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Fabrication, Mechanical Characterization, and Ranking of Shell Ash Reinforced Al-7075-Based Hybrid Composites

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Abstract. In the research article, the fabrication of Al-7075-based hybrid composites was done by stir casting technique with the addition of a mixture of crab shell ash (CSA), oyster shell ash (OSA), and snail shell ash (SSA). The mixtures of CSA, OSA, and SSA (MCOSA), CSA and OSA (MCOA), CSA and SSA (MCSA), as well as OSA and SSA (MOSA) with weight percentages in a range of 1–3% were added to the base material. The specimens were prepared according to the ASTM standards and tested for mechanical properties. The hardness, as well as impact, flexural, and tensile strengths of the composites, were increased as the amount of reinforcement to the base metal was increased, and compressive strength was decreased. The greatest tensile strength, tensile modulus, and compressive strength values were observed for the composite designated with AlOSA3. The maximum flexural strength and hardness values were observed for the compositions AlOS21 and AlCO12, respectively. Two techniques (TOPSIS and VIKOR) were successfully applied to the mechanical attributes of composites. The ranking results of both methods were compared. The ranking results for TOPSIS and VIKOR were the same for the index value 0.25. The composites filled with aquatic waste fillers can be used for automotive applications concerning their enhanced mechanical properties compared to the Al-7075 metal alloy properties.

Keywords: hybrid composite, mechanical properties, TOPSIS, VIKOR, ranking.

1. Introduction

Industries are rapidly shifting toward composites because of their improved properties, lower cost, environmental friendliness, and lighter weight in comparison, growing their desirability to substitute the traditional ones [1]. The various composites/amalgams are prepared by adding the altered reinforcements of numerous features to the metals to overcome the constraints imposed by conservative materials with a greater weight and lower physical and mechanical properties.

Composites have superior mechanical properties compared to conventional materials [2, 3]. Recently, researchers applied “metal matrix composites” in various automotive and aircraft components manufacturing and aerospace fields, marine fittings, electrical fittings, connectors, hang glider airframes, and pipelines. They turned to Al-7075 metal matrix hybrid composites as they give a high strength-to-weight ratio (HSWR), high wear and corrosion resistance, improved electrical performance, stiffness, and reduced density.

The enhancement in the above properties is due to particulate reinforcement and zinc up to 6.1 % in Al-7075 alloy. Al-7075 alloy exhibits a tensile strength of 572 MPa, yield strength of 503 MPa, and elongation of 10 % to 11 % [4].

Al-based hybrid metal matrix composites (AHMMC) are present-generation composites reinforced with two or more particulate reinforcements, known as hybridization, for further enhancement of properties compared to conventional metal matrix composites. It also lowers the manufacturing cost of composites.

2. Literature Review

Many researchers realized the experimental works on synthetic fillers reinforced Al-7075-based composites, and they found that the increase in % wt. of fillers like Al_2O_3, SiC, Al_2O_3 and SiC, Gr, SiC and Gr, SiC and MoS_2, SiC and B_4C, B_4C and Gr, TiC, Si_3N_4, B_4C and CDA, TiB_2, and TiO_2 has enhanced the mechanical properties, wear and corrosion resistance [5–10].

The previous investigations of researchers [11–17] show that the filler content as reinforcement in Al-7075 alloy is below 5 % wt. and the mechanical properties were enhanced.

In some of the research findings, filler concentration of 5–15 % wt. is incorporated in Al-7075 composites, and the results for mechanical characteristics are in increasing order up to 10 % wt. [18–25].

Subramaniam et al. [26], Kumar et al. [27], Sambathkumar et al. [28], and Rajesh et al. [29] performed research activities on industrial wastes and agro-waste reinforced Al-7075-based hybrid composites, and they also found that the mechanical properties and wear resistance of the composites are enhanced. From these sources, it is observed that almost all the industrial wastes are used as reinforcements in combination with metal oxide, nitride, and carbide reinforcements to the Al-7075 matrix, and so many combinations of reinforcements can be added to the Al-7075 to enrich the individualities of the composites.

Yu [30] and Zeleny [31] proposed a compromise solution in MCDM. The core concepts of VIKOR were designed by Opricovic [32]. Applications of VIKOR and TOPSIS were shown in [33, 34].

Using agro wastes as reinforcement to Al-based alloys enhanced all characteristics compared to Al-based alloys, but very little research is carried out on aquatic animal wastes as reinforcement.

The research gaps presented in the earlier investigation are as follows. Firstly, the usage of agro wastes, animal wastes, and aquatic shell ashes in the form of fillers is less or not reported in previous investigations done on Al-7075-based composites.

Secondly, using these naturally available micro/nanofillers as reinforcements instead of synthetic fillers in Al-7075 alloy with chemical and heat treatment process can produce high-quality, low-cost composites with enhanced characteristics.

Also, MCDM techniques are rarely implemented for the best composite selection based on various attributes of various alternatives.

Moreover, additional research should be conducted to develop fabrication techniques to overcome the challenges of improving the interfacial bonding between Al-7075 alloy and microfillers.

Based on these gaps, the research objectives are as follows:

– selection and preparation of filler materials in the form of ashes from crab, oyster, and snail shells;

– fabrication of Al-7075-based composites reinforced with the prepared ashes;

– mechanical characterization of composites according to ASTM standards;

– implementation of TOPSIS and VIKOR ranking methods for the best suitable composite for a particular application based on attributes of composites.

