

APPLICATION OF TAGUCHI FOR OPTIMIZATION OF MECHANICAL PROPERTIES OF THE DEVELOPMENT OF HYBRID REINFORCED ULTRA-HIGH DENSITY POLYETHYLENE COMPOSITE

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ABSTRACT

The human hard armour protection is a very important device in the hands of military and para-military in Nigeria. The problems of insecurity in almost all parts of the country have led to loss of lives and properties. The existing hard body armours have problem of weight which causes fatigue to the wearer after a long distance. This research has considered using hybrid composite which has the advantage of light weight, in addition to high mechanical properties. The quest for development of Human Hard Body Armour protection, a hybrid composite from the 6cm of (3-D) woven mat Carbon Fibre and particulates: 0.075 μ m Metal Chips (Mild Steel), 0.075 μ m of Aluminium Silicate (Glass), 0.040 μ m Alumina (Ceramic) were the reinforcements while the smelted ultra-high density Polyethylene was the matrix. The percentage by weight of Polyethylene (matrix) was varied from 44wt% to 76wt% for optimization. The samples specimen of composites were produced for Mechanical property tests ; Tensile Strength of (10x15x100)mm³, Impact Strength of (10x10x100)mm³, Flexural Strength of (30x30x100)mm³, and Hardness Strength of (30x30)mm². The experimental results showed that the highest Tensile Strength of 113MPa, Impact Strength of 2.855J, Flexural Strength of 122.517MPa and Hardness Strength of 67Hv were obtained. The Design of Experiment was carried out using Taguchi which involved Orthogonal Array of 25 runs (L₂₅), four factors and five levels. The Grey Relational Analysis (Minitab 16) combined the optimal values of the Tensile strength 10, 6, 5, 3, Flexural strength 10, 9, 9, 4, Impact strength 10, 8, 6, 4 and Hardness strength 20, 8, 5, 3 to single value for the production of Human Hard Body Armour Protection by computing, normalizing, calculating, analyzing, selecting and verifying the optimal parameters. It was noted that the optimal value from the Grey Relational Analysis was 10, 6, 5, 4. It was noted that Carbon Fibre has 96%, the highest contribution to impact energy for the Human Hard Body Armour Protection. Carbon fibre is recommended for the production of body armour with addition to particulates.

keywords: Taguchi, Grey Relational Analysis, Flexural, Hardness, Tensile, Impact

1. INTRODUCTION

The hybrid materials composite technology has had such a profound impact on the evolution of human civilization that historians have characterized. Each new era was brought about by the continuing quest for even better products, a quest that is very much in evidence today. The recent researchers focused on materials with superior performance characteristics, inspired primarily by the quest to conquer challenges confronting the society. The problem of insecurity in almost all parts of the world which have led to the loss of lives and properties has been the reason for this research work. It has become necessary to embark on research that required the use of locally made

materials that are abundant, reliable and has cost-effective for the production of hard body armour. This product helps to protect military and para-military that are the high target of the attack. The insecurity challenges include Terrorist, the Militant, Cattle Rustle, Kidnappers that have taken over all parts of the world and finally, the peace keeping nations of the world [1]. The high cost of this body armour has a negative effect on the world's economy because about 95% of this product of current price is high. It is economical to produce this product in the countries of the world with low cost for the purchase of hard body armour. In this work, the hard body armour which its materials are readily available, reliable, affordable and is new or unfamiliar to terrorist challenging the world is to be produced with hybrid composites, [2]. It is important to know that in an ever-changing world, where lack of respect, indiscipline, cultural and political unrest are the order of the day, appropriate personal protective equipment (PPE) such as bullet-resistant vests or stab-resistant vests have become an essential piece of equipment for many domestic frontline professionals. It is to be noted that lack of adequate safety measures can put an individual at risk, cause injury or even lead to death. It is relevant to those professionals guarding the country to be provided with an adequate human hard body armour protective device for their optimum performance. At times people prefer to close their eyes and not accept reality and neither responsibility, but body armour have regrettably become a real necessity within a frontline profession. These are the highlighted risk areas: Visiting people in their homes or offices to enforce laws and regulations. Policing the system increases the level of risk and subsequently the need for body armour or stab resistance. Certain geographical areas or trouble spots are high risks, such as poor or run-down council estates or high crime level areas. Dealing with certain high-risk individuals such as potentially violent or aggressive members of the public, drug users or dealers required the human hard body armour. Dealing with extremely frustrated disappointed customers (e.g. customers extremely unhappy with the service your partner organization has provided) needed the armour. Evicting people from their homes, dealing with individuals expressing extreme religious or political views also required the armour. Securing or protecting property, events or people are professional responsibility and enforcing the law demands the armour. Corporate manslaughter and homicide laws as well as health and safety regulations have been rewritten in countries around the world, in order to protect those who serve and risk their lives for others, [3]. Finally, in order to safeguard ourselves from this menace in the country, this research work was targeted on the importance of materials light weight with high impact value during the material selection. The consideration for military embarking on a distance journey on feet in the forest or desert wearing the armour is an important factor. So this research work is concerned with light weight human hard body armour which involves the selection of materials such as particulates of: $0.075\mu\text{m}$ of metal chips, $0.075\mu\text{m}$ aluminum silicate, $0.04\mu\text{m}$ alumina and 6cm of 3-D woven mat carbon fibre as reinforcements that has the density of $0.98\text{g}/\text{cm}^3$. The resin ultra-high density polyethylene which has density of $0.86\text{g}/\text{cm}^3$ which both the reinforcements and the resin have low densities therefore, it ensured producing light weight human hard body armour protection which is the research gap of this work.

2 LITERATURE REVIEW

[4] Studied the effect of different volume fractions of piassava fibres (10, 20, 30, 40, and 50 Vf) on the energy absorption and limit velocity of piassava fibre/epoxy composite using 7.62mm M1, full jacketed bullet with 9.7g. It was observed that the composites samples with 10Vf of piassava fibre exhibited excellent ballistic performance compared to Kevlar. [5] investigated into fatigue strength of natural/synthetic fibre-based composite materials. Hybridization is made by combining stiffer fibres (carbon and boron) with more compliant fibres (glass and Kevlar) to increase the strain to failure of the composite and hence enhance impact properties, the incorporation of glass fibre reduces the cost. Hybridization of the composite improved the impact performance and fatigue resistance. [6] carried

