

Review Article

Strength Enhancement Study on Composites of AA6066 Aluminium Alloy with Magnesium Oxide and Coal Ash

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Aluminium alloy is the most favourable material based on the various properties and economic factors. Always there are so many researches going on based on the enhancement of the material properties with various combinations and the various materials mixing rate depending upon the availability. These researches were focused on the augmentations of the properties, and then the corresponding properties can be used in the various applications depending upon the results. In this study, the AA6066 aluminium alloy composites were created with the magnesium oxide and coal ash with a variety of grouping. The specimens were named as AAMgOCA 1 to AAMgOCA 6 with respect to the volume concentration composition. Then, the composites were tested to identify the impact on various strengths such as yield strength, ultimate tensile strength, shear strength, and flexural strength. These strengths were compared with the two conditions of the composites such as annealed and heat-treated conditions. AAMgOCA 3 has the greatest results in heat-treated condition when compared with the annealed condition.

1. Introduction

There are number of researchers who were encouraged to conduct research to identify the new things and alteration of the existing things which are applicable for engineering materials especially in aluminium alloy due to its wide usage among all the places. Georgantzia et al. [1] explained the various uses of aluminium alloys in different structure-based applications with various recognizable buildings in UK, USA, UAE, Russia, etc. They also reviewed various researchers' point of view and gave idea about the different

grades of aluminium alloys. Davis JR [2] provided the outline of fundamental values and explanations for produced alloys and the equivalent subdivisions. He gave the method of annealed conditions for ductility, toughness, etc.

Zhu et al. [3] discussed the heat treatment conditions and methods of the various aluminium alloys with eight tests. They also followed the design code standards for preparation of the specimens. The various methods can be identified with the basic methods. Mukhopadhyay [4] individually reviewed the aluminium alloy 6XXX series with respect to designing and handing out through nearly

seventy-five references. He completely gave a variety of specifications, heat treatment methods, characteristics, and also the application point of view for the 6XXX series. AA6066 alloy has the percentage composition of 1.3% of magnesium, 1.6% of silicon, 1.15% of copper, 0.38% of chromium, and 1.05% of manganese, and the remaining is aluminium alloy in the total composition [4].

Tiryakioğlu et al. [5] talked about the harness strength in the aluminium alloy with some mathematical relations as well as the various SEM images in the different approaches. The considered material's pulverized powders are shown in Figure 1. Palani et al. [6] mentioned that the annealed casting specimens have higher dimensional stability and ductility when compared with the tempered specimens and similarly explained the hardened products which also have obtainable ductility in front of the elevated temperatures.

Imran et al. [7] investigated the composite specimen of Al7075 aluminium alloy with various combinations of the graphite and bagasse ash for testing of mechanical properties such as the ultimate tensile strength, hardness, percentage of elongation, and yield strength comparison. They also individually plotted and compared the various percentage variations with optimization technique. They concluded that the hybrid composites provided the greatest enhancement in their properties when compared with the individual alloy specimen.

Kumar et al. [8] focused only about the wear and tensile strength of the aluminium-based composite with silicon and titanium. From this investigation, microstructures were clearly identified and porosity can be controlled by the design parameters of the mold. Uthayakumar et al. [9] explained the hybrid composites of boron carbide- and silicon carbide-used aluminium alloy with various sliding circumstance for performance of the wear rate. Kumar and Dhiman [10] investigated and explained the response surface methodology-based hybrid and normal alloy of Al7075 aluminium alloy.

Senapati et al. [11] clearly explained the fly ash participation in the production of matrix composite of the aluminium alloy in the successive way. Mohammed Razzaq et al. [12] explained the reinforcement of the aluminium alloy with the fly ash composites. They clearly explained the basic properties and microstructure with XRD images and SEM images. The bulk density, porosity formation, impact strength, hardness, and brittleness of the reinforced composites were directly proportional to the fly ash content in the total proportions.