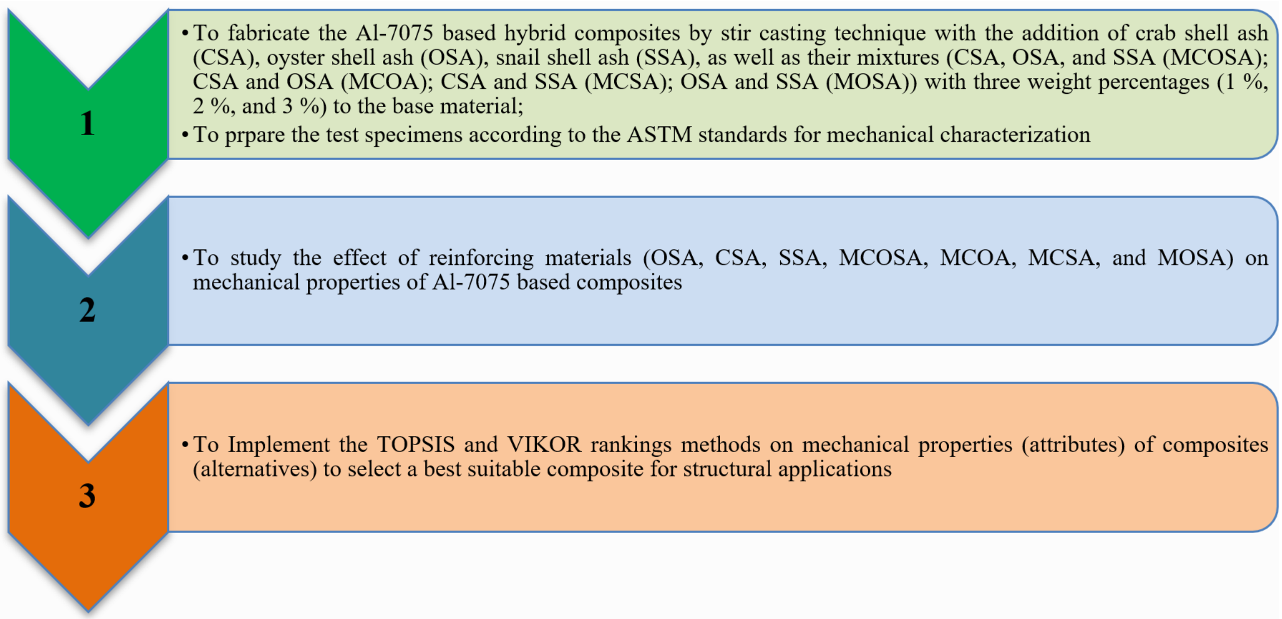

Figure 1 – The flowchart of the research methodology

Figure 1 represents the aims and objectives of the presented work. The first objective is selecting and preparing filler materials for Al-7075-based metal matrix composites. The selected filler materials are crab shell ash (CSA), oyster shell ash (OSA), snail shell ash (SSA), and their mixtures, and then fabrication of Al-7075-based composites filled with the above fillers as per the designated compositions by stir casting method and preparation of samples according to ASTM standards.

The second objective of the work is to find the mechanical characteristics and to study the effect of reinforcements on the mechanical properties of the composites.

The third objective of the work is ranking composites concerning their attributes by TOPSIS and VIKOR ranking methods and their comparative analysis.

3. Research Methodology

3.1. Materials selection

In the present research work, aluminium alloy Al-7075 is considered base matrix material due to its extensive usage in various fields of manufacturing sectors, together with aerospace and automotive fields for structural and bearing applications. Moreover, these Al-7075 metal matrix alloys exhibit good fatigue and tensile strength as steel, desirable thermal conductivity, formability, and machinability. The desired properties of Al-7075 alloy can be achieved through a heat treatment. From the spectrum analysis, the chemical composition of Al-7075 in percentages of elements is observed as follows: Al 87.27–89.97 %, Zn 5.1–6.1 %, Mg 2.1–2.9 %, Cu 1.2–2.0 %, Fe 0.5 %, Si 0.4 %, Mn 0.3 %, Cr 0.18–0.28 %, Ti 0.2 %, and others 0.05 %.

The reinforcements used in this work are CSA, OSA, SSA, and their mixtures: CSA, OSA, and SSA (MCOSA); CSA and OSA (MCOA); CSA and SSA (MCSA); OSA and SSA (MOSA).

The reasons for selecting these fillers are as follows:

– the abundant availability of crab, oyster, and snail shells in coastal as waste material after utilization of crab/oyster/snail products;

– from the previous studies, it is observed that the reinforcement can enhance the hardness, strength, and thermal conductivity of the matrix material, and the addition of the above fillers as reinforcement to the Al-7075 matrix can enhance the wear resistance too, apart from the enhancement of mechanical characteristics;

– using these fillers on a large scale can reduce the disposal problem and manufacturing cost of the Al-7075-based hybrid composites.

The shells are collected and cleaned in hot water to remove the remaining pieces. They are dried to remove moisture. After moisture removal, these shells are crushed into small pieces and burnt in a metal or ceramic container in the open air to produce the ash. The produced ash is collected and heated in a muffle furnace for two hours at 6000 °C to remove the carbon materials present in shell ashes, and then these particles were screened in a sieving machine with a size of 40–60 μm.

3.2. Experimentation methods

So many processing techniques are available, like powder metallurgy, liquid infiltration, diffusion bonding, squeeze casting, laser composite surfacing, and stir casting. The Al-7075-based composites with reinforcement are prepared by the stir casting method, as shown in Figure 2.

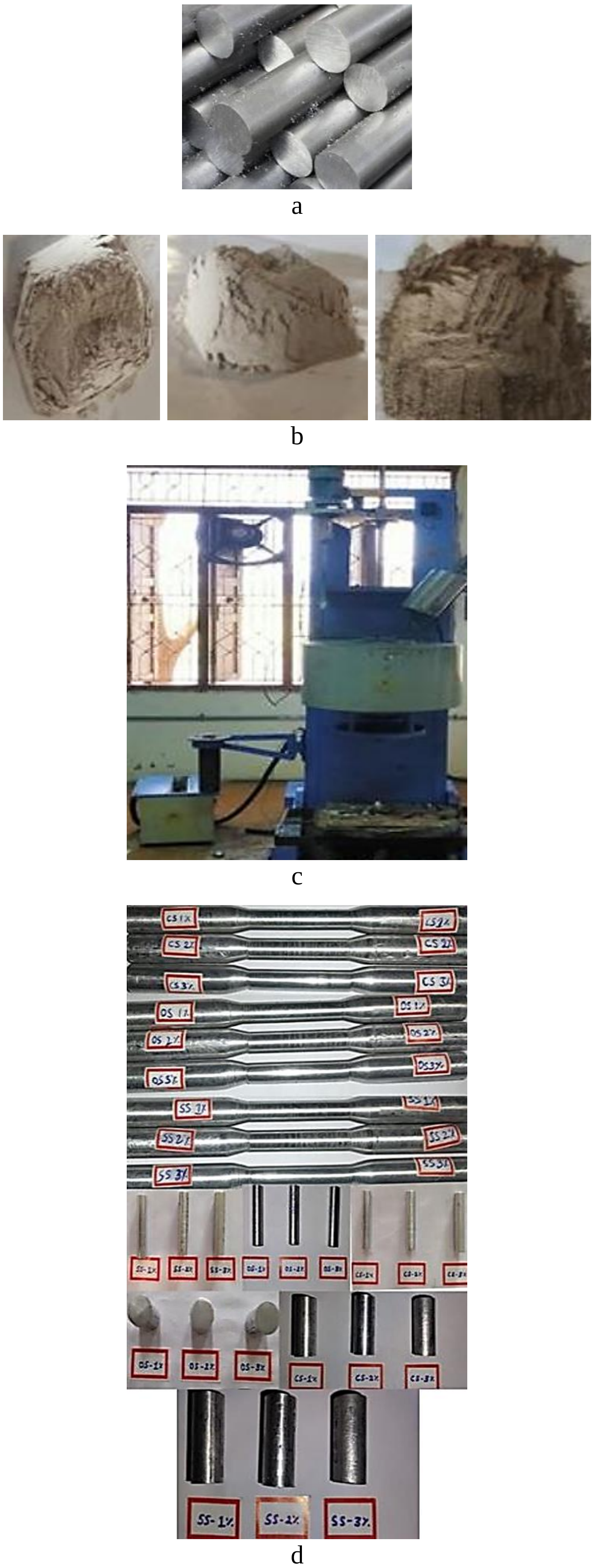

Figure 2 – Al-7075 based composites: a – Al-7075 pieces; b – reinforcements (left – OSA, center – SSA, right – CSA); c – stir casting setup; d – specimens prepared according to the ASTM standards