out failure analysis in composites, fibre-reinforced composites and hybrid composite. Due to the different diameters of the fibres in the hybrid composites, more effective stress transfer could take place because of the increase in the fibre-matrix interfacial area. This could result from the improvement in the aspect of the ratio (length to diameter ratio) of the fibres. It leads to low fuel and energy consumptions. The advantages of one reinforcement complement the disadvantages of another. Hybrid composite provides a lightweight characteristic in comparison to non-hybrid, hybrid composite materials depend on fibre orientations, fibre length, fibre content, fibre-matrix interfacial adhesion and failure strain of each fibre. [7] considered *Cocos nucifera* sheath (natural fibre) and hybridized it with Kevlar 29 for body armour. Eventually, sensitivity analysis was carried out to check the stability of the priority ranking. It was noted that the materials have the highest priority vector and it was selected as the most promising natural fibre for hybridization with Kevlar 29. [8] carried out an analysis on graphen, he discovered that it is a single atomic layer of graphite which composes of a hexagonal lattice of carbon atoms. Graphene has high strength and is lightweight but it is extremely expensive. The durability and flexibility of graphene proved it very helpful to troops who travel through the extreme condition. [9] produced a safety helmet using palm kernel fibre and shell particulates. The palm kernel fibre is the reinforcement while the epoxy resin is the matrix. The composite has impact strength of 7.2j/mm^2 , since impact energy is the most critical property. It was adopted for the production of the safety helmet. [10] designed a structured stab-resistance plate using crocodile armour and produced using 3-D printing technology-laser sintering (L.S). Carbon fibre was added to enhance the stab resistance properties of the body armour. Carbon fibre increased the plate stab resistance property. The SEM observations confirmed that the addition of Carbon fibre largely improved the plate stab-resistance property. [11] carried out the test for both wet and dry fabrics on bulletproof vests of Kevlar, Dyneema and Graphene. Two tests were ballistic V50, VO and military of fragment ballistic. UHMWPE was added to determine the increase in the performance of the ballistic materials. Dyneema has the advantage of water resistance bulletproof. Dry fabrics have the advantage of higher performance. It was noted that dry bulletproof vests have higher performance than wet bulletproof vests. UHMWPE improves the performance of graphene highest. Dyneema has water resistance for bulletproof production. Eask, [12] produced a bulletproof vest with shear thickening fluid. He also compared properties of plain-woven dyneema fabric and plain Kevlar fabric of the same specifications for body armour production. It was noted that it was economical to use proper shear thickening fluid. Plain woven Kevlar fabric was better than plain woven Kevlar. It was noted that using proper shear thickening fluid reduces the number of fabric layers. Plain woven dyneema fabric was superior to plain-woven Kevlar fabric having the same specifications. [13] developed military helmet using Coconut fibre reinforced polymer composite. The Coconut fibre (coir) was the reinforcement while epoxy was the resin. The laminate has an impact strength of 8.733j/mm^2 , which implies that it has suitable mechanical strength for bullet resistance. [14] QuadGard used sweating thermal manikin watter was examined the intrinsic clothing insulation (Rcl), intrinsic clothing evaporative resistance (Recl), micro-climate temperature and moisture retention of three QuadGard system (QGII, QG IV ventilated, and QG IV not ventilated). These were produced with two ballistic materials; dyneema and Kevlar with similar protection level. Kevlar has higher Rcl and Recl than dyneema. The ballistic material dyneema consistently measured lower Rcl and Recl than Kevlar but dyneema proved more comfortable. [15] worked on a composite of ballistic armour system based on small-size ceramics and fibre composite gave protection against $5.7 \times 28\text{mm}$ SS190 projectiles with increased penetration capabilities. The impact energy of the composite is high Due to the hybrid structure of the composite, $5.28 \times 28\text{mm}$ SS190 ammunition did not pass through the body armour.

3 MATERIALS AND METHODS

3.1 Materials

Carbon Fibre

Carbon fibre is considered for the following reasons: it has high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion that has made it relevant in military, aerospace, civil engineering, motorsports, along with other competition sports. Carbon fibre offers strength up to 5times greater than steel (weight for weight), it offers perfect conductivity and is black with a slight gloss that provides a unique pattern. It is a very rigid material, with young modulus of 240GPa. The higher the young modulus, the greater the rigidity of the material. Carbon fibre demonstrates low thermal expansion- it expands at high temperature and contracts at low temperature much less so than materials like steel and Al. It has more resistant to material fatigue-elements made from carbon fibre offer more strength during heavy duty operation. Carbon, like other composites, enables you to determine the strength of any area of an element in any direction. Finally, carbon fibre when combine with glass gives high compressive strength [16].

Ceramic-Alumina (Al_2O_3)

Clay is one of the materials selected for the following reasons: It has superior hardness, low density, high compressive strength. It breaks up the incoming projectile and dissipates its kinetic energy. Alumina has high performance with exceptional physical characteristics – highly or extremely temperature resistant, strong mechanical wear as it offers a very good mechanical strength. It offers excellent electrical insulation properties, has low dissipation factor, and a great dielectric strength. These properties enable the use in high voltage electrical application. It can resist most acid and alkalis even at increased temperature. Since Aluminum oxide materials can be ground using conventional abrasive tools on conventional CNC-machines, the manufacturing of complex work pieces based on this special ceramic material is possible. Precision work piece with a complex structure can be produced of Al_2O_3 Aluminum oxide because the potential complexity of the components manufactured of aluminum oxide is limited only by the machinery used. It has high purity of 99.7% of Al_2O_3 , coefficient of expansion $78 \times 10^{-7}/^{\circ}C$, (20-700°C). Thermal maximum operating temperature under mechanical load; approximately 1700°C, good thermal shock resistance and specific heat capacity of $990 JKg^{-1}k^{-1}$ [17]

Metal Chips (Mild Steel)

Mild steel is used because of its high strength and ductility, it is readily available materials and ability to withstand multiple hit of the projectile. It is known as mild steel because of its relative low carbon content. It has a high resistance to breakage. Mild steel, as opposed to higher carbon steels, is quite malleable, even when cold. This means it has high tensile and impact strength. Higher carbon steels usually shatter or crack under stress, while mild steel bends or deforms. Its modulus of elasticity of 300-380GPa, mohs hardness of 9 and modulus rupture of 300GPa. Metal chips of mild steel is considered here because of its light weight [18].

Glass-Aluminum Silicate (Al_2SiO_5)

It is considered because of its high hardness of 1-2 on the mohs scale of mineral hardness. It becomes very tough when it is combined with metal. The refractive index of aluminum silicate is 1.56 and the density is 2.8 to 2.9g/cm³. Aluminum Silicate has these industrial applications: Ceramic refractory, as well as to manufacture electric insulating materials and heating elements. It is used for making porcelain, spark plugs, enamel, bricks and cement [19].

Ultra-High Density Polyethylene (Resin)

High density polyethylene is chosen for resin because of its high ductility, toughness and structural integrity which spreads the forces resulting from the impact of a projectile over a large area.

It has little branching giving it stronger intermolecular forces and high tensile strength. It is known for its large strength to density ratio. The density of ultra-high density polyethylene can range from 930 to 970kg/m³ [20].

3.2 METHODS

The materials used for the production of the hard body armour protection: 6cm of 3-D woven Carbon Fibre, Metal Chips (mild steel), Glass-Aluminium Silicate (Al₂SiO₅), Ceramic-Alumina (Al₂O₃), Ultra-High Density Polyethylene (Resin), Silicon Wax, Petroleum Jelly, Gel coat material and other miscellaneous materials

Carbon Fibre

It was obtained from Nigerian Air Force, Air Force Base Kaduna. It is the dense carbon fibre with three dimensional woven fibre for high mechanical properties performance

Metal Chips (Mild Steel)

It was sourced from Air Force Institute of Technology Kaduna Central Workshop. The chips was taken to Chemical Engineering for Milling using Ball Milling Machine to particle sizes of 0.03mm in ABU Zaria. The Chips was further subjected to mechanical impact force using piston, in Building Technology Department of the same Institution which reducing the particle sizes to 0.075µm.

Aluminium Silicate (Al₂SiO₅)

it was sourced from Kaduna Metropolis where the particle sizes were reduced using hammer to the particle sizes of 0.01mm. The particle sizes were further reduced using Ball Milling Machine to 0.075 µm from ABU Zaria Kaduna.

Ceramic- Alumina (Al₂O₃)

It was sourced from Nigerian Research Institute of Metals and Mineral resources (Malani) in Kaduna. The material was milled with Ball Mill Machine in Chemical Engineering Department to the particle sizes of 0.04µm.

Ultra-High Density Polyethylene

It was bought from the National Institute of Leather and Polymer Technology Zaria. It was smelted using two roll mill.

Sample Preparation of the Materials for Mechanical Test

The percentage weight of aluminium silicate, alumina, metal chips (mild steel), polyethylene and carbon fibre each are measured with a digital weighing balance. The required pellets of polyethylene were smelted and the quantities of these particulates were added to the TwoRoll Mill and rolled for ten (10) minutes for proper mixing of the particulates. The composites were layed into the mould and were placed in a compressive machine at a holding temperature of 120°C for 15 minutes. The laminates produced are cooled in the air for about 30minutes before the mechanical test was carried out.

Mechanical Test

Sample specimen preparation for bending strength of (30 x 30 x 100) mm³, tensile strength of (100 x 15 x 10) mm³, impact strength of (100 x 10 x 10)mm³ and hardness strength of (30 x 30) mm² were carried out using flexural testing machine, universal electronic testing machine, charpy impact testing machine and Vickers hardness testing machine respectively.