Sivaprasad et al. [13] studied the aluminium composite with titanium diboride reinforcement and studied the mechanical properties and mentioned the various applications. Wang et al. [14] investigated the reinforcement of aluminium alloy with the metallic glass fiber with the help of the microstructures and various characteristics. They concluded that the adhesive strength is the prior quality for the composites of the metal matrix. Efsan et al. [15] clearly explained fly ash-based aluminium composites along with applications with respect to the mechanical and physical behaviours.

Singh and Chauhan [16] reviewed the hybrid composites of the aluminium alloy with a number of research articles and they concluded that the properties of the composites were increased with increasing the percentage concentration on the composites. Sun et al. [17] clearly explained the aluminium alloy, titanium oxide, and magnesium oxide-based composite in heat treatment condition with the help of SEM images and XRD images. Tong et al. [18] also investigated the alumina and magnesium oxide composite-based mechanical properties enhancement by heat treatment.

Manikandan et al. [19] discussed magnesium oxide with aluminium alloy composite by reinforcement. The mechanical properties like compression strength, hardness, and wear behaviour were analysed with various SEM images. They concluded that the wear rate can be increased with the increase of the percentage of the magnesium oxide in total volume percentage. Kheder et al. [20] discussed and compared the composite combination of the aluminium alloy with various percentages of aluminium oxide, silicon carbide, and magnesium oxide separately. Increase of these metals in aluminium alloy provides enhancement in the mechanical properties; also, they mentioned that the magnesium oxide with aluminium alloy composite can be used in the structural components in the construction field related applications with high strength. The combined effect of the aluminium alloy at any series with the hard reinforced particles induced the high strength of the composites even at any type of composite preparation process [21, 22]. The mechanical properties also increased gradually by addition of reinforcement particles into the aluminium alloy [23].

In this study, the aluminium alloy composite reinforcement is involved with magnesium oxide and the coal ash with various percentage. Then the composites were forced for annealed and heat-treated conditions. The corresponding mechanical properties for these composites with two conditions were compared to identify the greater results among the composites.

2. Experimental Procedure

For this approach, aluminium alloy AA6066 composites are created using magnesium oxide and coal ash as per the combination of volume percentage variation in the complete volume in Table 1. All the materials were available in the market which are collected and used for the experiments. The coal ash is collected from the thermal power stations outcome which is cleaned and filtered from the various dust particles. The entire composite contains eighty percent of aluminium alloy AA6066 as a major component. The remaining twenty percent of the composite is filled with magnesium oxide and coal ash. Magnesium oxide proportion decreased from twenty percent to zero percent with four percent decrement for each specimen.

Similarly, coal ash percentage is increased from zero contribution to twenty percent with decrement of four percent. There are six combinations of the specimens prepared. The name of composite created was as per the mixing material's notations AAMgOCA (AA means aluminium alloy, MgO means magnesium oxide, and CA means coal

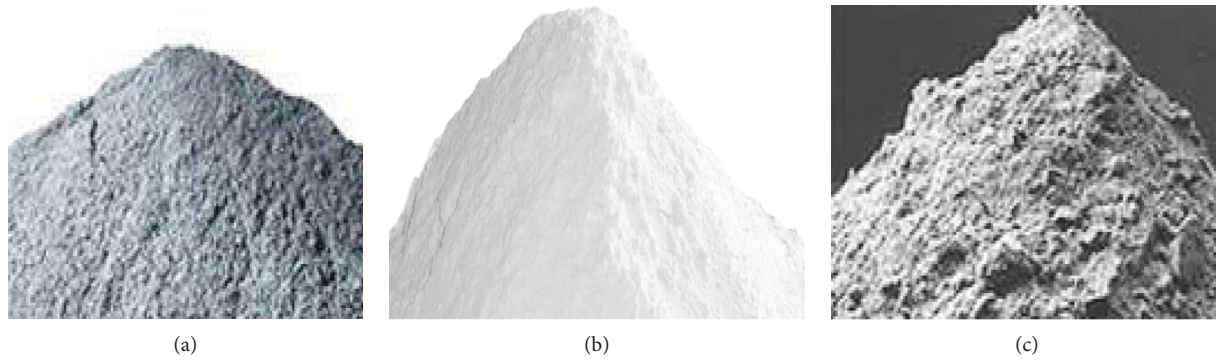


FIGURE 1: Powdered form of the materials. (a) AA6066. (b) MgO. (c) Coal ash.

