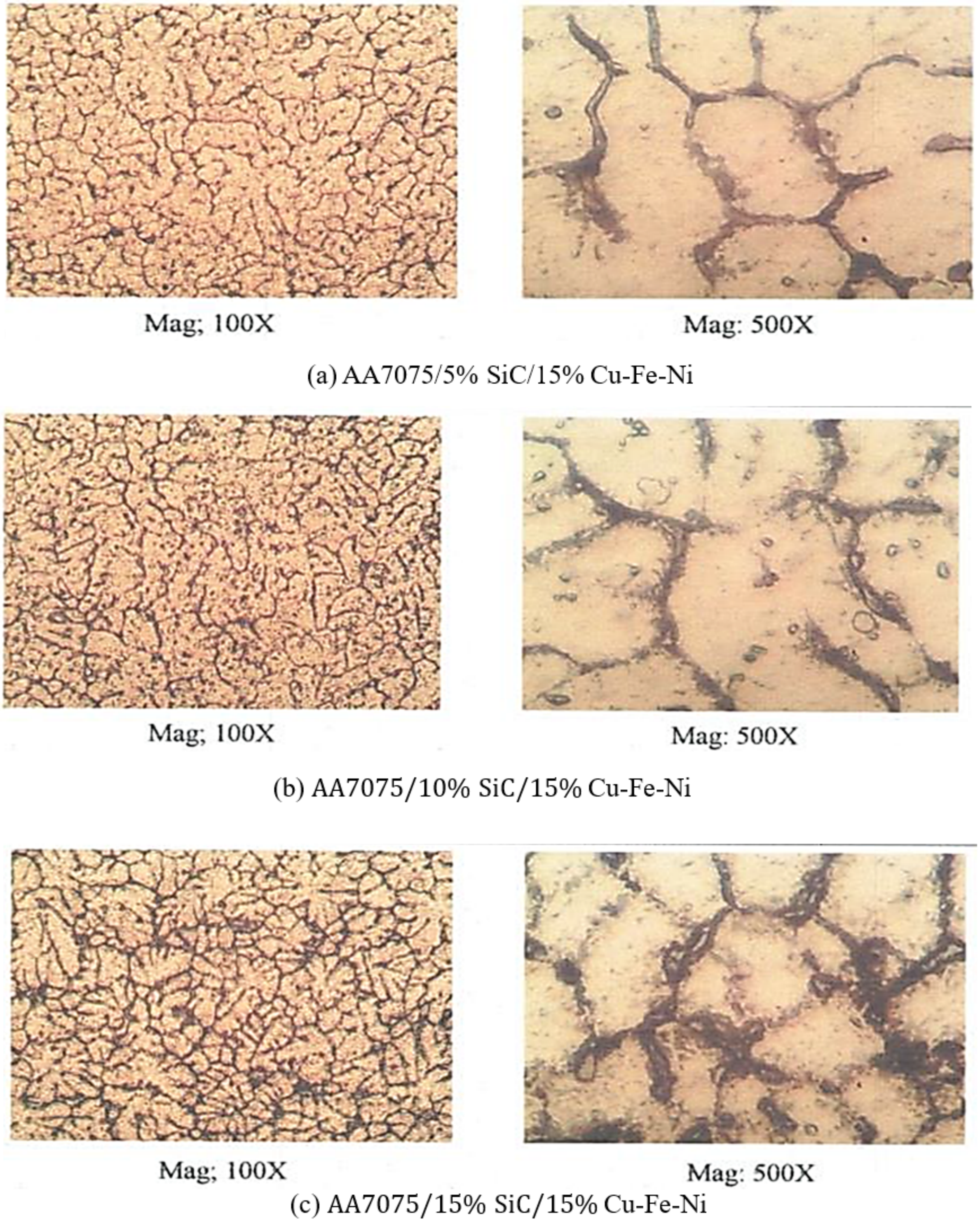

Figure 1

Microstructure of cast: (a) AA7075/5% SiC/15% Cu-Fe-Ni, (b) AA7075/10% SiC/15% Cu-Fe-Ni, (c) AA7075/15% SiC/15% Cu-Fe-Ni.