This is one of the most economical and advanced methods of fabrication. The systematic procedure of stir casting is as follows [4]:

1) Al-7075 alloy is melted above its melting temperature in a graphite crucible;

2) preheated reinforcing materials are added/mixed to Al-7075 alloy when its temperature reduces to semi-solid temperature;

3) reheating the mixture with continuous stirring to attain the refined microstructure and uniform distribution of reinforcement particulates throughout the matrix material. The parameters to be considered for mixing the matrix and reinforcement to refine the microstructure are the relative density of materials, geometry of the stirrer, temperature of melting, and solidification rate;

4) molten metal is poured into suitable dies to prepare the specimens according to ASTM standards:

– tensile test: ASTM B 557:2006 (length – 60 mm, diameter – 12 mm, span – 145 mm with 20 mm diameter);

– flexural/bending test: ASTM E-290 (60×10×10 mm);

– compressive test: ASTM E9-09 (10×10×30 mm);

– impact test: ASTM E23-02a (55×10×10 mm);

–Vickers microhardness (Hv) test: ASTM E92 (10×10×25 mm);

5) Testing of samples under experimental setups (Universal testing machine, Vickers microhardness tester, Charphy impact testing machine) for mechanical characterization like tensile strength (TS), tensile modulus (TM), flexural strength (FS), compressive strength (CS), impact strength (IS), and Vickers microhardness (Hv).

3.3. Application of TOPSIS and VIKOR

Multi-criteria decision-making (MCDM) is a subset of operational research that compares, ranks, and selects numerous alternatives for multiple and conflicting criteria. Decision-makers employed numerous MCDM methodologies to select one alternative among several decision-making models that suited their goals, objectives, desires, and values. Two popular MCDM methods are TOPSIS and VIKOR. Both are based on an aggregating function representing proximity to the optimal solution. To turn all criteria into a homogenous range, vector normalization, and linear scale normalization are used in TOPSIS and VIKOR. The VIKOR technique is a compromise strategy that seeks to maximize collective value while minimizing individual regret.

All mechanical properties are considered as attributes framed in a matrix form. Decision matrix, and then normalized matrix and weighted normalized matrices are formed. Positive ideal solution, Negative ideal solution, separation measures, and relative closeness to ideal solution were found based on which TOPSIS ranking is given to all the alternatives.

An alternative is selected based on its shortest distance from the positive ideal solution and longest distance from the negative ideal solution.

4. Results

4.1. Mechanical characteristics

This part of the article reports the experimental results of mechanical characteristics/properties of Al-7075-based hybrid composites filled with different shell ashes as fillers. The filler materials' comparative effects on the composites' mechanical characteristics have been discussed. Adding shell ash filler materials or particulate fillers significantly and robustly influences the physical and mechanical characteristics of Al-7075-based composites.

As indicated in the materials and methods section, Figure 3 depicts a bar graph for the composite vs. tensile strength type of the various Al-7075-based composites filled with the various reinforcements.

The tensile strength (TS) of the Al-7075 alloy is 542 MPa, and the tensile strength of Al-7075-based composites reinforced with CSA and OSA has increased from 546 MPa to 564 MPa and 552 MPa to 602 MPa, respectively, with an increase in reinforcement weight percentage from 0 to 3 % wt. Including SSA reinforcement from 1 % to 3 % in the Al-7075 matrix lowered the composite's tensile strength from 516 MPa to 496 MPa.

Furthermore, the maximum tensile strength of the AlOSA3 composite is 602 MPa, whereas the lowest tensile strength of the AlSSA3 composite is 496 MPa. The tensile strength of the Al-7075-based composite reinforced with MCOSA, MCOA, MCSA, and MOSA was higher than that of the composite AlSSA3. The loss or drop in tensile strength may be caused by stress concentration in the matrix because of irregularly formed particle corners and the existence of pores between the matrix and reinforcement, resulting in poor adhesive bonding between them.

Figure 4 depicts the tensile modulus (TM) of all Al-7075-based hybrid composites.

It was discovered that the filler concentration had a similar influence on tensile modulus as it did on tensile strength. The maximum and minimum tensile modulus of the composites AlOSA3 and AlSSA3 are 77 GPa and 61 GPa, respectively, whereas the tensile modulus of the un-reinforced Al-7075 alloy was 69 GPa. The most significant tensile modulus might be attributed to relative strain rates during the tension test.

Compared with Al-7075 alloy, the composites filled with SSA at 1, 2, and 3 % wt. had the lowest tensile modulus values of 66, 64, and 61 GPa, respectively. Following the composite AlOSA3, the composites with maximum tensile modulus of 76, 75, 74, and 73.5 GPa are AlCO1, AlCO12/AlCOS111, AlCO21, and AlOS21. CSA, OSA, and SSA mixtures (MCOA, MCSA, and MOSA) were reinforced at 0–3 % wt.