TABLE 1: Percentage details of the composites for the experimental purpose.

Composite name	Volume percentage of the total composite (%)		
	AA6066	MgO	Coal ash
AAMgOCA 1	80	20	0
AAMgOCA 2		16	4
AAMgOCA 3		12	8
AAMgOCA 4		8	12
AAMgOCA 5		4	16
AAMgOCA 6		0	20

ash) with number from 1 to 6 for the various combinations of metals.

The individual specimens were prepared by the sand molding method. Sand molding process was created by tightly packing of sand with the addition of clay binder and correct level of water in the molding boxes. The mold cavity was formed by the way of pattern. The metal pattern was used for this experimental work; it formed the required shape of the samples after casting. The molten metal was poured into the mold cavity through the gate way; after filling the mold cavity, the molten material was allowed to cool. After solidification process, the casting part was removed from the sand mold; finally, the unwanted projection was removed by the fettling process. The metals used for this investigation were taken in the form of powder with the dimension from 30 microns to 70 microns. Here, the specimen was prepared with the dimension of 40 mm diameter and 200 mm length in three numbers for each combination. Then, the prepared rod specimens were carried for the two conditions such as annealed (900 K) condition and the heat-treated (1100 K) condition and then cooled artificially. Each specimen should maintain these two conditions.

In this place, there are four different mechanical strength tests conducted for the strength comparison on each combination in two conditions. The strengths considered for this experimental investigation were followed such as yield strength (YS), ultimate tensile strength (UTS), shear strength (SS), and flexural strength (FS). All these tests were conducted with the help of the universal testing machine mentioned in Figure 2. ASI brand universal testing machine was used to conduct the tensile test; the universal testing machine had a



FIGURE 2: UTM for the testing.

capacity of 60 tones. The model of the UTM was named UTE-60; this machine was functioning hydraulically. The bending test was also termed flexural test; it was conducted by universal testing machine with three-point bend fixture; normally, 3-point bend fixture was used. Then the created specimens were prepared as per the testing standards of the individual testing conditions with respect to the universal testing machine. In this experimental work ASTM E8 standard procedure was used to conduct the tensile test.

Ultimate tensile strength and the yield strength can be measured in single specimen with the single attempt of the testing. But the shear strength and flexural strength need separate specimens and separate arrangement change in the UTM. Then the corresponding arrangements were created with respect to the testing and Figure 3 shows the arrangement and testing method for the flexural strength. Finally, the experimental results from the individual tests were taken for both annealed condition and heat treatment conditions.

3. Result and Discussion

The complete experimental results of yield strength (YS), ultimate tensile strength (UTS), shear strength (SS), and

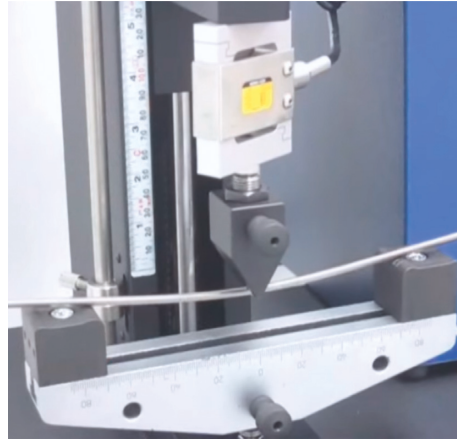


FIGURE 3: Flexural testing.

flexural strength (FS) obtained from the various testing conducted with annealed conditions and heat-treated conditions for the each specimens are clearly pointed out in Tables 2 and 3 correspondingly in the unit of MPa for all the strengths.