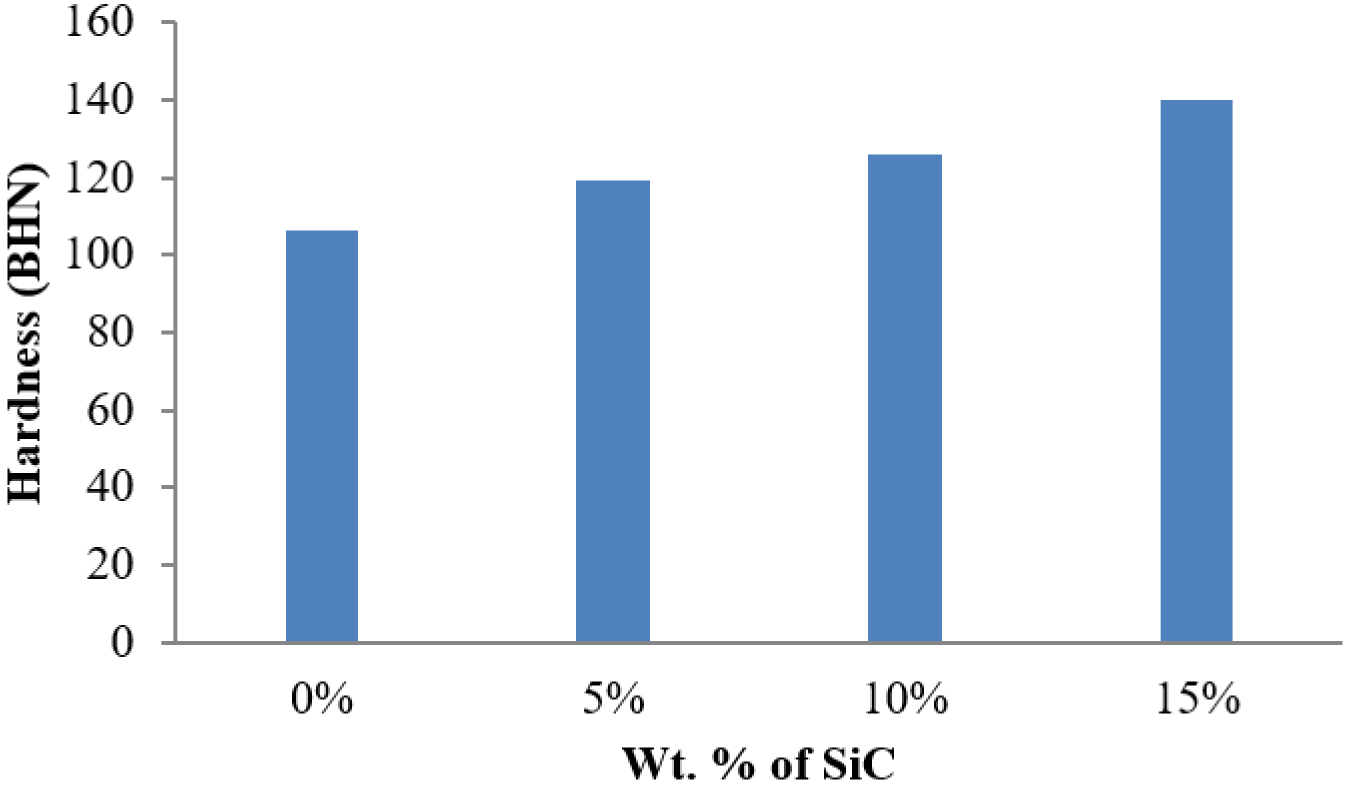

Figure 2

Brinell hardness of hybrid composites.