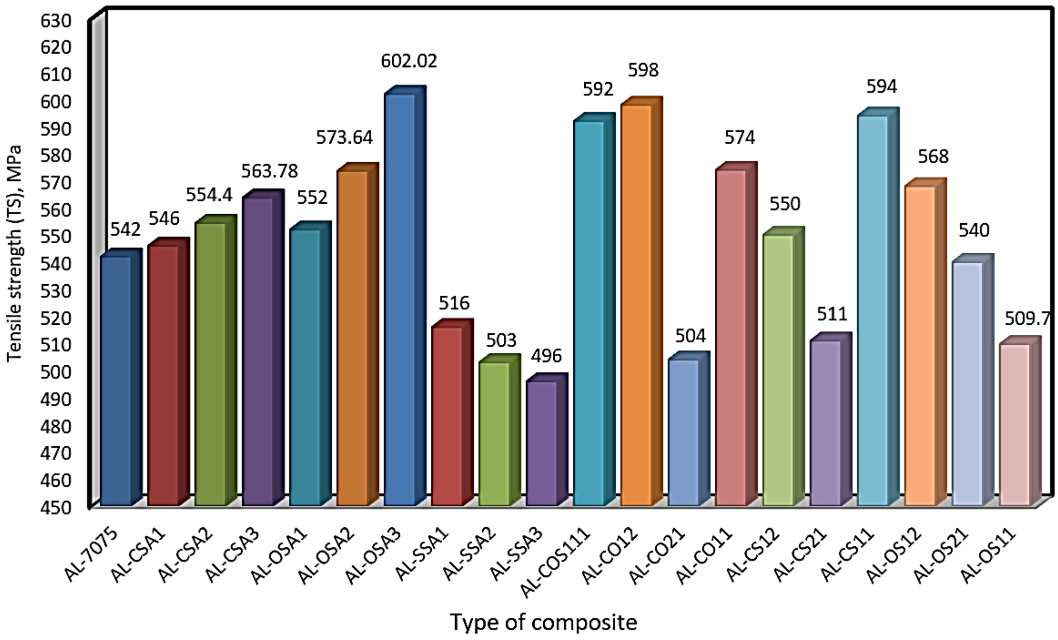

Figure 3 – Type of composites vs. tensile strength, MPa

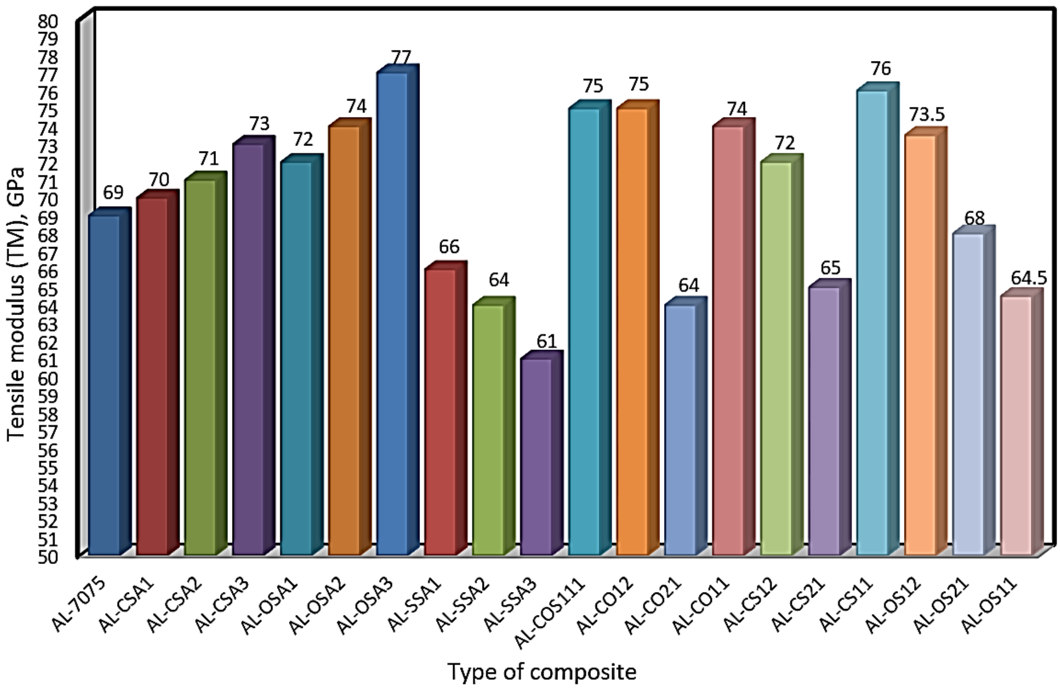

Figure 4 – Type of composites vs. tensile modulus, GPa

As demonstrated in Figure 5, the compressive strength of Al-7075-based composites ranges from 150 MPa to 838 MPa. The compressive strength of Al-7075 alloy is 426 MPa, and as the addition of CSA/SSA increases, the compressive strength of the composites decreases, whereas the compressive strength of composites filled with OSA increases as the OSA particulates increase.

The compressive strength graph indicated that a mixture of two or three fillers as reinforcement produced higher compressive strength results than CSA, OSA, or SSA. The composite's compressive strength may have increased because of its high hardness and low void content. The compressive strength of the composite diminishes as the void content increases. The highest compressive strengths of AlOSA3 and AlCO12 composites are 838 MPa and 832 MPa, respectively, whereas the lowest compressive strength of AlSSA3 composite is 150 MPa.

According to Figure 6, the composite occupied with OSA and SSA at 2 and 1 % wt., correspondingly, has the highest FS of 612 MPa and the lowest FS of 452 MPa.

