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Application of Response Surface Methodology for Optimization of Parameters in Metal Powder Reinforced Polyethylene Terephthalate Matrix Composite

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The mechanical properties of the composite material are greatly influenced by the processing parameters. The degree of loading of the reinforcement particles and particle size play a crucial role in deciding the mechanical properties of the metal powder reinforced polymer matrix (MPRPM) composite material. The motive behind this research work was to accomplish optimum mechanical properties particularly, the tensile strength, the flexural strength, and the ductility in terms of percentage elongation of the metal powder reinforced in the Polyethylene Terephthalate (PET) matrix composite. After making the desired composite material, specimens were prepared and tested for anticipated mechanical properties. The effects of reinforcement loading in the matrix by weight and particle size on the mechanical properties were studied using central composite design through response surface methodology (RSM). A central composite design was incorporated to analyse the mechanical properties of the composite. The second-order polynomial model was used to predict the tensile strength, the flexural strength, and the percentage elongation. The two input process parameters namely percentage of reinforcement material, and the particle size of the reinforcement material were found to affect the properties. Also, the effect of input parameters on the above-mentioned properties have been verified using analysis of variation (ANOVA) technique. Encouraging consequences were found in the study. The optimized reinforcement of the metal powder was recorded to be 1.11374 % reinforcement of the metal powder by weight and that of particle size of the reinforcement metal powder was recorded to be 1.64975 µm. The optimized value of output responses i.e. tensile strength, % elongation and flexural strength was found out to be 11.3002 MPa, 11.3383 % and 11.0196 MPa for respectively.

Keywords: Response Surface Methodology (RSM), Metal Powder Reinforced Polymer Matrix (MPRPM) Composite, ANOVA techniques, central composite design, and Polyethylene Terephthalate (PET).

1. Introduction

The interest in the study of metal particle-reinforced polymer matrix material is increasing in terms of the mechanical properties and behavior of the composite material. Implementation of optimization techniques such as the response surface methodology (RSM) is necessary in the optimization of process parameters of composite materials.

To optimize the effect of process variables, Response Surface Methodology (RSM) is one of the statistical tools used to design experiments. Principles of Design of Experiments (DOE) are the base of RSM. DOE is a field of applied statistics that plans, conducts, analyses, and interprets controlled tests to assess factors that affect parameter values. Response surface methodology or RSM uses a statistical method for designing experiments and optimization.

Mechanical properties

Polymer matrix composites, particularly polyethylene terephthalate (PET) matrix reinforced with inorganic particles find a vital role in many engineering applications with the mechanical properties of the same play a vital role in selection of these composite materials [1]. Many researchers earlier presented their work on mechanical properties of polymer-based composites. Sharma et al. [2] used fly ash as reinforcement in the matrix of PET to make different concentrations varying from 5% to 50% of fly ash reinforcement. They observed that 10 % fly ash by weight showed 22-27 MPa tensile strength, and 20 % fly ash by weight shows 28-34 MPa tensile strength [2]. Cinar et al. [3] found that when marble dust is used as reinforcement in recycled PET matrix observed an enhancement in the mechanical properties. They observed that the hardness increases to 35 VPN for 25 % particle reinforcement while flexural and tensile strength were reported to be about 50 MPa and 16 MPa [3]. Hayder et al. [4] studied the effect of the addition of aluminum oxide (Al_2O_3), and Calcium oxide (CaO) nanoparticles in the polymer matrix for different combinations of reinforcements on the tensile strength of the composites. They observed that 15% of reinforcement resulted in tensile strength of about 53.2 MPa at 550^0C and 47.2 MPa for 10% reinforcement at 850^0C while the bending strength was observed to be 69.5 MPa and 73.5 MPa for 550^0C and 850^0C, respectively. Also, the hardness values reported by them at the above mentioned conditions are found to be 89 and 79 shore D value, respectively. Nikolai et al. [5] studied the effect of addition of fly ash filler in PET polymer on the compressive behavior of the composite and found that the compressive strength was 52 MPa for 55 % reinforcement while the same was 78 MPa for 65 % reinforcement of fly ash. Osorio et al. [6] reinforced zinc particles in PET matrix to enhance the mechanical properties and found that the Shore hardness increased to 9 MPa at 20 % weight while the impact resistance rose from 8 J/m at 30 % weight to 10 J/m at 40 % weight. Nikam et al. [7] tried to reinforce Al_2O_3 nanoparticles in a PET matrix and observed that the tensile modulus increases to 2800 MPa for 4 % while the same decreased slightly to 2500 MPa with an increase in the weight % of the nanocomposite. Also, they observed that there was slight decrease in the ductility with the increase in the weight % of the reinforcements [7].