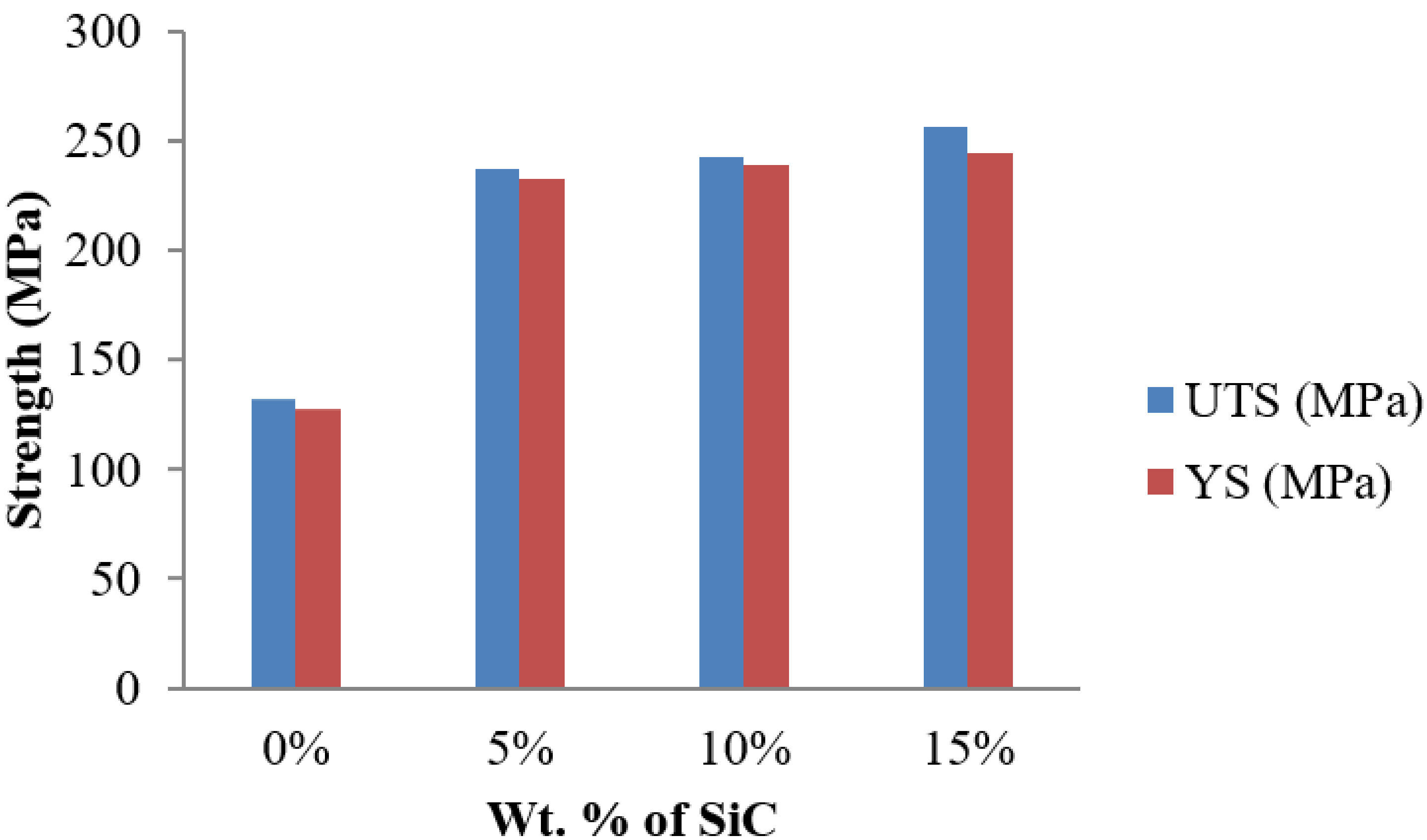

Figure 3

Tensile strength and yield strength of hybrid composites.