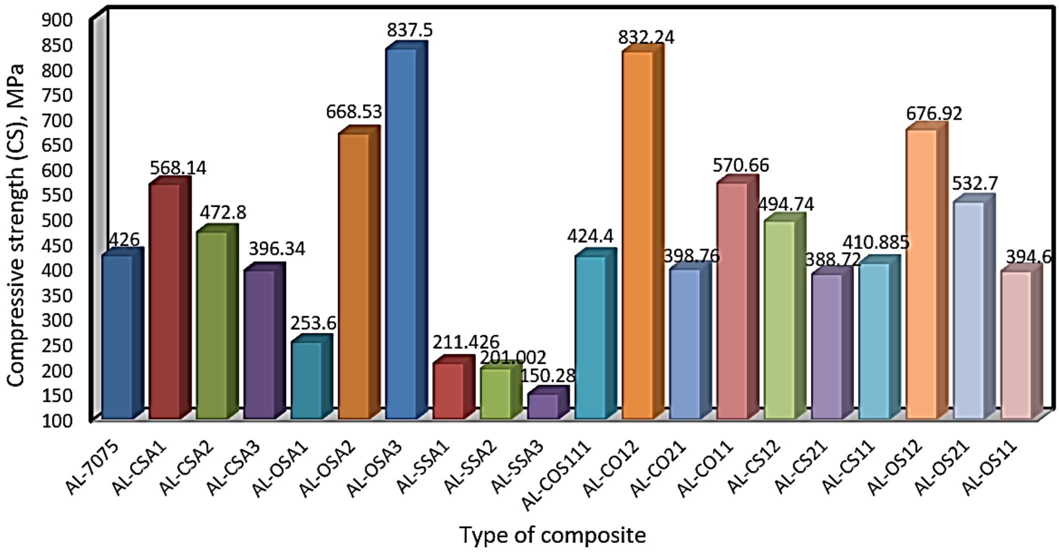

Figure 5 – Type of composites vs. compressive strength, MPa

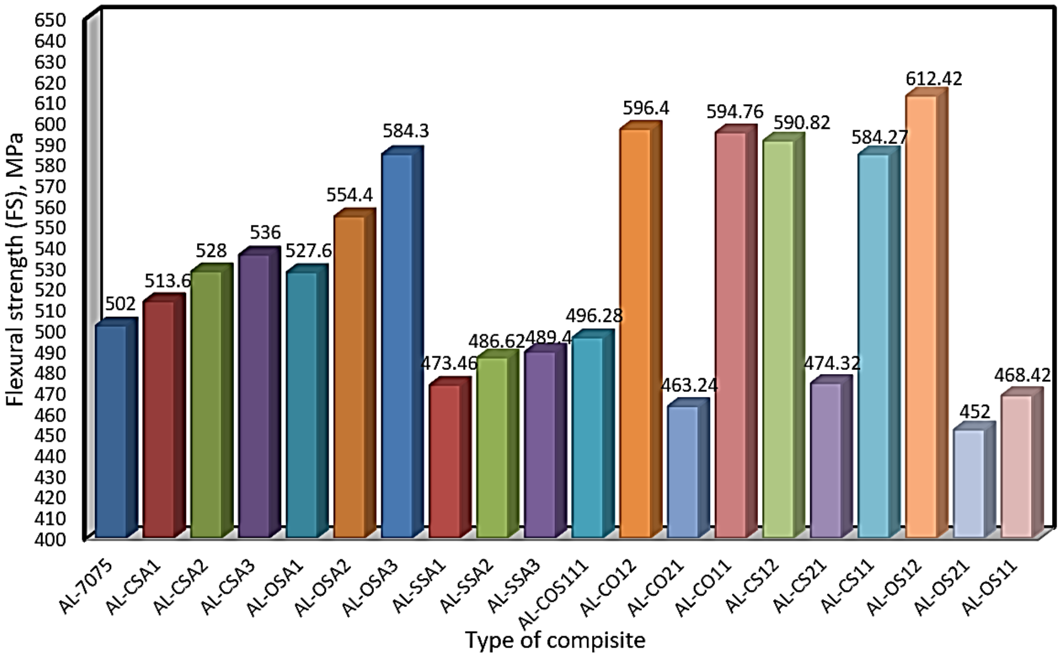

Figure 6 – Type of composites vs. flexural strength, MPa

Flexural strength increases up to 3 % wt. of the reinforcements as the weighting fraction of fillers CSA/OSA/SSA increases. The increase in FS might be attributed to robust matrix-reinforcement adhesion and uniform reinforcement distribution. Except for the composites AlCS11, AlOS11, AlCS12, and AlCOS111, the composites filled with a combination of two fillers outperformed the unreinforced Al-7075 alloy and reinforced with a single reinforcement. Because of variable particle shapes, sizes, and non-uniform temperature distribution, pores may exist between the matrix and reinforcing materials. It is recommended that the hybrid composite be filled with OSA and SSA at 2% and 1% wt. %'s can be used for structural purposes.

Figure 7 illustrates the effect of various reinforcements on the impact strength of Al-7075 composites. After comparing with pure Al-7075 metal alloy, composites reinforced with CSA and OSA demonstrated higher impact strength values. The impact strength values of composites reinforced with SSA have decreased with increasing amounts. This might be attributed to increased porosity and cluster formation in composites, as shown in the microstructure of the composites.

Except for the composites AlCS12, AlOS12, and AlOS11, the impact strengths of Al-7075 composites are increased by the hybridization effect when reinforced with the two fillers. The most significant and minimum impact strengths of the composites AlCO12 and AlSSA3 were 23.0 J and 9.6 J, respectively. The restriction of displacement movement by hard reinforcing particles is responsible for the improvement in IS of the Al-7075 hybrid composites.

From Figure 8, the composite AlCO12 has a peak Hv value of 202, whereas AlSSA1 has a lower Hv value of 170.