1.1 Response surface method

Designs of Experiments (DOE) is being used to optimize the reinforcement parameters of the composite materials over the past few decades and response surface methodology (RSM) is one of the available techniques which is widely being used to optimize the reinforcement parameters. Roopesh et al. [8] developed four quadratic models to correlate the process variables to the responses and employed the RSM for the optimization of multi-objective process parameters. Iliyasu et al. [9] used the RSM technique based on central composite (circumscribed) design (CCD) to fit the first-degree polynomial to produce the composite material. Radhika and Raghu [10] determined the dry sliding wear behavior of the composite material and suggested the possible applications of the developed composite material. Chelladurai et al. [11] investigated the preparation of the composite material and predicted the hardness of composite material using the RSM technique. Nagabhooshanam et al. [12] worked to reduce the shrinkage porosity formation using RSM-based Box-Behenken Design (BBD) and determined optimized process conditions in the manufacturing of the composite material.[12] Niranjan et al. [13] developed mathematical models based on response surface methods and tested the developed model using analysis of variation (ANOVA) and found the model to be adequate. Yasser et al. [14] used the response surfaces technique ANOVA and the mathematical models for predicting mechanical properties of the nanocomposite. Rostamiyan et al. [14] used RSM technique to optimize the estimated tensile and flexural properties of nanocomposite. Kumar et al. [15] developed a mathematical model by response surface method and used the same to optimize the process parameters of hybrid polymer matrix composite and the result were used for the preparation of the composite material. Tharazi et al. [16] employed statistical analysis to optimize the tensile parameters of the composite using the DOE technique and highlighted the importance of RSM. Ragunath et al. [17] incorporated the RSM to discuss the mechanical properties of sisal-glass fiber hybrid composite for optimizing of mechanical properties. [17] Singh et al. [18] used the RSM to investigate the effect of reinforcement micro-particles on the mechanical properties of composite material while Laouici et al. [19] developed mathematical models for predicting the tensile strength and the Young’s modulus and tested the same with the ANOVA technique and found a close agreement with the same. Yadav et al. [20] studied the effect of machining parameters and incorporated the RSM for optimizing the machining parameters. The study of literature suggests that the mechanical properties play a crucial role on the performance of the structures made of composite and nanocomposites and hence, several researchers used various techniques to optimize these properties. Amongst the many techniques used to optimize the material property parameters, research showed the RSM is widely used. Hence, the present work deals with the optimization of the mechanical properties of novel metal powder reinforced polymer matrix (MPRPM) composite material using central composite design through response surface methodology (RSM). The ANOVA technique has been used to develop a polynomial equation to determine the accuracy of the optimized properties.

2. Experimentation

A novel composite material reinforced with the metal powder in the matrix of polyethylene terephthalate (PET) was developed using compression molding technique and was tested for tensile and flexural tests on a Universal Testing machine. The various steps involved in the preparation of the MPRPM composite are displayed in figure 1. The results of the tests were optimized using central composite design through Response Surface Methodology.