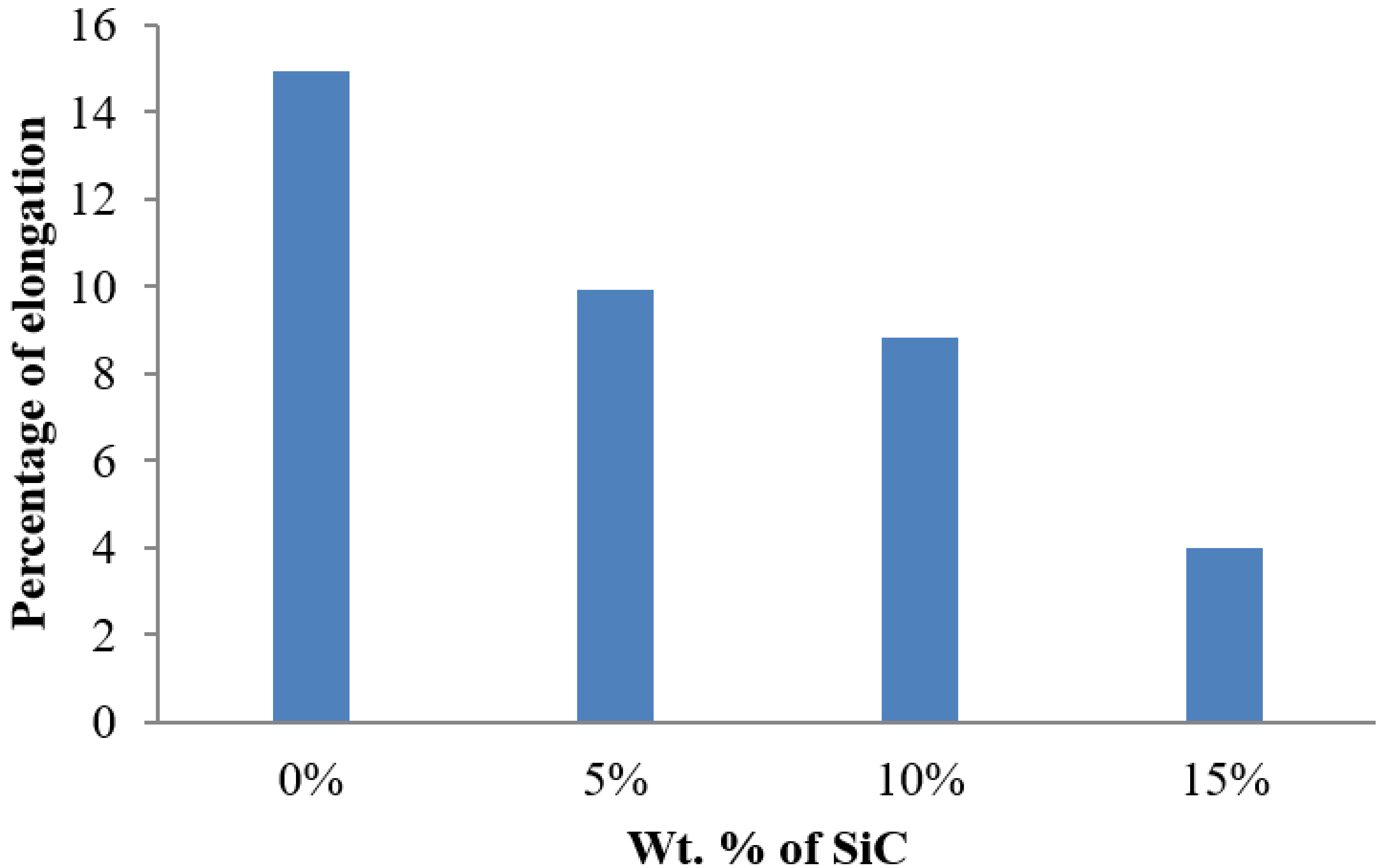

Figure 4

Percentage of elongation for hybrid composites.