Figure 3 represents the yield strength comparison in the form of three-dimensional surface plot for both annealed and heat-treated specimens. Annealed specimens have less yield strength when compared with heat-treated specimens' results. For heat-treated condition, the maximum yield strength (415 MPa) is reached for the specimen AAMgOCA 3 and the minimum yield strength (395.59 MPa) is achieved for the specimen AAMgOCA 1. For the greatest result the annealed specimens were very low when compared with lowest heat-treated specimen.

The experimental outcomes of the ultimate tensile strength comparison for the annealed and heat-treated conditions are explained in Figure 4 as a three-dimensional surface plot. From this plot, ultimate tensile strength of heat-treated specimens' results was greater than the annealed specimens with higher difference. The supreme ultimate tensile strength of 452.76 MPa has been obtained for the specimen AAMgOCA 3 for heat-treated specimens. Similarly, the greatest ultimate tensile strength value for annealed condition can be achieved for the same specimen as 172.98 MPa which is very low.

The measured experimental results of shear strength for heat-treated specimens and annealed specimens were clearly mentioned as the three-dimensional surface plot in Figure 5. The highest and lowest shear strength for the annealed specimens were 109.12 MPa (AAMgOCA 3) and 103.87 MPa (AAMgOCA 1), respectively. Similarly, the greatest and smallest shear strength values for the heat-treated specimens were 265.85 MPa (AAMgOCA 3) and 253.04 MPa (AAMgOCA 1). Among these values, the lowest values of the heat-treated specimen were also higher than the highest shear strength value of the annealed specimens.

In Figure 6, the three-dimensional surface plot was plotted for the comparison on the flexural strength results from the experiments for heat-treated specimens comparison with the annealed specimens. The maximum and

TABLE 2: Experimental outcome of the specimens in annealed conditions.

Specimen name	Annealed specimens (MPa)			
	YS	UTS	SS	FS
AAMgOCA 1	91.2	164.645	103.87	78.455
AAMgOCA 2	93.48	168.761	106.466	80.416
AAMgOCA 3	95.817	172.98	109.128	82.426
AAMgOCA 4	94.619	170.817	107.764	81.396
AAMgOCA 5	93.436	168.682	106.417	80.378
AAMgOCA 6	92.268	166.574	105.087	79.374

TABLE 3: Experimental outcome of the specimens in heat-treated conditions.

Specimen name	Heat-treated specimens (MPa)			
	YS	UTS	SS	FS
AAMgOCA 1	395.59	430.95	253.045	130.39
AAMgOCA 2	405.479	441.723	259.371	133.649
AAMgOCA 3	415.616	452.766	265.855	136.99
AAMgOCA 4	410.421	447.107	262.532	135.278
AAMgOCA 5	405.291	441.518	259.250	133.587
AAMgOCA 6	400.225	435.999	256.009	131.917

minimum flexural strength for the heat-treated specimens were 136.99 MPa (AAMgOCA 3) and 130.89 MPa (AAMgOCA 1), respectively. Similarly, the supreme and least flexural strength values for the annealed specimens were 82.42 MPa (AAMgOCA 3) and 78.45 MPa (AAMgOCA 1). Among these values, the lowest flexural strength (136.99 MPa) of the heat-treated specimen was also higher than the highest flexural strength (82.42 MPa) of the annealed specimens.

The comparisons of the all experimental results based on the strength for the specimens in both heat-treated and annealed condition were clearly mentioned as a bar chart in Figure 7. These composites have the highest ultimate tensile strength and lower flexural strength among these strengths. The annealed specimens have the lower results when compared with heat-treated specimens for all specimens'