Tensile Test

The tensile test was carried out using Universal Electronic Testing Machine, WDW-100KN 190536. The test samples were placed and gripped in between the jaws of the machine. The load was gradually applied through a hydraulic press until deformation occurred and the result was displayed digitally [21], Ultimate tensile strength stresses were calculated using equations 2.1 and 2.2;

$$\sigma = \frac{P}{A} \quad (1)$$

$$A = \frac{\pi d^2}{4} \quad (2)$$

Where P is the maximum applied load; A is the cross-sectional area of the machine sample, d is the diameter of the machined samples.

Impact Test

The impact test was carried out on the Charpy impact testing Machine in accordance to HD96QD (15J & 25J). The machine consists of tops between which the test sample is inserted. With the specimen positioned in the vice, a blow was stroked by two released pendulums in opposite directions from their calibrated standard height to fracture off the specimen. The energy retained was determined by the height rise of the pendulum as indicated by the dial gauge. The difference between the energy input and energy retained gave the energy absorbed [22].

Hardness Test

The hardness values of the hybrid fibre composites were determined in accordance with the ASTM E140 standard using the Vickers Hardness testing machine present in the shell office, department of Mechanical Engineering A.B.U., Zaria. The machine consists of a digital display reading HV and HB.,0.42cm steel ball indenter with a load of 0.3kgf. The specimen prepared to a good finish of perfectly horizontal surface were indented. The depth of indentation indicated the hardness of the laminates [23].

Flexural Test

The machine used for the flexural test is a universal tester of model Nr. 261. It has a hydraulic press that actuates the pressure of the machine to grip the load and the result of the force is displayed digitally on the machine of the composite materials. The Universal Material Testing Machine is situated in Mechanical Engineering Department, ABU Zaria [24].

Taguchi Method of Experimental Design and Analysis

The composite materials were optimized for the production of hard body armour protection. Taguchi produced a transformation of the replica in data into another value, which is the response calculation of the variation present. This transformation is the signal to noise (S/N) ratio. The S/N ratio was intended to be used as the measure of the effect of noise factors on the target characteristics. Here, the S/N ratio is calculated based on the higher the better. S/N ratio values are tabulated in Table 4 as shown in appendix. This characteristic is a non-negative measurable characteristic that has an extreme state value of infinity. Normalization is a transformation execution on a single data input to share out the data evenly and scale it into an acceptable range for further analysis. The quality characteristics were chosen in this study integrated with Tensile, Flexural, Impact and Hardness strength (higher-the-better) that is better the performance of all parameters. These characteristics were adopted for both the S/N ratio and Normalized S/N ratio. A grey-based Taguchi technique was used to solve the multi-objective problems. The integrated grey based Taguchi technique combines

advantages of both grey relational analysis and Grey Relational Grade with Taguchi technique. The four selected parameters were considered with five levels which four experimental mechanical properties were determined. Experimental design was carried out using Taguchi where the collections of data are searched by orthogonal array L₂₅ conditions. Moreover, the ultra-high density polyethylene was the filler used to fabricate the samples.

The experimental results of the composites were conducted and obtained from the tensile, flexural, impact and hardness strength of the percentage by weight of the composite. The density of each sample specimen was determined by weighing the sample on electronic weighing balance for the mass. The sample specimens were later inserted into the water and the change of volume of the water were measured and calculated as recorded below according to archimedian principle. The density was calculated using equation 3.

$$\rho = \frac{M}{V} \tag{3}$$

Where ρ is the density, m is the mass, and v is the volume of the each sample.

4 RESULTS AND DISCUSSION

Table 1 shows the mechanical properties such as tensile, flexural, impact and hardness strength of hybrid composites parameters.

Table 1. Experimental Results for the Mechanical Properties of the Reinforced Composite.

S/No	Tensile Strength(MPa)	Flexural Strength(MPa)	Impact Strength(j/mm) ²	Hardness Strength(Hv)	Density g/cm ³
1	113	85.43	2.46	57	0.887
2	22.335	122.51	2.855	29.92	0.9025
3	20.265	102.72	1.615	35.43	1.061
4	8.865	94.878	2.225	43.06	0.8625
5	7.2	122.73	2.505	41.3	1.129
6	58	76	2.33	65	0.969
7	10	52.15	1.72	47.4	0.9038
8	12.135	59.8	1.68	60.06	0.998
9	11.735	61.97	1.975	55.13	0.9575
10	9.335	60.12	1.925	52.13	0.842
11	61.24	42.33	1.566	41	0.9608
12	7.335	61.3	1.575	57.43	0.9216
13	11.465	107.08	2.525	61.47	1.013
14	10.4	76.91	1.575	67.13	1.006
15	9.065	34.138	2.2	62.13	0.965
16	10.135	104.73	1.55	56.83	1.028
17	5.935	77.89	1.925	58.8	1.165
18	8.8	58.79	2.35	64.7	1.048
19	5.535	81.66	0.8	37	1.0436
20	44.09	73.83	1.4	61.27	0.998
21	8.265	58.5	1.3	41.83	1.253
22	10.8	58.05	2.05	44.23	1.197
23	10.375	59.78	2.2	53.1	1.0418
24	9.8	82	1.9	55.86	1.075
25	75.02	43.48	1.733	25	1.058

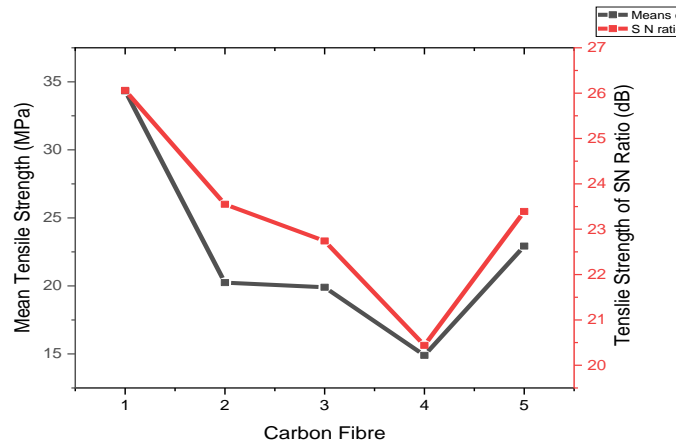


Figure 1. Variation of Tensile Strength of CMAA Composite with Carbon Fibre Content

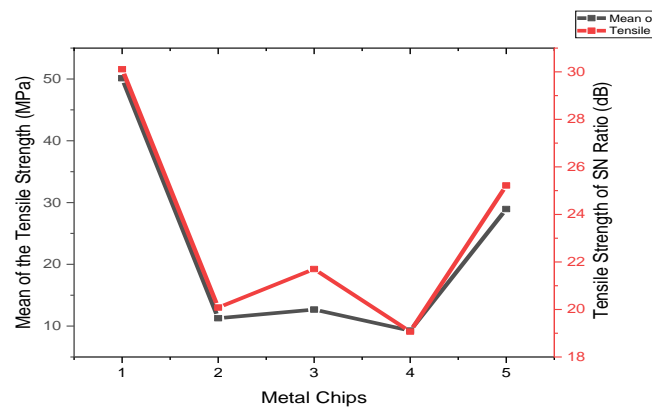


Figure 2. Variation of Tensile Strength of CMAA Composite with Metal Chips Content

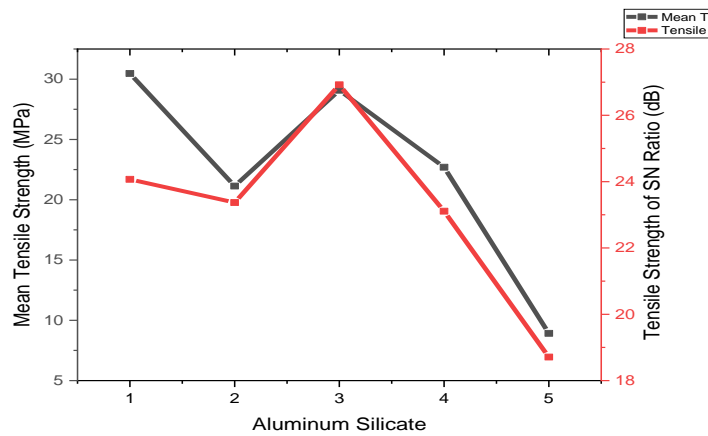


Figure 3. Variation of Tensile Strength of CMAA Composite with Aluminum Silicate Content