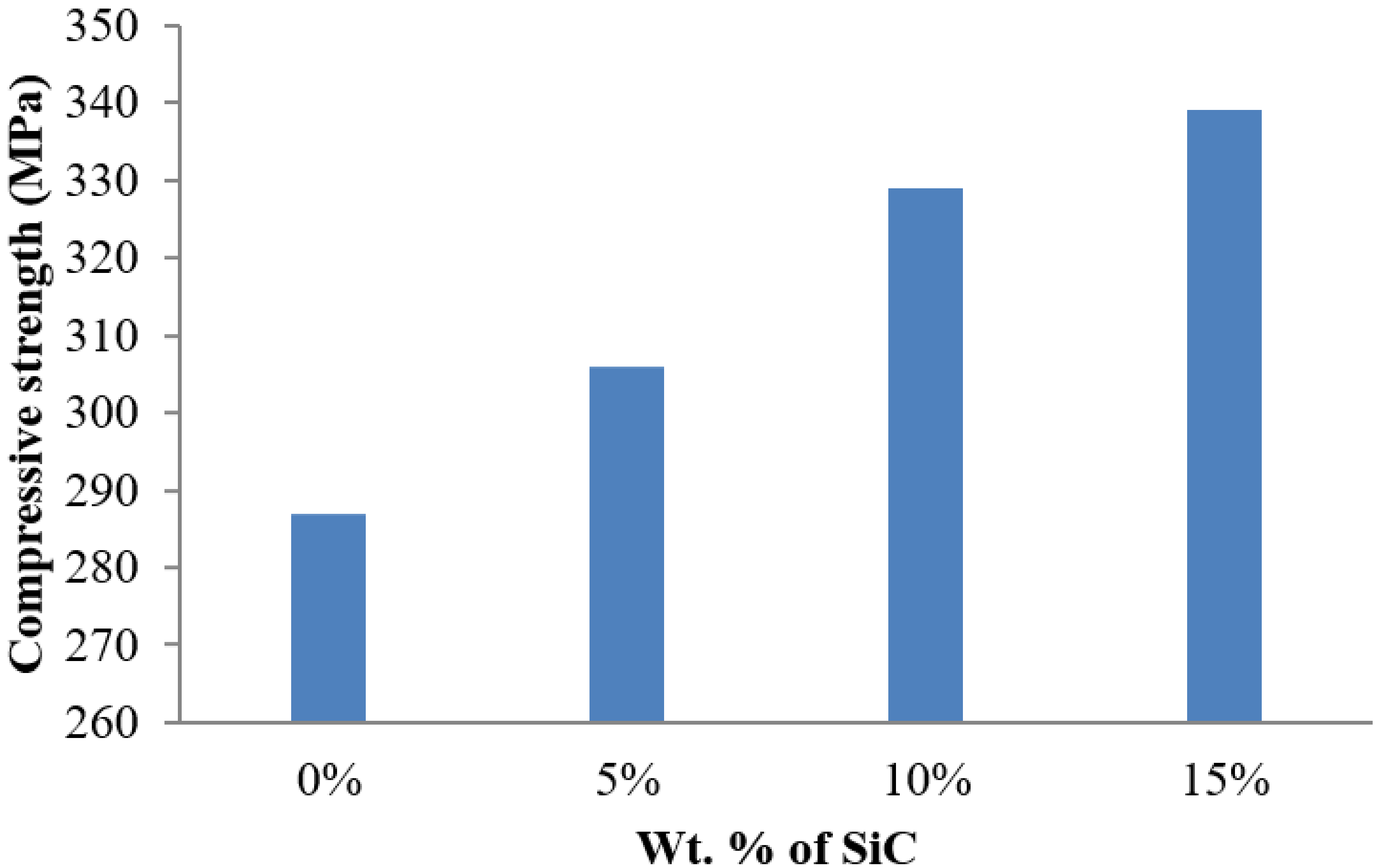

Figure 5

Compressive strength for hybrid composites.