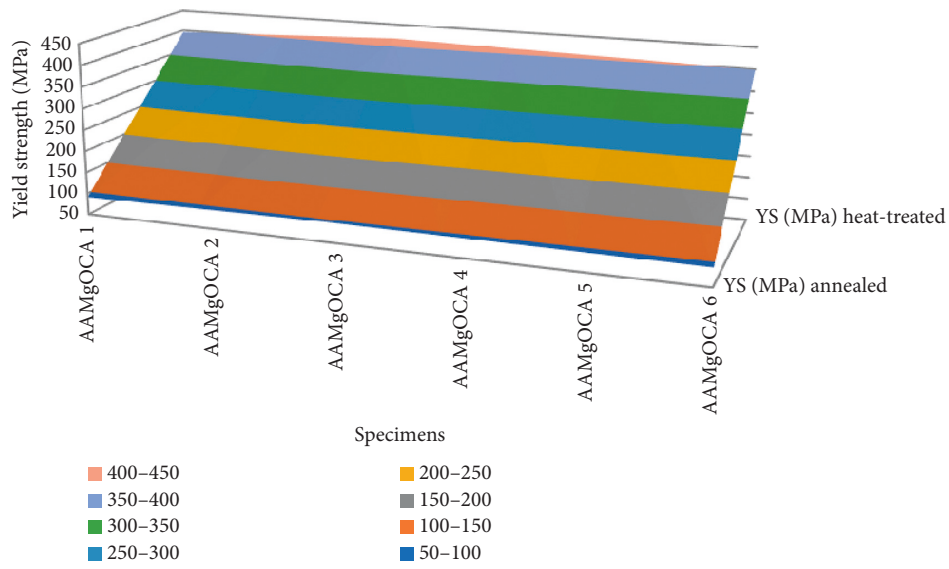


FIGURE 4: Three-dimensional surface plot comparison on yield strength.

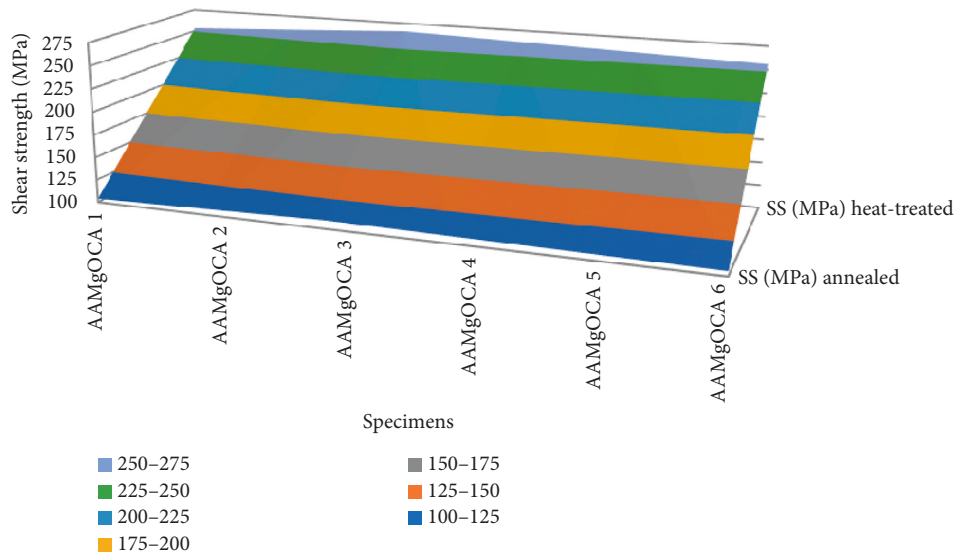


FIGURE 5: Three-dimensional surface plot comparison on shear strength.