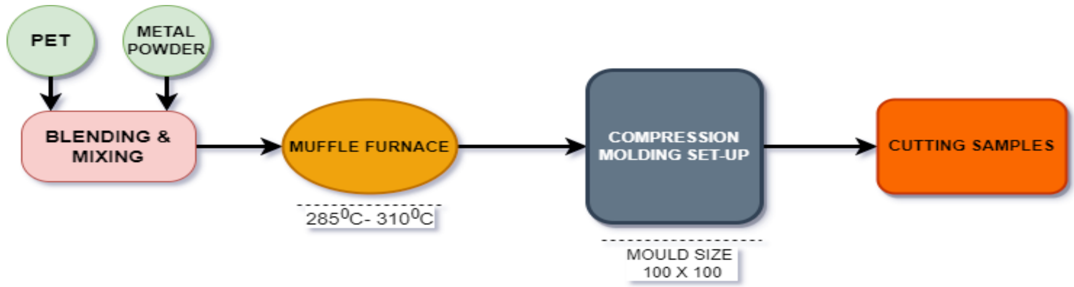


Fig 1: Schematic representation of Sample preparation for carrying experimentation

2.1 Materials

The composite material developed incorporate, the metal particle which acts as a reinforcement in the Polyethylene terephthalate (PET) polymer matrix. The reinforcing material is mild steel in powder form and was supplied from the local industry scrap while the PET material is the matrix phase. The compression molding manufacturing process has been employed for the preparation of the composite.

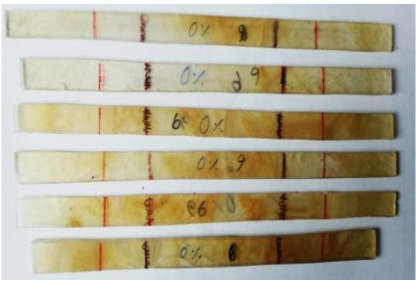
2.2 Sample preparation

Samples were cut from a sheet prepared by the compression molding technique. Variation in the samples was obtained by changing the mild steel powder particle size and different combinations of mild steel powder reinforcement (by varying the weight percentage of the metal powder) into the matrix. Table 1 explains the different variations of particle size for different weight percentages (wt%) of the metal powder are shown. A total of 27 samples with different combinations of reinforcement of mild steel powder for different particle size of varying weight percentages were prepared. The weight percentages range from 0 wt % to 4 wt% with 0.5% increments while the particle size are categorized into three types greater than 4µm, 2µm to 4µm, and less than 2µm, respectively. The samples for different weight, are displayed in figure 2.

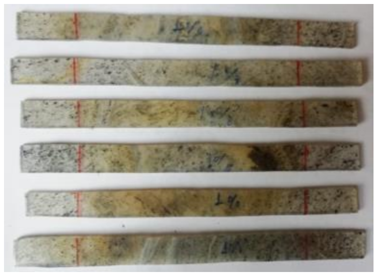
2.3 Testing for Mechanical Properties

Tensile and Flexural Test:

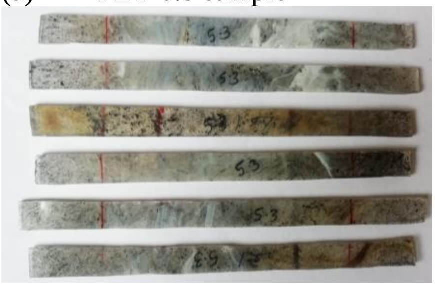
The samples prepared were tested as per ASTM standards for tensile testing and flexural testing by a Universal Testing Machine of the make KIC-2-100-C according to ASTM D3039 and ASTM D790 at the crosshead speed of 2.00 mm/min. All the samples cut from similar compression moulded sheets for different wt% of metal powder reinforcements were coded as PET-X.X which are shown in figure 2.