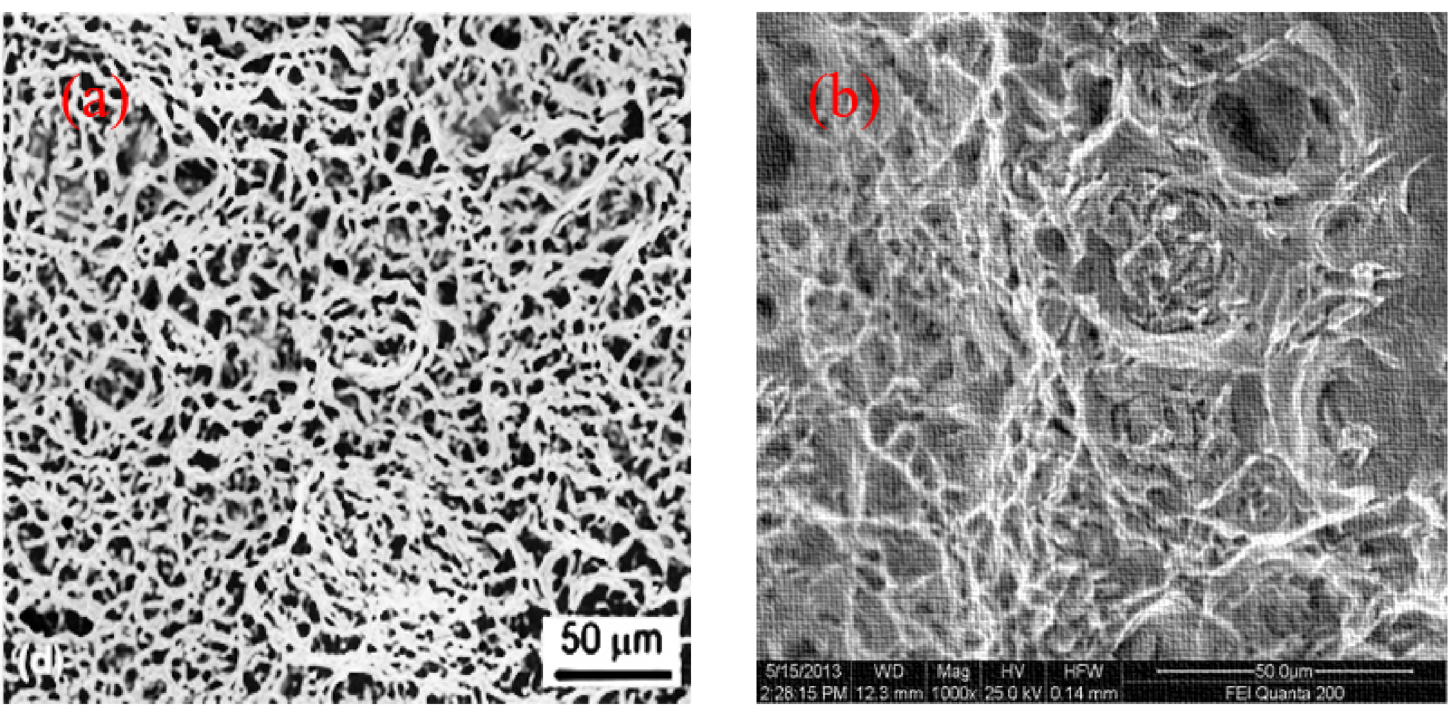

Figure 6

Fracture surface of Aluminium hybrid composites: (a) with reinforcement in 15 % SiC and (b) Without reinforcement.