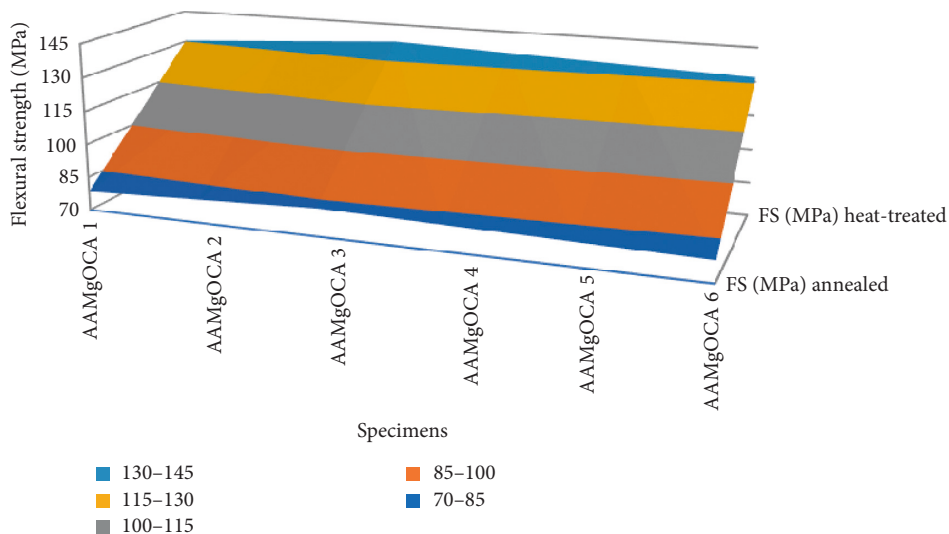


FIGURE 6: Three-dimensional surface plot comparison on flexural strength.

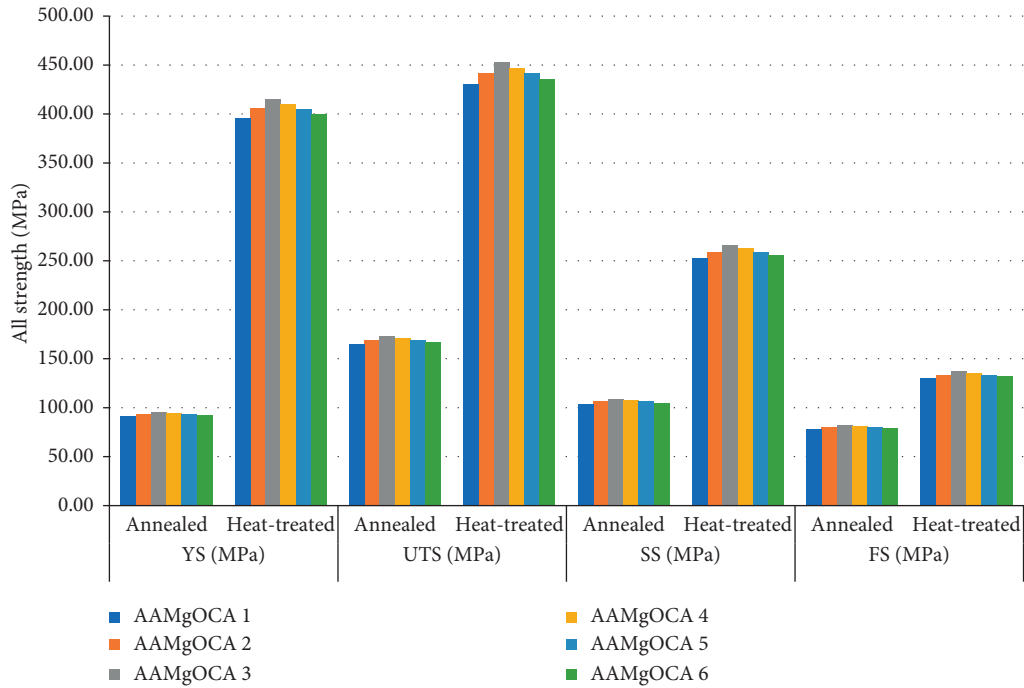


FIGURE 7: Comparison of all specimen results based on strength.