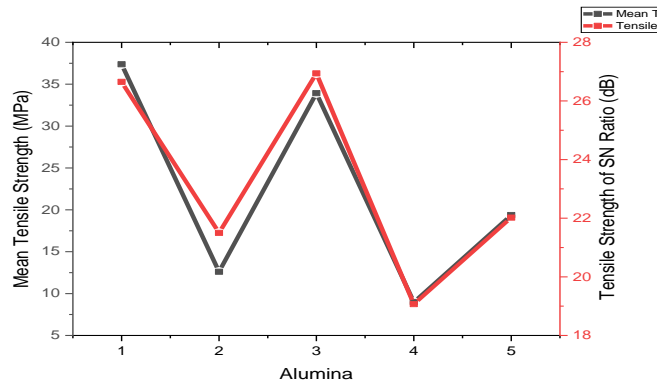


Figure 4. Variation of Tensile Strength of CMAA Composite with Alumina Content

The percentage contribution of each process parameter is given in the ANOVA table, exposed in Table 2, it can be seen that the percentage by weight of carbon fibre has 6.20%, metal chips has 31.912%, glass has 13.41%, ceramic has 18.22% on the multiple performance characteristics. This suggests that percentage weight of metal chips reinforced with ultra-high density polyethylene is more important in tensile strength. It has relative significance parameters of 81.3% and error pooled of 0.31.

Table 2. (ANOVA) Analysis of Variance for SN Ratios of Tensile Strength

Source	D F	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Carbon F	4	80.51	80.51	20.13	0.4	0.804	6.2
Metal Ch	4	403.66	403.66	100.92	2.01	0.187	31.12
Al ₂ SiO ₅	4	173.98	173.98	43.49	0.86	0.524	13.41
Al ₂ O ₃	4	236.4	236.4	59.1	1.17	0.391	18.22
Residual Error	8	402.41	402.41	50.3			31.05
Total	24	1296.97					100

The percentage contribution of each process parameter is given in the ANOVA table, exposed in table 3, it can be seen that the percentage by weight of metal chips has 34.59%, carbon fibre has 6.00%, glass has 8.40%, ceramic has 18.46% on the multiple performance characteristics. This suggests that percentage weight of metal chips reinforced with ultra-high density polyethylene is more important in tensile strength. It has relative significance parameters of 83.2% and error pooled of 0.33.

Table 3. (ANOVA) Analysis of Variance for Means Ratios of Tensile Strength

Source	D F	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Carbon F	4	1049	1049	262.3	0.37	0.823	6
Metal Ch	4	6011	6011	1502.8	2.13	0.168	34.59
Al ₂ SiO ₅	4	1465	1465	366.3	0.52	0.725	8.4
Al ₂ O ₃	4	3208	3208	802	1.14	0.405	18.46
Residual Error	8	5641	5641	705.1			32.55
Total	24	17374					100

Table 4. The Optimal values of Predicted and Experiment for Tensile Strength of the Composite

	Optimal process parameter settings	Predictive values	Experiment values
S/N Ratio	A1B1C1D1	37.1759	41.0616
Tensile strength(MPa)	A1B1C1D1	93.9746	113

4.1 Modeling equation for the tensile strength

$880.33 - 14.38 A - 71.63 B - 146.39 C + 37.10 D - 0.07 A*B + 2.41 A*C - 0.43 A*D + 12.16 B*C - 2.56 B*D - 0.86 C*D$. This shows that the parameters were varied into ten different orientation to obtain the optimal value for the result using Grey Relational Analysis. The model indicates good correlations between the experimental and predicted results.

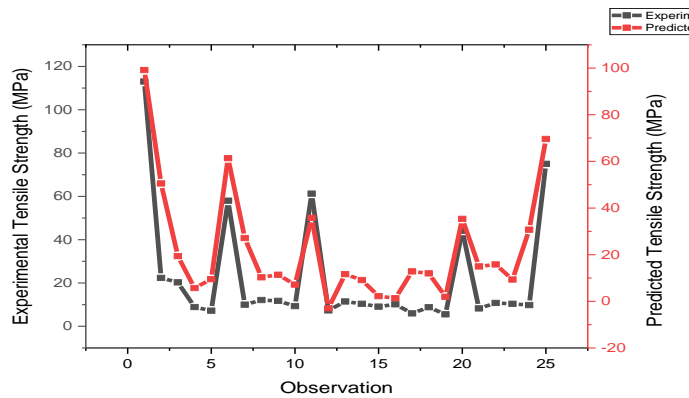


Figure 5. Model for Variation of Tensile Strength of CMAA Composite

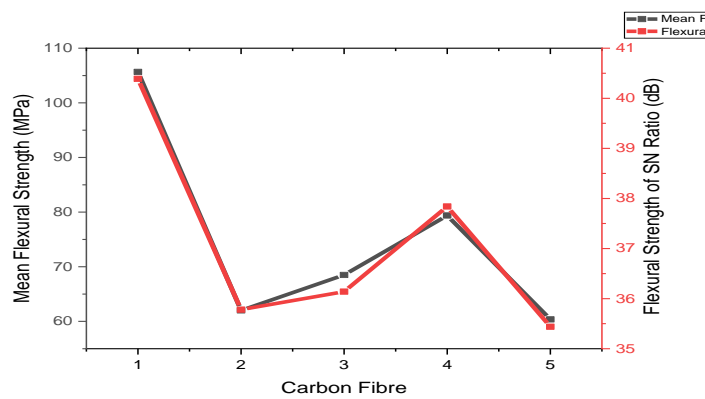


Figure 6. Variation of Flexural Strength of CMAA Composite with Carbon Fibre Content

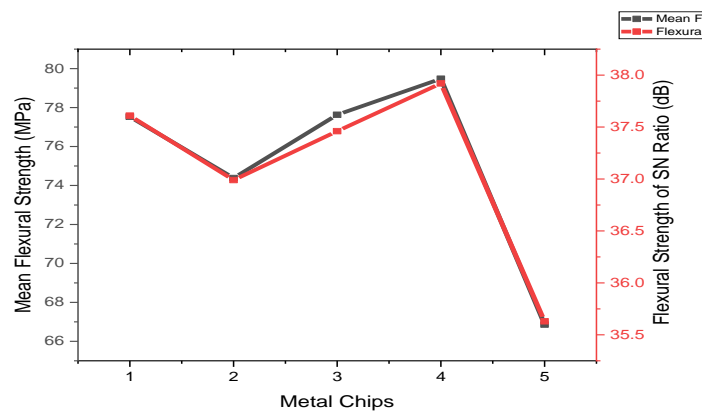


Figure 7. Variation of Flexural Strength of CMAA Composite with Metal Chips Content

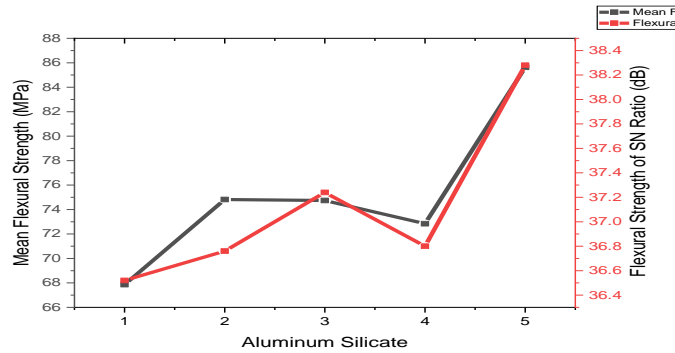


Figure 8. Variation of Flexural Strength of CMAA Composite with Aluminum Silicate Content