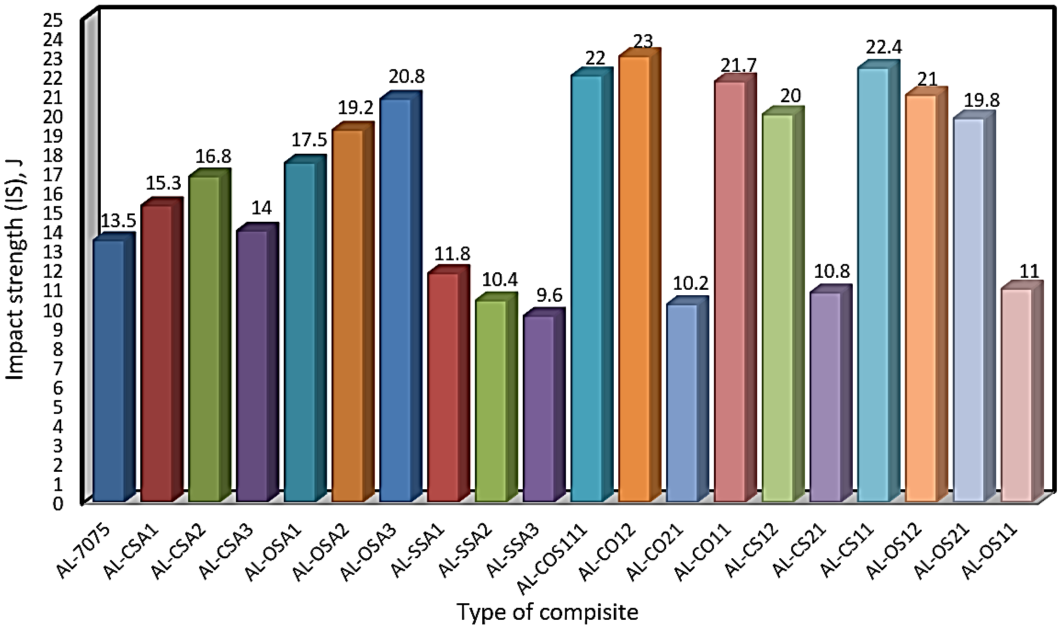

Figure 7 – Type of composites vs. impact strength, J

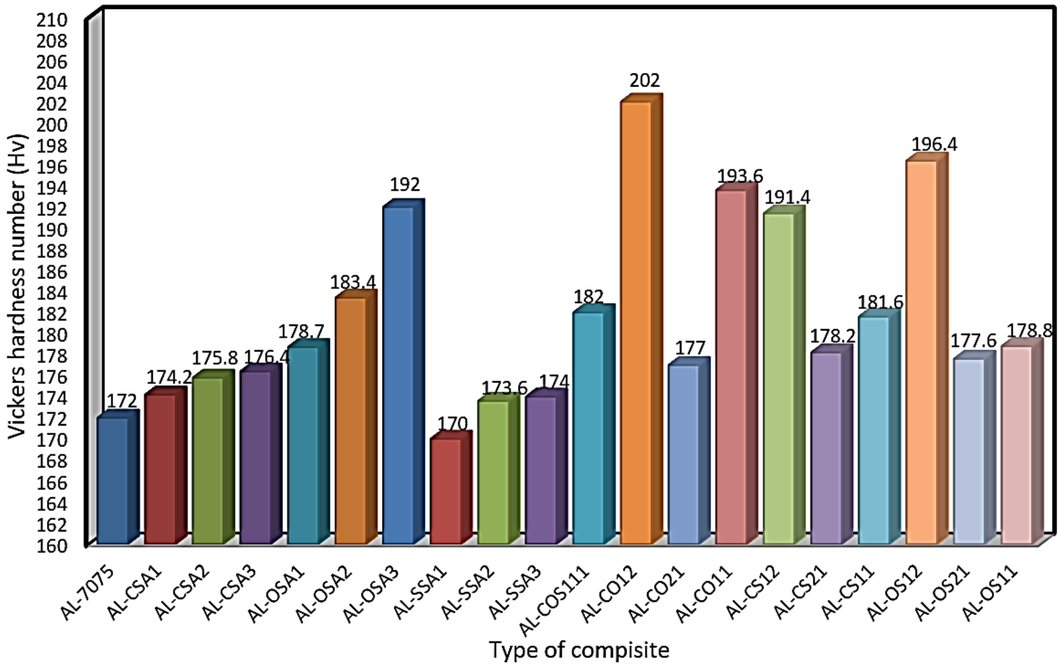

Figure 8 – Type of composites vs. Vickers microhardness, Hv

The rising trend of hardness value is noticed up to 3% wt. by increasing the weight fraction of reinforcements CSA/OSA/SSA.

This is because including reinforcing particles in the Al-7075 matrix increases the surface area of reinforcement, resulting in more significant resistance to plastic deformation and an increase in composite hardness. The presence of pores and spaces may reduce the hardness of the composites. Compared to single particle filler reinforced composites, the composites AlCO12, AlOS21, and AlCO21 reinforced with two fillers performed well.

4.2. Implementation of TOPSIS and VIKOR ranking procedures

TOPSIS and VIKOR ranking methods are implemented to the composites considered as alternatives and their characteristics as attributes.

The results are tabulated in Tables 1–10 according to the following step-by-step process:

1) step 1 – preparation of decision matrix for mechanical properties (Table 1);

2) step 2 – calculation for normalized decision matrix (Table 2);

3) step 3 – calculation for variance of different attributes (Table 3);

4) step 4 – calculations for weights of different attributes (Table 4);

5) step 5 – calculation for weighted normalized matrix (Table 5);

6) step 6 – finding of best and worst ideal solutions (Table 6);

7) step 7 – finding the separation measures, relative closeness, and ranking (Table 7);

8) step 8 – utility measures calculation for the VIKOR method by utilizing normalized matrix values and weight fraction values in the TOPSIS ranking process (Table 8);

9) step 9 – calculation of the sum of utility measures (Si) and regret measures (Ri) along with their indices and rankings (Table 9);

10) step 10 – calculation of Qi (sum of Qsi and Qri) at index values of v = 0.25, 0.50, and 0.75, along with their ranking (Table 10).

Table 1 – Decision matrix

Composite designation	TS	TM	CS	FS	IS	Hv
Al-7075	542	69	426.00	502.0	13.5	172.0
Al-CSA1	546	70	568.14	513.6	15.3	174.2
Al-CSA2	554	71	472.80	528.0	16.8	175.8
Al-CSA3	564	73	396.34	536.0	14.0	176.4
Al-OSA1	552	72	253.60	527.6	17.5	178.7
Al-OSA2	574	74	668.53	554.4	19.2	183.4
Al-OSA3	602	77	837.50	584.3	20.8	192.0
Al-SSA1	516	66	211.43	473.5	11.8	170.0
Al-SSA2	503	64	201.00	486.6	10.4	173.6
Al-SSA3	496	61	150.28	489.4	9.60	174.0
Al-COS111	592	75	424.40	496.3	22.0	182.0
Al-CO12	598	75	832.24	596.4	23.0	202.0
Al-CO21	504	64	398.76	463.2	10.2	177.0
Al-CO11	574	74	570.66	594.8	21.7	193.6
Al-CS12	550	72	494.74	590.8	20.0	191.4
Al-CS21	511	65	388.72	474.3	10.8	178.2
Al-CS11	594	76	410.89	584.4	22.4	181.6
Al-OS12	568	74	676.92	612.4	21.0	196.4
Al-OS21	540	68	532.70	452.0	19.8	177.6
Al-OS11	510	65	394.60	468.4	11.0	178.8
TOTAL	10 990	1404	9310.2	10 528	330.8	3628

Table 2 – Normalized decision matrix

Composite designation	TS	TM	CS	FS	IS	Hv
Al-7075	0.049	0.049	0.046	0.048	0.041	0.047
Al-CSA1	0.050	0.050	0.061	0.049	0.046	0.048
Al-CSA2	0.050	0.051	0.051	0.050	0.051	0.048
Al-CSA3	0.051	0.052	0.043	0.051	0.042	0.049
Al-OSA1	0.050	0.051	0.027	0.050	0.053	0.049
Al-OSA2	0.052	0.053	0.072	0.053	0.058	0.051
Al-OSA3	0.055	0.055	0.090	0.055	0.063	0.053
Al-SSA1	0.047	0.047	0.023	0.045	0.036	0.047
Al-SSA2	0.046	0.046	0.022	0.046	0.031	0.048
Al-SSA3	0.045	0.043	0.016	0.046	0.029	0.048
Al-COS111	0.054	0.053	0.046	0.047	0.067	0.050
Al-CO12	0.054	0.053	0.089	0.057	0.070	0.056
Al-CO21	0.046	0.046	0.043	0.044	0.031	0.049
Al-CO11	0.052	0.053	0.061	0.056	0.066	0.053
Al-CS12	0.050	0.051	0.053	0.056	0.060	0.053
Al-CS21	0.046	0.046	0.042	0.045	0.033	0.049
Al-CS11	0.054	0.054	0.044	0.055	0.068	0.050
Al-OS12	0.052	0.052	0.073	0.058	0.063	0.054
Al-OS21	0.049	0.048	0.057	0.043	0.060	0.049
Al-OS11	0.046	0.046	0.042	0.044	0.033	0.049
TOTAL	0.050	0.050	0.050	0.050	0.050	0.050