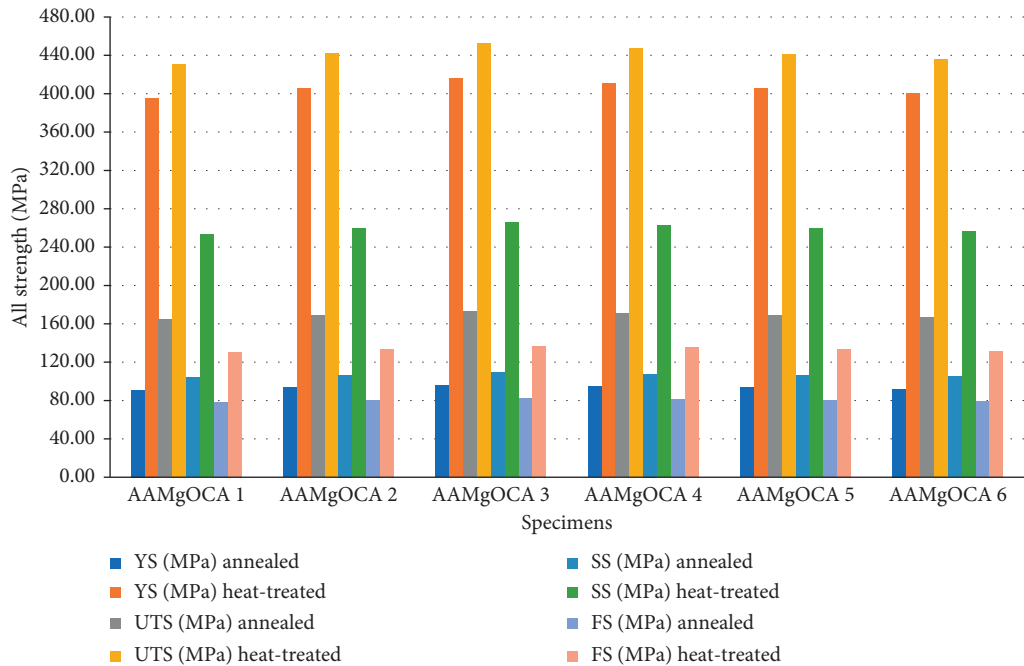


FIGURE 8: Comparison of all experimental results based on specimens.

yield strength (YS), ultimate tensile strength (UTS), shear strength (SS), and flexural strength (FS). The values of all strengths were increased up to the AAMgOCA 3, and then, the strengths were decreased up to AAMgOCA 6.

Similarly, Figure 8 gives the details of experimental results of all strengths for both heat-treated and annealed condition with respect to the individual specimens. Among these six specimens AAMgOCA 3 had the greatest results of

TABLE 4: Maximum experimental results.

Specimen name	YS (MPa)		UTS (MPa)		SS (MPa)		FS (MPa)	
	Annealed	Heat-treated	Annealed	Heat-treated	Annealed	Heat-treated	Annealed	Heat-treated
AAMgOCA 3	95.82	415.62	172.98	452.77	109.13	265.86	82.43	136.99

all strengths when compared with other specimens for both heat-treated and annealed condition. Similarly, AAMgOCA 1 specimen had the minimum values of all tested results in the investigation for both annealing and heat-treated condition. The maximum strength values are mentioned in Table 4 for specimen AAMgOCA 3.

4. Conclusion

The mechanical strength enhancement study on composite of AA6066 aluminium alloy with magnesium oxide and coal ash through various experimental results produced the following as conclusions:

- (i) The composite of the AA6066 aluminium alloy with magnesium oxide and coal ash with different combinations based on Table 1 is possible.
- (ii) In all the experimental results, annealed specimens have the lower results in strength value
- (iii) Similarly, for all the experimental results, heat-treated specimens have the higher results in strength value
- (iv) From the comparison, the specimen “AAMgOCA 3” has reached the highest experimental results for both conditions (Table 4)
- (v) The strength values get increased up to the specimen AAMgOCA 3, and then the results start to decrease simultaneously
- (vi) So, the coal ash participation less than MgO produced the good result when compared with the higher coal ash concentration specimens’ results
- (vii) Therefore minimizing the coal ash content and maximizing the MgO participations provide the greatest result in strength
- (viii) At last, 80% of AA6066 aluminium alloy with 12% of MgO and 8% of coal ash reached the maximum yield strength, ultimate tensile strength, shear strength, and flexural strength when compared with the remaining composite specimens

Data Availability

The data used to support the findings of this study are included in the article. Further data or information are available from the corresponding author upon request.

Disclosure

This work was performed as a part of the Employment of College of Engineering and Technology, Hawassa University, Hawassa, Ethiopia.

Conflicts of Interest

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

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