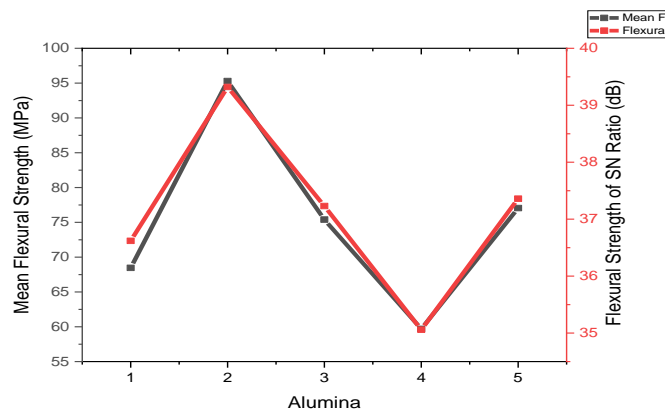


Figure 9. Variation of Flexural Strength of CMAA Composite with Alumina Content

The percentage contribution of each process parameter is given in the ANOVA table, exposed in Table 5, it can be seen that the percentage by weight of carbon fibre has 47.20%, metal chips has 9.05%, glass has 26.51%, ceramic has 11.76% on the multiple performance characteristics. This suggests that percentage weight of carbon fibre reinforced with ultra-high density polyethylene is more important flexural strength. It has relative significance parameters of 99.3% and error pooled of 0.12. Comparing the result with [26], application of Taguchi approach with optimization of the mechanical properties of snail-shell-filler/chicken-feather-fibre polymer based hybrid composite validates the result.

Table 5. (ANOVA) Analysis of Variance for SN Ratios of Flexural Strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Carbon F	4	83.936	83.936	20.984	8.03	0.007	47.2
Metal Ch	4	16.101	16.101	4.025	1.54	0.279	9.054
Al ₂ SiO ₅	4	9.736	9.736	2.434	0.93	0.492	5.475
Al ₂ O ₃	4	47.151	47.151	11.788	4.51	0.034	26.51
Residual Error	8	20.894	20.894	2.612			11.76
Total	24	177.818					100

The percentage contribution of each process parameter is given in the ANOVA table, exposed in Table 6, it can be seen that the percentage by weight of carbon fibre has 53.15%, metal chips has 3.83%, glass has 6.47%, ceramic has 22.61% on the multiple performance characteristics. This suggests that percentage weight of carbon fibre reinforced with ultra-high density polyethylene is more important flexural strength. It has relative significance parameters of 97% and error pooled of 0.099. Comparing the result with [26], application of Taguchi approach with optimization of the mechanical properties of snail-shell-filler/chicken-feather-fibre polymer based hybrid composite validates the result.

Table 6. (ANOVA) Analysis of Variance for Means Ratios of Flexural Strength

Source	D F	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Carbon F	4	83.936	83.936	20.984	8.03	0.007	47.2
Metal Ch	4	16.101	16.101	4.025	1.54	0.279	9.054
Al ₂ SiO ₅	4	9.736	9.736	2.434	0.93	0.492	5.475
Al ₂ O ₃	4	47.151	47.151	11.788	4.51	0.034	26.51
Residual Error	8	20.894	20.894	2.612			11.76
Total	24	177.818					100

Table 7. The Optimal values of Predicted and Experiment for Flexural Strength of the Composite

	Optimal process parameter settings	Predictive values	Experiment values
S/N Ratio	A1B4C5D2	39.7693	41.76
Flexural strength	A1B4C5D2	93.9746	122.517

4.2 The modeling equation for flexural Strength of the composite

$290.39 + 4.69 A - 25.60 B - 25.03 C - 20.03 D - 0.75 A*B + 0.33 A*C - 0.38 A*D + 3.01 B*C - 3.72 B*D - 0.86 C*D$. This means that the parameters were varied into ten different orientation to obtain the optimal value for the result using Grey Relational Analysis. The model indicates good correlations between the experimental and predicted results.

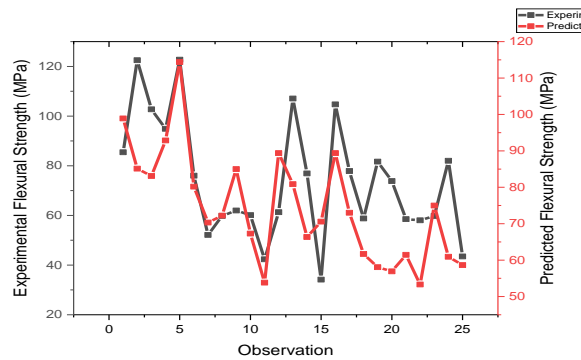


Figure 10. Model for Variation of Tensile Strength of CMAA Composite

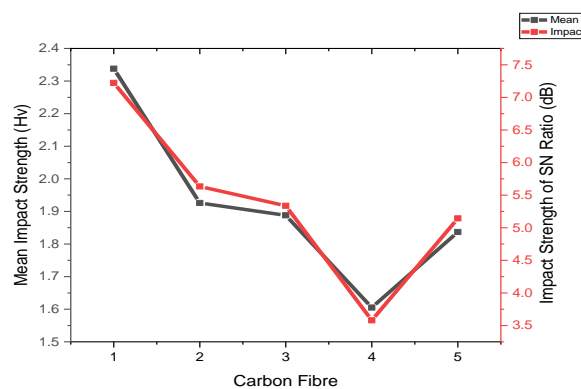


Figure 11. Variation of Impact Strength of CMAA Composite with Carbon Fibre Content

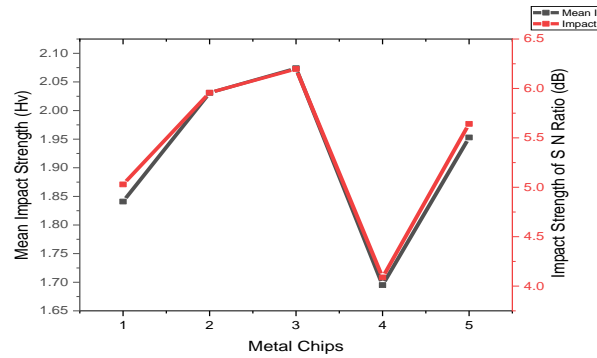


Figure 12. Variation of Impact Strength of CMAA Composite with Metal Chips Content

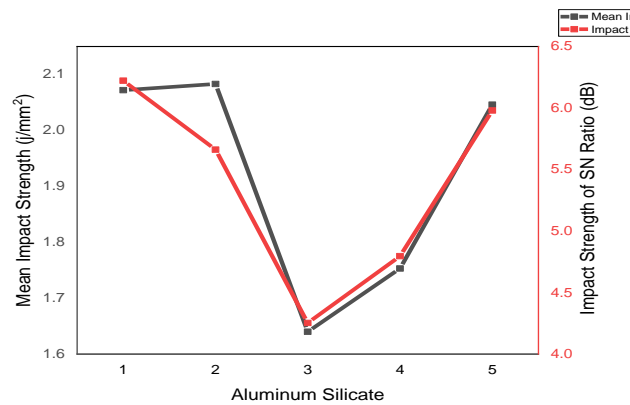


Figure 13. Variation of Impact Strength of CMAA Composite with Aluminum Silicate Content

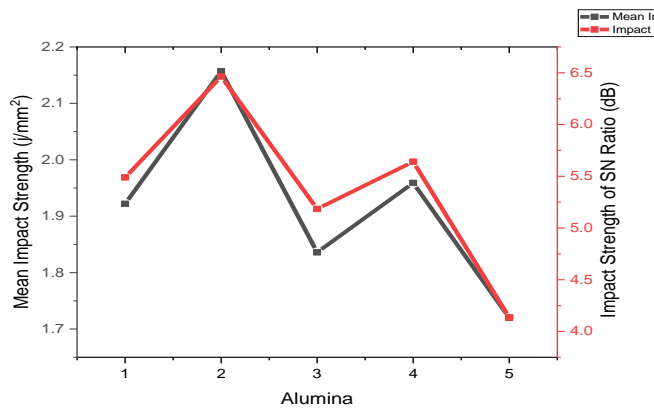


Figure 14. Variation of Impact Strength of CMAA Composite with Alumina Content

The percentage contribution of each process parameter is given in the ANOVA table, exposed in Table 8, it can be seen that the percentage by weight of carbon fibre has 25.67%, metal chips has 10.87%, glass has 10.48%, ceramic has 10.80% on the multiple performance characteristics. This suggests that percentage weight of carbon fibre reinforced with ultra-high density polyethylene is more important impact strength. It has relative significance parameters of 62.5% and error pooled of 0.42. Comparing the result with [26], application of Taguchi approach with optimization of the mechanical properties of snail-shell-filler/chicken-feather-fibre polymer based hybrid composite validate the result.