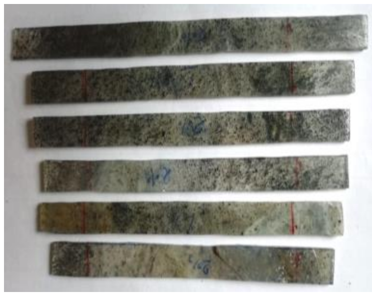
(a) PET-0.5 sample



(b) PET-1.0 sample



(C) PET-1.5 sample



(D) PET-2.0 sample

(E) PET-2.5 sample

(F) PET-3.0 sample

(G) PET-3.5 sample

(H) PET-4.0 sample

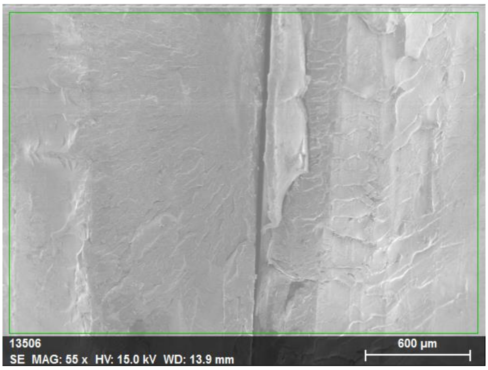
Fig 2: Sample cut from compression moulded sheet for different wt% of metal powder reinforcements

Table 1: Parameters for sample preparations

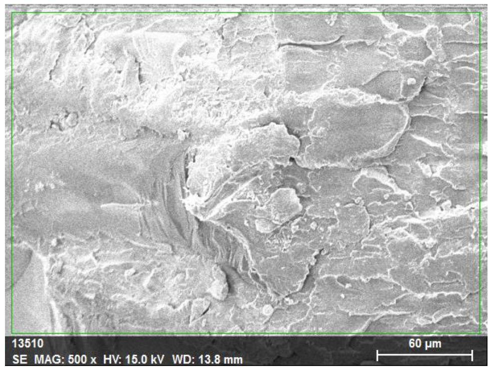
S. No.	Weight percentage of reinforcement of the metal powder (wt %)	Particle Size (µm) (micrometers)
1	0	> 4
2	0.5	
3	1	
4	1.5	
5	2	
6	2	
7	3	
8	3.5	
9	4	
10	0	2-4
11	0.5	
12	1	
13	1.5	
14	2	
15	2	
16	3	
17	3.5	
18	4	
19	0	< 2
20	0.5	
21	1	
22	1.5	
23	2	
24	2	
25	3	
26	3.5	
27	4	

Scanning Electron Microscope

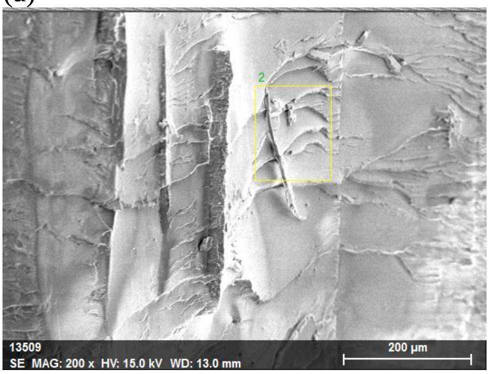
SEM was carried out using JOEL JBM-6380-A scanning electron microscope operated at 15.0 KV for characterization of the microstructure and evaluation of dispersion of reinforcement in the matrix. SEM micrographs were shown in Figure 3 (a)-(d) and EDS spectrums were plotted in Figure 4 (a)-(d). the micrographs and EDS spectrum show the presence of metal powder in the polymer matrix and the dispersion of the reinforcement of metal powder in the entire matrix.