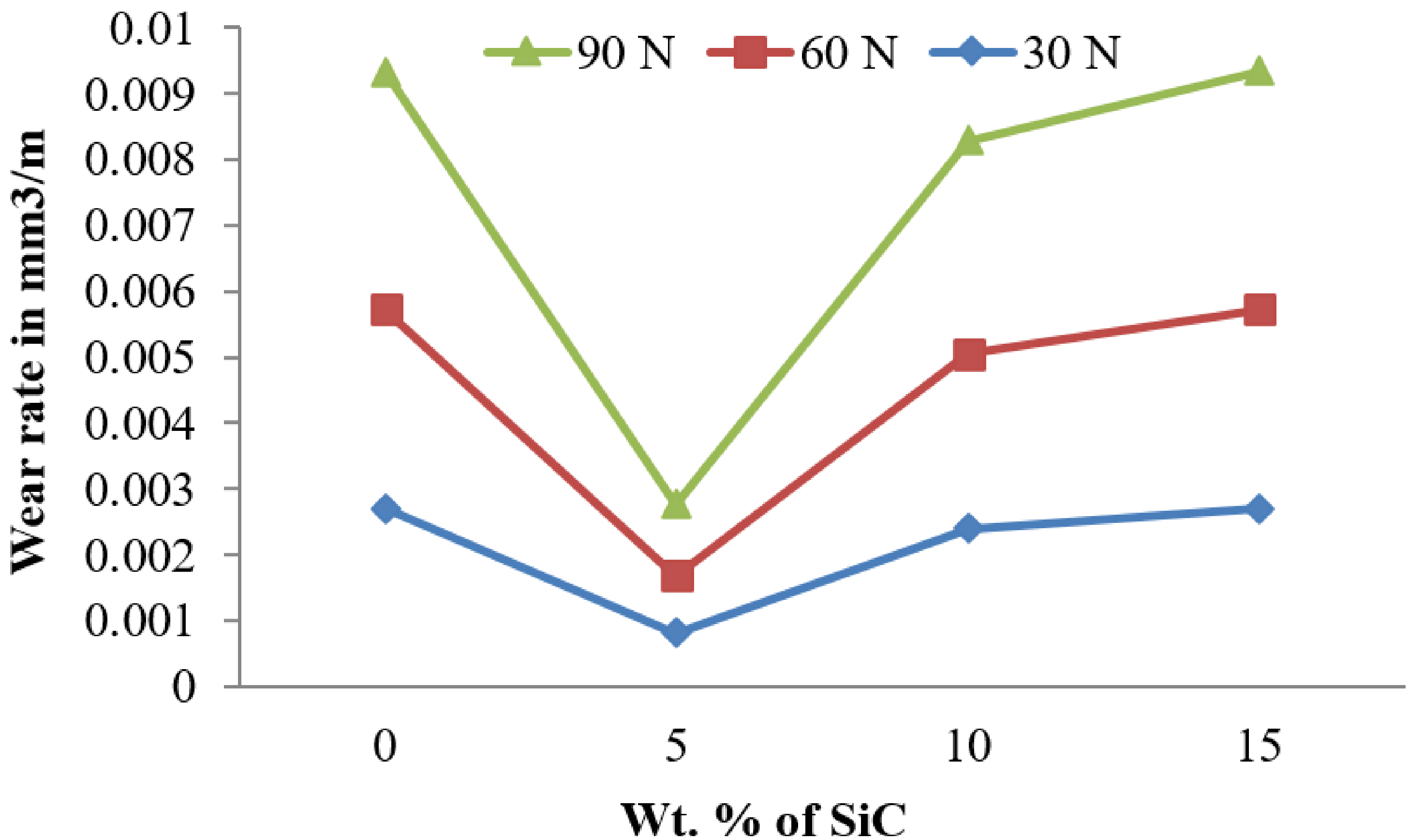

Figure 7

Wear rate of hybrid composites.