Table 8. (ANOVA) Analysis of Variance for SN Ratios of Impact Strength

Source	D F	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Carbon F	4	33.76	33.76	8.441	1.22	0.375	25.67
Metal Ch	4	14.3	14.3	3.576	0.52	0.727	10.87
Al2SiO5	4	13.79	13.79	3.447	0.5	0.739	10.48
Al2O3	4	14.21	14.21	3.554	0.51	0.729	10.8
Residual Error	8	55.44	55.44	6.93			42.18
Total	24	131.51					100

Table 9. (ANOVA) Analysis of Variance for Means Ratios of Impact Strength

Source	D F	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Carbon F	4	1.4097	1.4097	0.3524	1.46	0.299	27.16
Metal Ch	4	0.4696	0.4696	0.1174	0.49	0.746	9
Al2SiO5	4	0.8593	0.8593	0.2148	0.89	0.511	16.55
Al2O3	4	0.5236	0.5236	0.1309	0.54	0.709	10.08
Residual Error	8	1.927	1.927	0.2409			
Total	24	5.1893					100

Table 10. The Optimal values of Predicted and Experiment for Impact Strength of the Composite

	Optimal process parameter settings	Predictive values	Experiment values
S/N Ratio	A1B4C5D2	39.7693	41.76
Flexural strength	A1B4C5D2	93.9746	122.517

4.3 The modeling equation for impact strength of the composite

$5.33 - 2.89 A - 0.73 B + 0.739 C - 0.739 D - 0.21 A*B + 0.1 A*C + 0.002 A*D - 0.004 B*C - 0.09 B*D - 0.04 C*D$. This means that the parameters were varied into ten different orientation to obtain the optimal value for the result using Grey Relational Analysis. The model indicates good correlations between the experimental and predicted results.

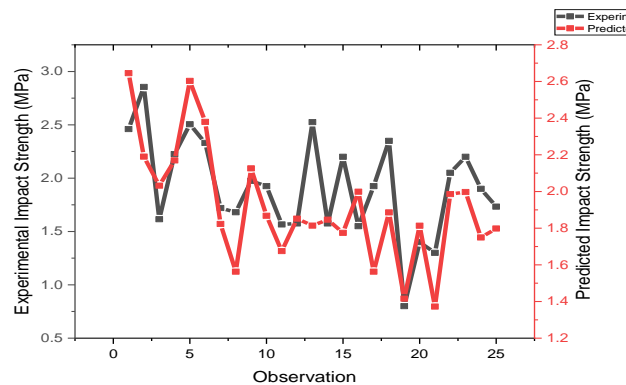


Figure 15. Model for Variation of Tensile Strength of CMAA Composite

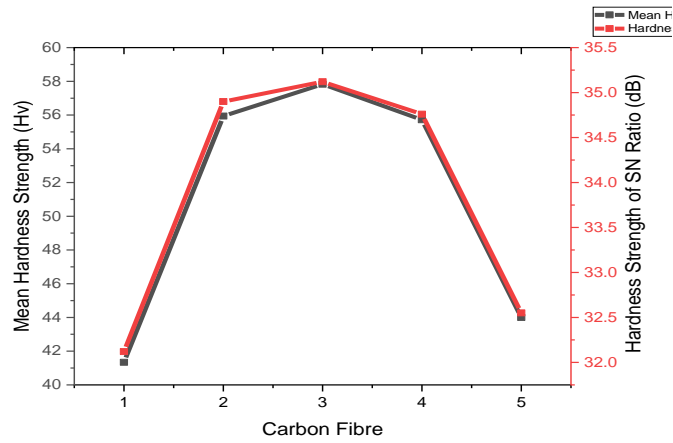


Figure 16. Variation of Hardness Strength of CMAA Composite with Carbon Fibre Content

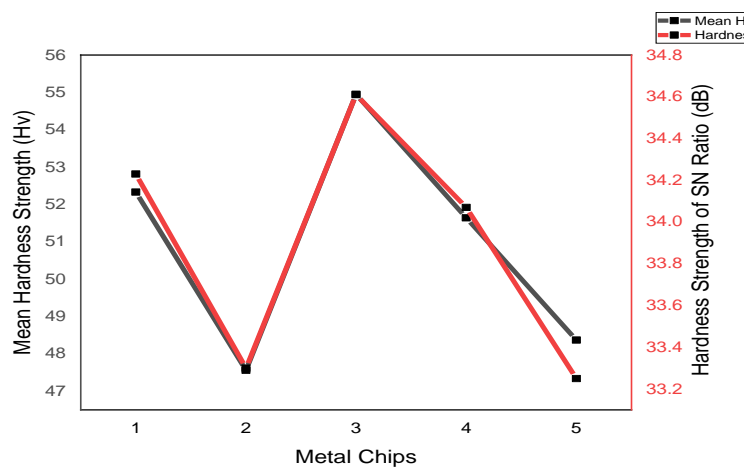


Figure 17. Variation of Hardness Strength of CMAA Composite with Metal Chips Content

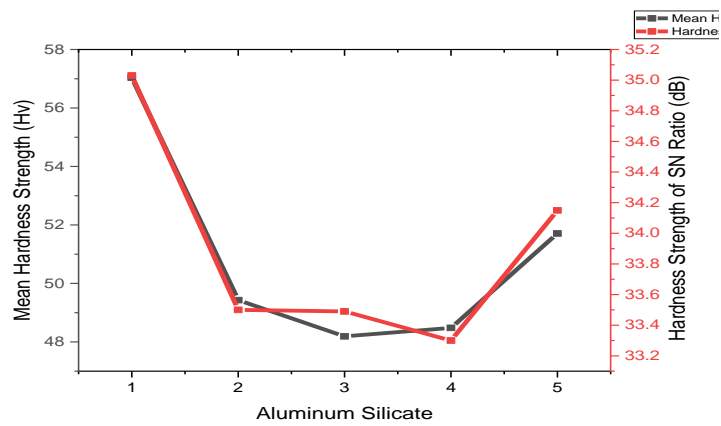


Fig.18 Variation of Impact Strength of CMAA Composite with Aluminum Silicate Content

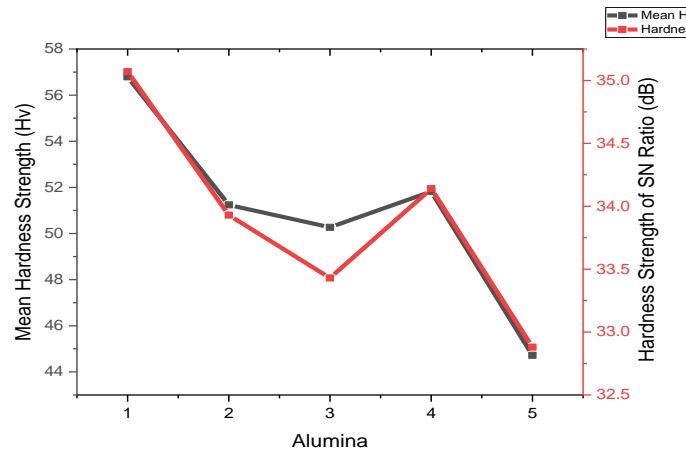


Figure 19. Variation of Hardness Strength of CMAA Composite with Alumina Content

The percentage contribution of each process parameter is given in the ANOVA table, exposed in table 11, it can be seen that the percentage by weight of carbon fibre has 34.21%, metal chips has 5.93%, glass has 8.4%, ceramic has 11.22% on the multiple performance characteristics. This suggests that percentage weight of carbon fibre reinforced with ultra-high density polyethylene is more important hardness strength and has relative significance parameters of 76% and error pooled of 0.4. Comparing the result with [26], application of Taguchi approach with optimization of the mechanical properties of snail-shell-filler/chicken-feather-fibre polymer based hybrid composite validate the result.