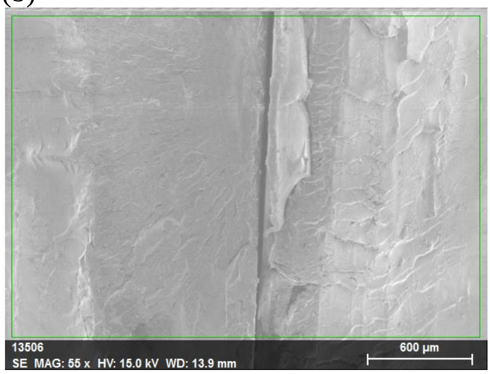
(a)



(b)

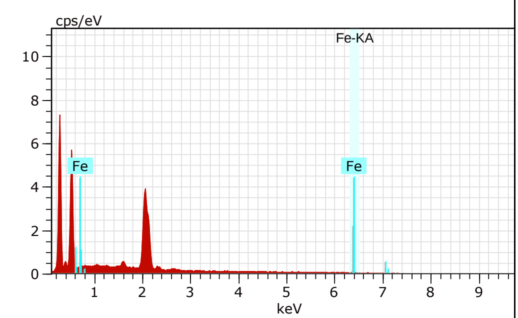


(c)

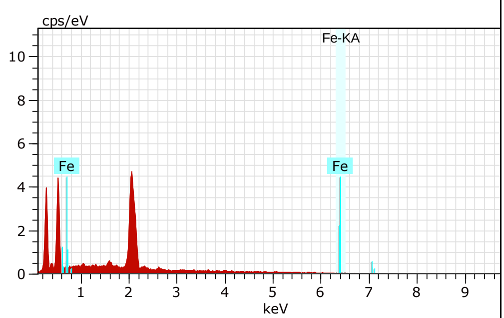


(d)

Fig 3. Scanning Electron micrographs (a,b, c, d) for different concentrations of the reinforcement material in the matrix



(a)



(b)

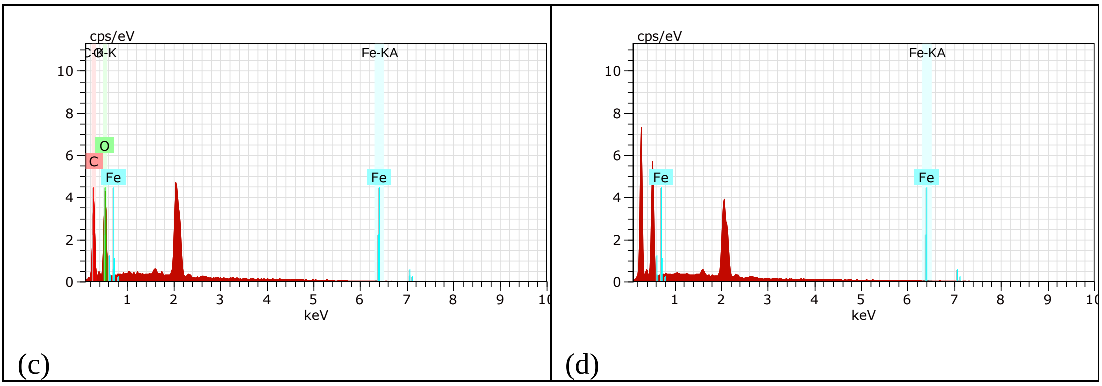


Fig 4. EDS spectrums(a,b, c, d) for different concentrations of the reinforcement material in the matrix

Results of tests:

From the obtained results, it is found that there is a slight increase in percentage elongation for PET-2.0 and for samples of PET beyond 2.0 there is a decrease in the percentage elongation. It has been observed that the with a good distribution of particulates in the matrix that it for good reinforcing mechanism of the composite, the results showed an improvement in the strength of the composite with increase in weight percentage (wt %) of metal powder in PET [7]. An increase in the tensile strength of the material is recorded with the increase in the reinforcement concentration and this increase in the tensile strength is due to the considerable growth in particle loading [7, 21]. Considerable growth was recorded in flexural strength with an increase in particle concentration and the observed data suggests that the degree of dispersion of reinforcement particulates plays an important role in deciding the mechanical properties [22]. Observation of the images and micrographs of the samples showed that the homogeneity of distribution of M.S. particulate into the PET matrix increases up to PET-2.0. However, as the PET-X increased further, it was observed that the uniformity of distribution was a bit disturbed. Accumulation of particulates at higher PET-X contents resulted in an agglomeration effect in certain areas.[25]