Table 3 – Variance of attributes

TS	TM	CS	FS	IS	Hv
0.0000005	0.0000007	0.0000180	0.0000054	0.0000845	0.0000068
0.0000001	0.0000000	0.0001215	0.0000015	0.0000141	0.0000040
0.0000002	0.0000003	0.0000006	0.0000000	0.0000006	0.0000024
0.0000017	0.0000040	0.0000552	0.0000008	0.0000590	0.0000019
0.0000001	0.0000016	0.0005181	0.0000000	0.0000084	0.0000006
0.0000048	0.0000073	0.0004755	0.0000071	0.0000647	0.0000003
0.0000229	0.0000235	0.0015964	0.0000302	0.0001658	0.0000085
0.0000093	0.0000089	0.0007448	0.0000253	0.0002053	0.0000099
0.0000179	0.0000195	0.0008072	0.0000143	0.0003445	0.0000047
0.0000237	0.0000429	0.0011464	0.0000124	0.0004401	0.0000042
0.0000150	0.0000117	0.0000195	0.0000082	0.0002724	0.0000000
0.0000195	0.0000117	0.0015515	0.0000442	0.0003814	0.0000321
0.0000171	0.0000195	0.0000514	0.0000360	0.0003673	0.0000015
0.0000050	0.0000073	0.0001275	0.0000421	0.0002433	0.0000112
0.0000000	0.0000016	0.0000099	0.0000374	0.0001094	0.0000075
0.0000123	0.0000137	0.0000680	0.0000245	0.0003011	0.0000008
0.0000164	0.0000171	0.0000344	0.0000302	0.0003138	0.0000000
0.0000028	0.0000055	0.0005156	0.0000667	0.0001818	0.0000170
0.0000007	0.0000025	0.0000521	0.0000500	0.0000971	0.0000011
0.0000131	0.0000165	0.0000580	0.0000303	0.0002805	0.0000005
0.0000091	0.0000108	0.0003986	0.0000233	0.0001968	0.0000058

Table 4 – Weight fraction

TS	TM	CS	FS	IS	Hv	Total
0.01419860	0.0167573	0.6185649	0.036207	0.3053424	0.0089287	1.0000000

Table 5 – Weighted normalized matrix

TS	TM	CS	FS	IS	Hv
0.0007003	0.0008235	0.0283031	0.0017264	0.0124611	0.0004232
0.0007054	0.0008355	0.0377468	0.0017663	0.0141226	0.0004286
0.0007163	0.0008474	0.0314124	0.0018158	0.0155071	0.0004326
0.0007284	0.0008713	0.0263325	0.0018434	0.0129226	0.0004340
0.0007132	0.0008594	0.0168490	0.0018145	0.0161532	0.0004397
0.0007411	0.0008832	0.0444166	0.0019066	0.0177224	0.0004513
0.0007778	0.0009190	0.0556428	0.0020095	0.0191993	0.0004724
0.0006667	0.0007877	0.0140470	0.0016283	0.0108919	0.0004183
0.0006499	0.0007639	0.0133544	0.0016735	0.0095996	0.0004272
0.0006408	0.0007281	0.0099845	0.0016831	0.0088612	0.0004281
0.0007649	0.0008952	0.0281968	0.0017068	0.0203069	0.0004478
0.0007726	0.0008952	0.0552934	0.0020511	0.0212300	0.0004970
0.0006512	0.0007639	0.0264933	0.0015931	0.0094150	0.0004355
0.0007416	0.0008832	0.0379142	0.0020454	0.0200300	0.0004764
0.0007106	0.0008594	0.0328701	0.0020319	0.0184609	0.0004710
0.0006602	0.0007758	0.0258262	0.0016312	0.0099689	0.0004385
0.0007675	0.0009071	0.0272989	0.0020094	0.0206762	0.0004468
0.0007339	0.0008773	0.0449740	0.0021062	0.0193839	0.0004833
0.0006977	0.0008116	0.0353922	0.0015545	0.0182762	0.0004370
0.0006585	0.0007698	0.0262169	0.0016109	0.0101535	0.0004400

Table 6 – Best and worst ideal solutions

Ideal solutions	TS	TM	FS	ILSS	IS	HV
PIS	0.0007778	0.0009190	0.0556428	0.0021061	0.0212299	0.000497
NIS	0.000640	0.000728	0.009984	0.001554	0.008861	0.000418

Table 7 – Separation measures, relative closeness, and ranking

Composite designation	Separation measures of attributes		Relative closeness	Ranking
	S*	S-	C*	R
Al-7075	0.02871444060545	0.01867010616524	0.394012551298	12
Al-CSA1	0.01925920266757	0.02825750490356	0.594685666326	6
Al-CSA2	0.02489898524891	0.02243689613111	0.473993416347	9
Al-CSA3	0.03046612537776	0.01684828570656	0.356092051458	13
Al-OSA1	0.03912584243711	0.01001926353571	0.203871033288	17
Al-OSA2	0.01176332263984	0.03555629949146	0.751407088434	4
Al-OSA3	0.00203314401912	0.04681693027363	0.958379919610	2
Al-SSA1	0.04286437486899	0.00454282103562	0.095825558735	18
Al-SSA2	0.04386122334310	0.00345214732516	0.072963462049	19
Al-SSA3	0.04730654717070	0.00012899815163	0.002719440680	20
Al-COS111	0.02746450801591	0.02151186436698	0.439229434937	10
Al-CO12	0.00035462874960	0.04696997141732	0.992506460734	1
Al-CO21	0.03145783079589	0.01651819292320	0.344300999598	14
Al-CO11	0.01776938473023	0.03008470658460	0.628675746587	5
Al-CS12	0.02294075071961	0.02482254215704	0.519699138440	8
Al-CS21	0.03187639475810	0.01588071818465	0.332530951016	16
Al-CS11	0.02834957885045	0.02096751464806	0.425157144524	11
Al-OS12	0.01082752492019	0.03654222116486	0.771425312250	3
Al-OS21	0.02047290688565	0.02709618718505	0.569617473580	7
Al-OS11	0.03144612322892	0.01628395511282	0.341167575637	15