Table 11. (ANOVA) Analysis of Variance for SN Ratios Hardness Strength

Source	D F	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Carbon F	4	41.094	41.094	10.274	1.7	0.242	34.21
Metal Ch	4	7.129	7.129	1.782	0.3	0.873	5.93
Al ₂ SiO ₅	4	10.097	10.097	2.524	0.42	0.792	8.406
Al ₂ O ₃	4	13.475	13.475	3.369	0.56	0.7	11.22
Residual Error	8	48.309	48.309	6.039			40
Total	24	120.104					100

The percentage contribution of means for each process parameter is given in the ANOVA table, exposed in table 12, it can be seen that the percentage by weight of carbon fibre has 36.33%, metal chips has 5.64%, glass has 8.27%, ceramic has 11.44% on the multiple performance characteristics. This suggests that percentage weight of carbon fibre reinforced with ultra-high density polyethylene is more important for hardness strength and has relative significance parameters of 80% and error pooled of 0.38. Comparing the result with [26], application of Taguchi approach with optimization of the mechanical properties of snail-shell-filler/chicken-feather-fibre polymer based hybrid composite validate the result.

Table 12. (ANOVA) Analysis of Variance for Means Ratios of Hardness Strength

Source	D F	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Carbon F	4	1178.1	1178.1	294.52	1.9	0.204	36.33
Metal Ch	4	183	183	45.74	0.29	0.874	5.644
Al ₂ SiO ₅	4	268.4	268.4	67.09	0.43	0.782	8.278
Al ₂ O ₃	4	371	371	92.75	0.6	0.675	11.44
Residual Error	8	1241.8	1241.8	155.23			38.3
Total	24	3242.2					61.69

Table 13. The Optimal values of Predicted and Experiment for Hardness Strength of the Composite

	Optimal process parameter settings	Predictive values	Experiment values
S/N Ratio	A3B3C1D1	34.7796	36.5383
Hardness strength (Hv)	A1B3C1D1	54.5928	67.13

4.4 Modeling equation for hardness Strength of the composite

$10.69 + 0.11 A - 0.96 B - 2.08 C + 0.79 D - 0.03 A*B + 0.03 A*C - 0.02 A*D + 0.21 B*C - 0.022 B*D - 0.87 C*D$. This means that the parameters were varied into ten different orientation to obtain the optimal value for the result using Grey Relational Analysis. The model indicates good correlations between the experimental and predicted results.

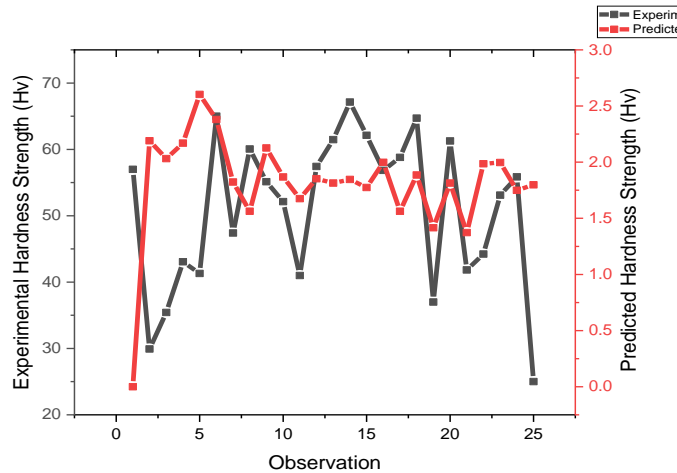


Figure 20. Model for Variation of Hardness Strength of CMAA Composite

Table 14. Validating the results using Grey Relational Analysis (Minitab 16)

S/N	Carbon fibre	Metal Chips	AL2SiO5	AL2O3	MEAN	SNRA1
1	10	6	5	3	0.749778	-2.50135
2	10	7	6	4	0.700272	-3.09466
3	10	8	7	5	0.477964	-6.41209
4	10	9	8	6	0.588533	-4.60459
5	10	10	9	7	0.587226	-4.62389
6	15	6	6	5	0.63192	-3.98676
7	15	7	7	6	0.497169	-6.06993
8	15	8	8	7	0.50834	-5.87692
9	15	9	9	3	0.515901	-5.74867
10	15	10	5	4	0.572082	-4.85084
11	20	6	7	7	0.491327	-6.17259
12	20	7	8	3	0.520944	-5.66418
13	20	8	9	4	0.632468	-3.97923
14	20	9	5	5	0.566911	-4.92971
15	20	10	6	6	0.542269	-5.3157
16	25	6	8	4	0.537836	-5.387
17	25	7	9	5	0.491433	-6.17071
18	25	8	5	6	0.56126	-5.01672
19	25	9	6	7	0.420364	-7.5275
20	25	10	7	3	0.535342	-5.42738
21	30	6	9	6	0.386333	-8.26077
22	30	7	5	7	0.430418	-7.32219
23	30	8	6	3	0.493642	-6.13176
24	30	9	7	4	0.499529	-6.02878
25	30	10	8	5	0.448069	-6.97309

Response table shows the rank of the parameters in composite for the production of human hard body armour. It also shows the relationship between mean and the noise signal ratio of the parameters, which is the degree of influence of real and desired variation parameters of the composite. Comparing the result with [26], application of Taguchi approach with optimization of the mechanical properties of snail-shell-filler/chicken-feather-fibre polymer based hybrid composite validate the result.

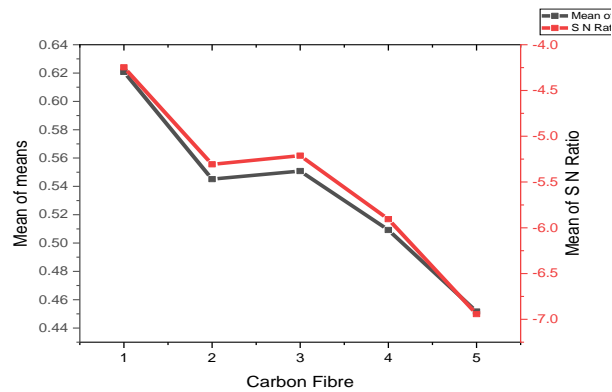


Figure 21. Variation of Grey Relational Analysis of CMAA Composite with Carbon Fibre Content

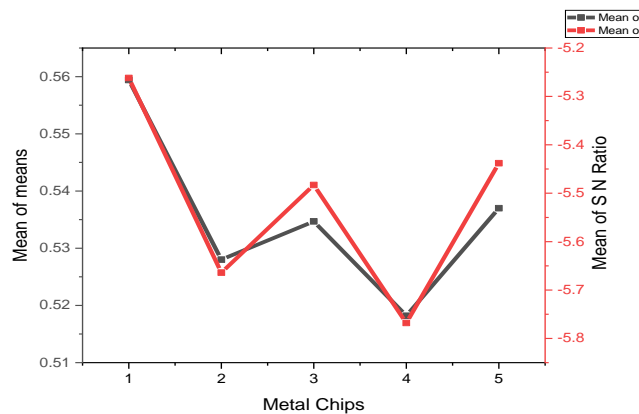


Figure 22. Variation of Grey Relational Analysis of CMAA Composite with Metal Chips Content