In a few cases, it was also observed that the accumulation of particles occurred at the edges than the core. This is because of a sudden impact at the center during compression molding resulting in a greater flow of particulates towards the edges.[26]

3. Optimization

3.1 Response Surface Method

Response surface methods (RSM) is one of the available techniques to optimize the operating parameters or conditions in the system from Design of Experiments (DOE) techniques [23]. When the number of potential input variables affects the characteristics or performance of a product or a process, RSM is particularly preferred [24]. Various parameters affect the mechanical properties of the composite material prepared and in the present study, the weight percentage of metal powder particles for reinforcement was taken as the first factor (input parameter) while the particle size was considered as the second factor (input parameter). The weight percentage of the metal powder reinforcement were varied from 0 % to 4 % with 0.5% incremental increase with particle size taken were categorized into three types particularly <2µm, from 2-4µm, and >4µm, coded as 1, 2, and 3 respectively. A total of nine samples for each combination of factors were tested and values after testing as per ASTM standards were used for optimization. Table 2 shows the input processing parameters and their responses in detail for response surface methods while table 3 shows the input parameters considered.

Table 2: Input process parameters and responses

Run	Factor 1 A: Weight% Metal Powder (wt%)	Factor 2 B: Particle Size (µm) (micrometres)	Response 1 Tensile Strength (MPa)	Response 2 Flexural Strength (MPa)	Response 3 % elongation (% El)
1	0	3	10.23	10.38	13.24
2	0.5	3	11.38	10.97	13.16
3	1	3	11.91	10.87	12.84
4	1.5	3	13.16	11.21	12.46
5	2	3	13.35	11.34	12.36
6	2	3	12.84	11.21	12.12
7	3	3	12.46	10.63	11.91
8	3.5	3	12.36	10.41	11.38
9	4	3	12.12	10.1	10.23
10	0	2	9.4	10.34	12.52
11	0.5	2	10.34	10.94	12.5
12	1	2	11.37	11.06	12.41
13	1.5	2	12.41	11.26	11.84
14	2	2	12.7	11.1	11.37
15	2	2	12.52	10.84	11.26
16	3	2	11.84	10.42	10.74
17	3.5	2	11.26	10.54	10.34
18	4	2	10.74	9.99	9.94
19	0	1	8.77	10.46	11.84
20	0.5	1	9.38	10.8	11.78
21	1	1	10.25	10.74	11.76
22	1.5	1	11.76	10.86	11.27
23	2	1	11.97	11.12	10.76
24	2	1	11.78	10.79	10.68
25	3	1	11.27	10.15	10.25
26	3.5	1	10.76	10.04	9.38
27	4	1	10.68	9.29	9.07

Table 3: Input factors considered

Factor	Name	Type	Sub Type	Minimum	Maximum	Coded Low	Coded High	Mean	Std. Dev
A	Weight% Metal Powder (wt%)	Numeric	Continuous	0	4	-1 ↔ 0.00	+1 ↔ 4.00	1.94	1.3
B	Particle Size (µm) (micrometres)	Numeric	Continuous	1	3	-1 ↔ 1.00	+1 ↔ 3.00	2.00	0.8321

To investigate the influence of characteristics on the properties of the prepared composite material, Analysis of Variation (ANOVA) was used. The reason behind considering the

ANOVA was to determine the significance of the parameters considered such as particle size, and variation in the reinforcement on the mechanical properties such as tensile strength, ductility, and flexural strength.

3.2 Analysis of Variation (ANOVA)

Design of Experiments was incorporated to analyze the obtained results using Response Surface Methodology (RSM). The response parameters obtained using the above were analysed using ANOVA [19] and the results for the ANOVA pertaining to the tensile strength are shown in Table 4 while the results pertaining to percentage elongation, and the flexural strength are shown in Tables 5 and 6.