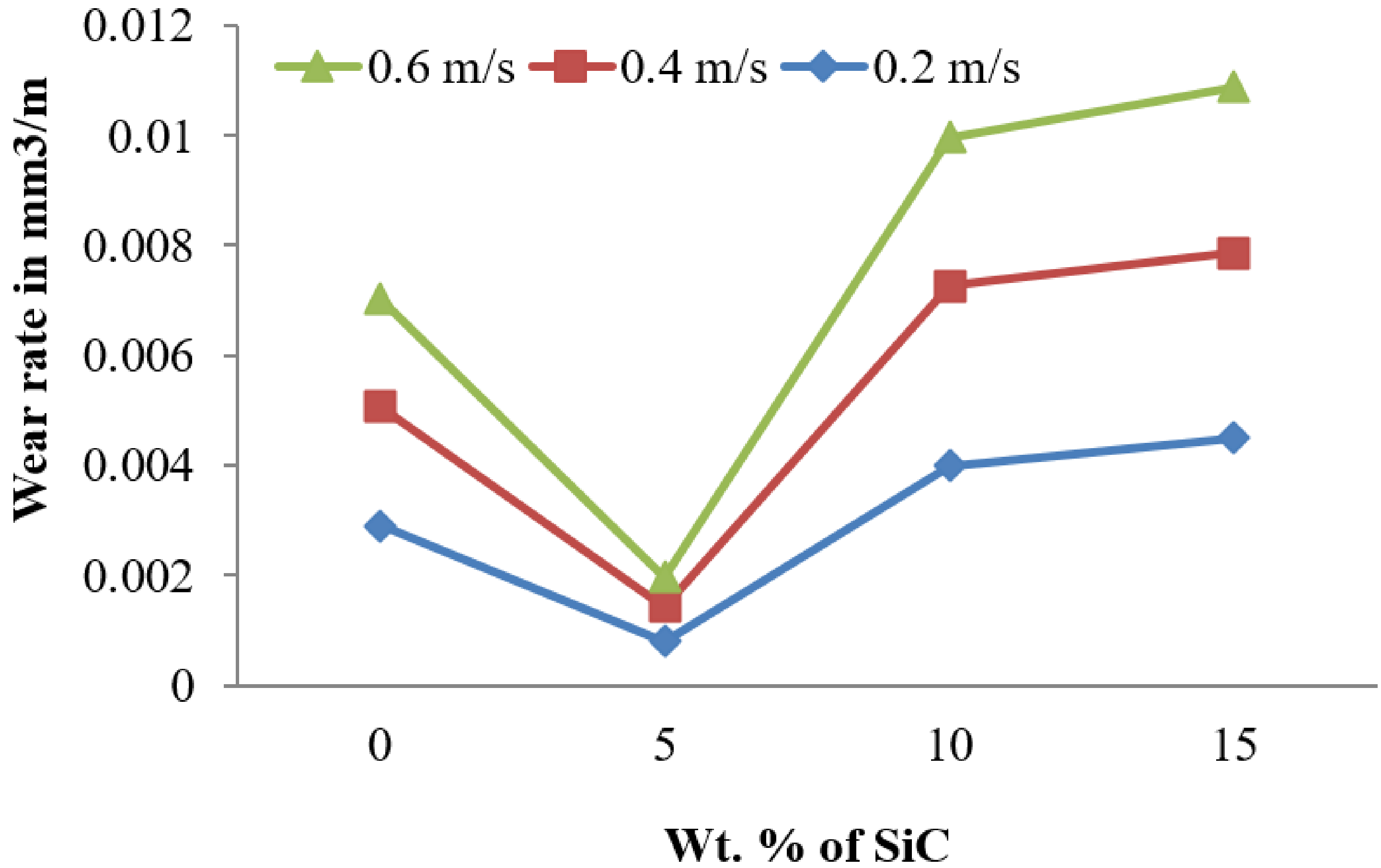

Figure 8

Wear rate of hybrid composites with varying sliding speeds.