Table 8 – Utility measure

TS	TM	CS	FS	IS	Hv
0.00804	0.008379	0.370390	0.024923	0.216474	0.008929
0.00750	0.007331	0.242450	0.022304	0.175458	0.008274
0.00638	0.006284	0.328266	0.019054	0.141278	0.007798
0.00512	0.004189	0.397087	0.017248	0.205081	0.007619
0.00670	0.005237	0.525567	0.019144	0.125327	0.006935
0.00380	0.003142	0.152089	0.013095	0.086590	0.005536
0.00000	0.000000	0.000000	0.006347	0.050131	0.002976
0.01152	0.011521	0.563528	0.031364	0.255212	0.009524
0.01326	0.013615	0.572910	0.028394	0.287113	0.008453
0.01420	0.016757	0.618565	0.027766	0.305342	0.008333
0.00134	0.002095	0.371830	0.026214	0.022787	0.005952
0.00054	0.002095	0.004735	0.003616	0.000000	0.000000
0.01313	0.013615	0.394909	0.033671	0.291670	0.007441
0.00375	0.003142	0.240182	0.003986	0.029623	0.002500
0.00697	0.005237	0.308517	0.004875	0.068360	0.003155
0.01219	0.012568	0.403946	0.031170	0.277998	0.007083
0.00107	0.001047	0.383995	0.006354	0.013672	0.006072
0.00456	0.003666	0.144538	0.000000	0.045574	0.001667
0.00831	0.009426	0.274350	0.036208	0.072918	0.007262
0.01236	0.013092	0.398653	0.032502	0.273441	0.006905

Table 9 – Sum of utility measures (Si) and regret measures (Ri) along with their indices and their rankings

Si	VIKOR index Qsi	Ranking at Qsi	Regret measure Ri	VIKOR index Qri	Ranking at Qri
0.637132	0.6389	13	0.370390	0.5957	10
0.463320	0.4616	10	0.242450	0.3873	6
0.509057	0.5082	11	0.328266	0.5271	9
0.636346	0.6381	12	0.397087	0.6392	14
0.688909	0.6918	14	0.525567	0.8485	17
0.264253	0.2584	4	0.152089	0.2401	4
0.059454	0.0495	2	0.050131	0.0740	2
0.882668	0.8895	18	0.563528	0.9103	18
0.923746	0.9314	19	0.572910	0.9256	19
0.990963	1.0000	20	0.618565	1.0000	20
0.430220	0.4278	9	0.371830	0.5980	11
0.010983	0.0000	1	0.004735	0.0000	1

Si	VIKOR index Qsi	Ranking at Qsi	Regret measure Ri	VIKOR index Qri	Ranking at Qri
0.754433	0.7586	17	0.394909	0.6356	13
0.283185	0.2778	5	0.240182	0.3836	5
0.397111	0.3940	6	0.308517	0.4949	8
0.744955	0.7490	16	0.403946	0.6504	16
0.412214	0.4094	8	0.383995	0.6179	12
0.200000	0.1929	3	0.144538	0.2278	3
0.408469	0.4056	7	0.274350	0.4392	7
0.736956	0.7408	15	0.398653	0.6417	15

Table 10 – VIKOR indices and rankings at various indexes *v*

$v = 0.25$		$v = 0.50$		$v = 0.75$	
Qi	Ranking	Qi	Ranking	Qi	Ranking
0.6065	12	0.6173	12	0.6281	12
0.4058	6	0.4244	7	0.4430	8
0.5224	9	0.5177	11	0.5130	11
0.6389	13	0.6387	13	0.6384	13
0.8093	17	0.7701	17	0.7310	17
0.2447	4	0.2493	4	0.2538	4
0.0678	2	0.0617	2	0.0556	2
0.9051	18	0.8999	18	0.8947	18
0.9271	19	0.9285	19	0.9300	19
1.0000	20	1.0000	20	1.0000	20
0.5555	10	0.5129	9	0.4704	10
0.0000	1	0.0000	1	0.0000	1
0.6664	14	0.6971	15	0.7279	16
0.3571	5	0.3307	5	0.3042	5
0.4697	8	0.4445	8	0.4192	7
0.6750	16	0.6997	16	0.7243	15
0.5658	11	0.5136	10	0.4615	9
0.2190	3	0.2103	3	0.2016	3
0.4308	7	0.4224	6	0.4140	6
0.6665	15	0.6913	14	0.7160	14

TOPSIS and VIKOR ranking methods are successfully implemented for the composites. Ranking results are incorporated in the Tables 7, 9, and 10.

The comparative analysis of the TOPSIS and VIKOR rankings shows that the results are the same for both techniques, and it happened at VIKOR's index $v = 0.25$. The best composite from the results is Al-CO12.

5. Discussion

The stir casting technique can be applied to fabricate Al-7075-based hybrid composites successfully.

The addition/accumulation of strengthening elements (CSA, OSA, and SSA) and their mixtures (MCOSA, MCOA, MCSA, and MOSA) as reinforcements to the Al-7075-based alloys allow for enhancing their mechanical properties.

The tensile strength (TS) of the Al-7075 alloy is 542 MPa, and the tensile strength of Al-7075-based composites reinforced with CSA and OSA has increased from 546 MPa to 564 MPa and from 552 MPa to 602 MPa, respectively, with an increase in reinforcement weight percentage from 0 to 3 % wt. Furthermore, the maximum tensile strength of the AlOSA3 composite is 602 MPa, whereas the lowest tensile strength of the AlSSA3 composite is 496 MPa.

The tensile strength of the Al-7075-based composite reinforced with MCOSA, MCOA, MCSA, or MOSA is higher than that of the composite AlSSA3.

The maximum and minimum tensile modulus of the composites AlOSA3 and AlSSA3 are 77 GPa and 61 GPa, respectively, whereas the tensile modulus of the un-reinforced Al-7075 alloy is 69 GPa.

The highest compressive strengths of AlOSA3 and AlCO12 composites are 838 MPa and 832 MPa, respectively, whereas the lowest compressive strength of AlSSA3 composite is 150 MPa.

The composite occupied with OSA and SSA at 2 and 1 % wt. has the highest and lowest flexural strengths of 612 MPa and 452 MPa, correspondingly.

The most significant and minimum impact strengths of the composites AlCO12 and AlSSA3 were 23.0 J and 9.6 J, respectively.

The composite AlCO12 has a peak Vickers microhardness value of 202, whereas AlSSA1 has a lower value of 170.

6. Conclusion

The key findings of this research article are as follows. Firstly, using these aquatic animal shells as reinforcements in various combinations of Al alloys reduced the composites' weight.

Also, the proceeded reinforcements can be used as potential materials for manufacturing automotive parts with Al-alloys.

Finally, TOPSIS and VIKOR ranking methods were successfully implemented to determine the most suitable composite for structural applications based on mechanical properties, and the comparative analysis of both methods was done.

The comparative analysis of the TOPSIS and VIKOR rankings showed that the results are the same for both techniques, which happened at VIKOR's index *v* = 0.25. The best composite is Al-CO12.

Further, the fabrication cost of Al-based composites can be reduced to some extent by using the above fillers as reinforcement in place of synthetic fillers. Using these fillers can also reduce environmental pollution and disposal problems.

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