Table 4: ANOVA results for Tensile Strength

Source	Sum of Squares	DoF	Mean Square	F-value	p-value	Status
Model	34.24	5	6.85	58.1	< 0.0001	significant
A: Weight% Metal Powder (wt%)	6.47	1	6.47	54.86	< 0.0001	
B: Particle Size (µm) (micrometres)	9.59	1	9.59	81.4	< 0.0001	
AB	0.0394	1	0.0394	0.3344	0.5692	
A^2	18.89	1	18.89	160.31	< 0.0001	
B^2	0.0299	1	0.0299	0.2534	0.6199	
Residual	2.47	21	0.1179			
Lack of Fit	2.31	18	0.1284	2.34	0.2637	not significant
Pure Error	0.1643	3	0.0548			
Cor Total	36.71	26				

Standard deviation = 0.3433 R-square = 0.9326

Table 5: ANOVA results for percentage elongation

Source	Sum of Squares	DoF	Mean Square	F-value	p-value	
Model	29.66	5	5.93	47.51	< 0.0001	significant
A: Weight% Metal Powder (wt%)	5.19	1	5.19	41.58	< 0.0001	
B: Particle Size (µm) (micrometres)	9.22	1	9.22	73.81	< 0.0001	
AB	0.0082	1	0.0082	0.0660	0.7997	
A^2	15.90	1	15.90	127.30	< 0.0001	
B^2	0.0078	1	0.0078	0.0627	0.8048	
Residual	2.62	21	0.1249			
Lack of Fit	2.54	18	0.1411	5.16	0.1007	not significant
Pure Error	0.0820	3	0.0273			
Cor Total	32.29	26				

Standard deviation= 0.3534 R-square = 0.9188

Table 6: ANOVA results for Flexural Strength

Source	Sum of Squares	DoF	Mean Square	F-value	p-value	
Model	31.44	5	6.29	155.91	< 0.0001	significant
A: Weight%	21.38	1	21.38	530.05	< 0.0001	

Metal Powder (wt%)						
B: Particle Size (µm) (micrometres)	9.3	1	9.3	230.53	< 0.0001	
AB	0.0451	1	0.0451	1.12	0.3024	
A^2	0.4601	1	0.4601	11.41	0.0028	
B^2	0.0078	1	0.0078	0.194	0.6641	
Residual	0.847	21	0.0403			
Lack of Fit	0.8089	18	0.0449	3.54	0.1625	not significant
Pure Error	0.038	3	0.0127			
Cor Total	32.29	26				

Standard deviation= 0.1696 R-square = 0.8987

The 'F' value of the models for tensile strength, percentage elongation, and flexural strength were 58.1, 47.51, and 155.91, respectively which can be inferred and correlated to the model as significant. A very small P-value (tensile strength) with $P < 0.0001$ signifies that the generated model had a very little chance of showing error in the value of 'F' due to noise. The P value of less than 5 % and the determination to co-efficient R^2 of more than 89 % show that there was a relationship between the variables under consideration and they were represented adequately by the model [17].

3.3 Second-order polynomial of equations

The statistical equations model were developed based on data displayed in the table 4-6 and the experimental results based on ANOVA form the basis for the development of such equations and the same were given as follows:

$$TS = 8 + 2.70174*\%A + 0.52169*B - 0.036585\%a*b - 0.561415\%A^2 + 0.070556B^2 \quad (1)$$

$$\%El = 8.1972 + 2.436*\%A + 0.605*B - 0.016*\%A*B - 0.515\%A^2 + 0.0361B^2 \quad (2)$$

$$FS = 11.44 + 0.424*\%A + 0.496*B - 0.039\%A*B - 0.0876\%A^2 + 0.0361B^2 \quad (3)$$

Where TS is Tensile Strength, %El is percentage elongation, FS is Flexural Strength, A is the percentage of metal powder reinforcement, and B is the particle size. Since the R^2 value for the above equations was found to be more than 89 % and the predicted R^2 was in reasonable agreement with the Adjusted R^2 (i.e. the difference is less than 0.2), the equations 1-3 can be used to predict the tensile strength, the flexural strength, and the percentage elongation. However, these equations were valid only for the metal powder reinforcements in weight percentages (wt %) ranging from 0 wt% to 4 wt% in the matrix of the composite material.