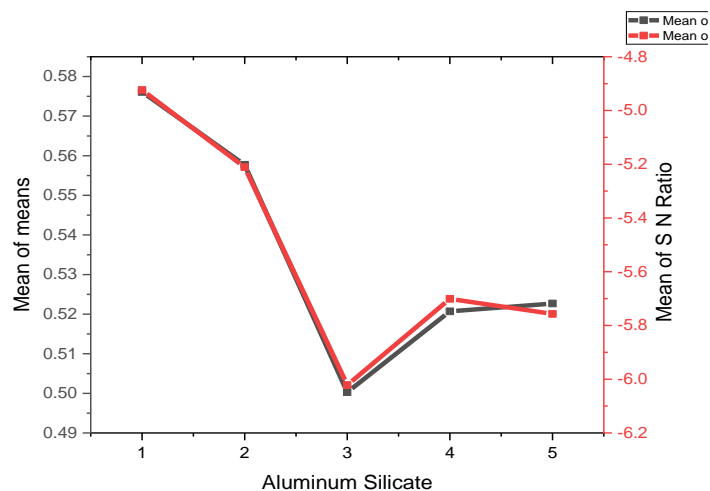


Figure 23. Variation of Grey Relational Analysis of CMAA Composite with Aluminum Silicate Content

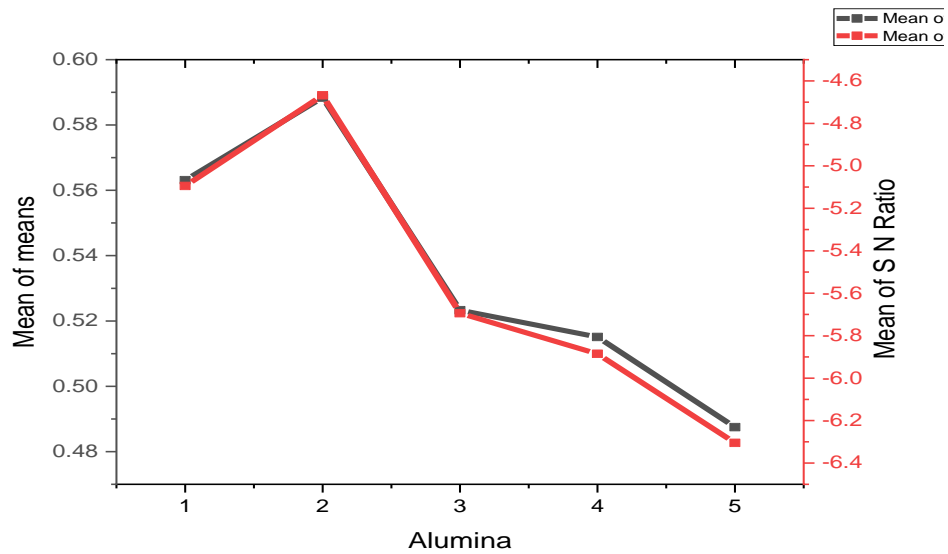


Figure 24. Variation of Grey Relational Analysis of CMAA Composite with Alumina Content

Table 15. The Mean and SN Ratios for Grey Relational Analysis

	Optimal process parameter settings	Predictive values	Experiment values
S/N Ratio	A1B1C1D2	-2.9586	-2.50135
Grey strength	A,1B1C1D2	0.712925	0.749778

The main effect of parameter for tensile strength of main plot for SNAR is A1, B1, C3, D3, the flexural strength is A1, B4, C5, D2, the impact strength is A1, B3, C1, D2, the hardness strength is A3, B3, C1, D1 finally, the grey relational analysis effect parameter combines all the optimum values of the mechanical properties to give a final optimized value which is A5, B4, C3, D5. The mean of means effect of parameter for tensile strength is A1, B1, C1, D1, the flexural strength is A1, B4, C5, D2, the impact strength is A1, B3, C1, D2, the hardness strength is A3, B3, C1, D1 and the mean of means of grey relational analysis is A1, B1, C1, D2. Comparing the result with [26], application of Taguchi approach with optimization of the mechanical properties of snail-shell-filler/chicken-feather-fibre polymer based hybrid composite validate the result.

Table 16. (ANOVA) Analysis of Variance for SN Ratios of Grey relational Analysis

Source	D F	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Carbon F	4	19.6731	19.6731	4.9183	4.17	0.04	46.66
Metal Ch	4	0.7849	0.7849	0.1962	0.17	0.949	1.861
Al2SiO5	4	3.9564	3.9564	0.9891	0.84	0.537	9.37
Al2O3	4	8.3195	8.3195	2.0799	1.77	0.229	19.73
Residual Error	8	9.4261	9.4261	1.1783			22.37
Total	24	42.16					100

The percentage contribution of each process parameter is given in the ANOVA table, exposed in table 18, it can be seen that the percentage by weight of carbon fibre has 46.66%, metal chips has 1.861%, glass has 9.37%, ceramic has 19.73% on the multiple performance characteristics. This suggests that percentage weight of carbon fibre reinforced with ultra-high density polyethylene is more important in tensile strength, flexural strength, hardness strength. It has relative significance parameters of 96% and error pooled is 0.2237. Comparing the result with [26], application of Taguchi approach with optimization of the mechanical properties of snail-shell-filler/chicken-feather-fibre polymer based hybrid composite validate the result.

Table 17. (ANOVA) Analysis of Variance for Means Ratios of Grey Relational Analysis

Source	D F	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Carbon F	4	0.076612	0.076612	0.019153	4.34	0.037	45.73
Metal Ch	4	0.004645	0.004645	0.001161	0.26	0.894	2.772
Al ₂ SiO ₅	4	0.018819	0.018819	0.004705	1.07	0.433	11.23
Al ₂ O ₃	4	0.032157	0.032157	0.008039	1.82	0.218	19.19
Residual Error	8	0.035304	0.035304	0.004413			21.07
Total	24	0.167538					100

4.5. Modeling equation for Grey Relational Analysis

1.659 - 0.032 A - 0.73 B - 0.081 C - 0.049 D - 0.01 A*B + 0.04 A*C - 0.0002 A*D + 0.0003 B*C + 0.010 B*D - 0.0027 C*D. This means that the parameters were varied into ten different orientation to obtain the optimal value for the result using Grey Relational Analysis. The model indicates good correlations between the experimental and predicted results.

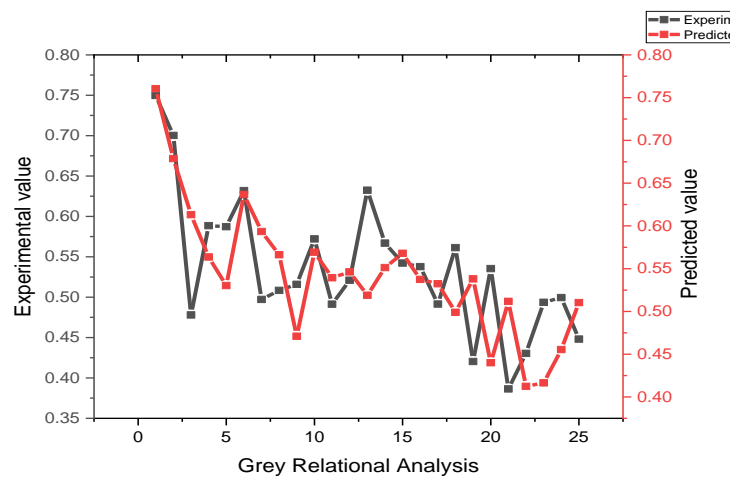


Figure 25. Modeling the Variation of Grey Relational Analysis of CMAA Composite

5 CONCLUSIONS

The mechanical properties of carbon fibres, metal chips, aluminum silicate, alumina and ultra-high density polyethylene composite have been studied using integrated Taguchi Grey Relational Analysis Technique. The mechanical properties: Tensile Strength, Flexural Strength, Impact strength and Hardness Strength of the composites were determined. These properties were studied under the variation of the reinforcements embedded in the matrix of ultra-high polyethylene resin. The variations of the mechanical properties as these parameters changes were the particulates of metal chips, alumina, aluminum silicate and 3-D woven carbon fibre on the mechanical properties of the composite at 95% confidence level. CF has 96%, Al₂O₃ has 39.64%, Al₂SiO₅ has 19.8% and MC has 3.8%. Carbon fibre has significance of performance and any alteration of the material affects the mechanical properties of the composite. The optimal value for the composite was gotten from grey relational analysis which is 10, 6, 5, 4.

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