3.4 Accuracy check of the Model

Any predicting model behaviour was based on the accuracy that the model provided us. To assess them the Figures 5-7 display the actual values versus the predicted values of the Tensile Strength (MPa), Percentage Elongation (%El), and the Flexural Strength (MPa), respectively. It was observed from these graphs that all the data was within the reasonable limits and no abnormal pattern of the data was observed from these figures.

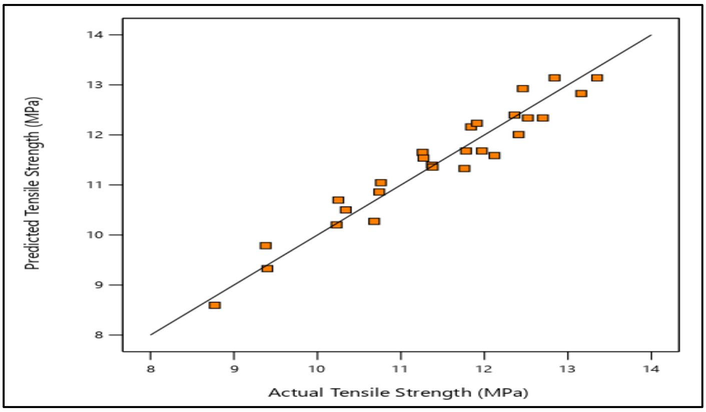


Fig 5 The Actual value vs Predicted Value of the Tensile Strength (MPa)

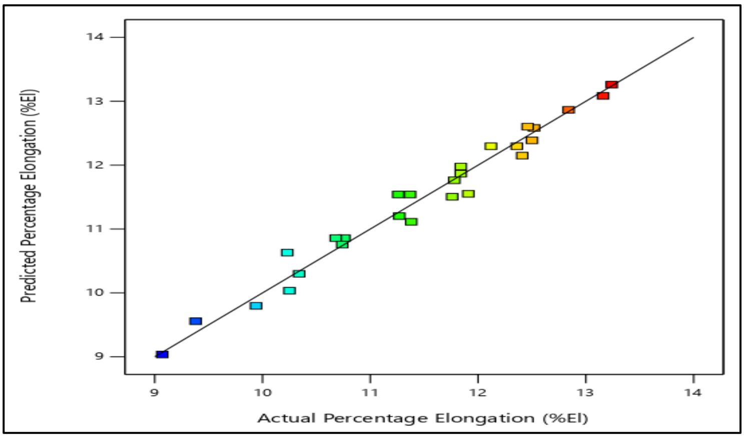


Fig 6 The Actual value vs Predicted Value of the Percentage elongation (%El)

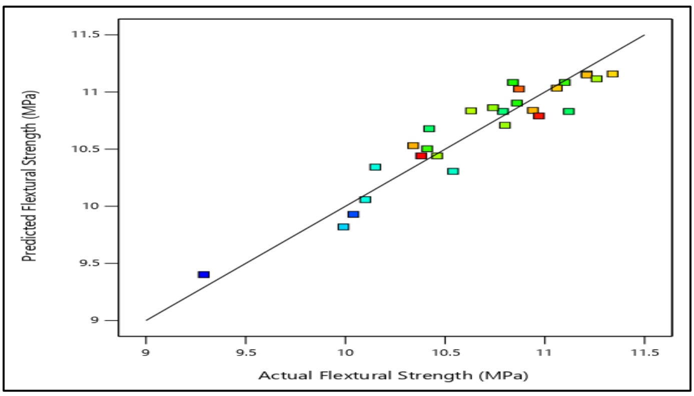


Fig 7 The Actual value vs Predicted Value of the Flexural Strength (MPa)

3.5 Input process parameter optimization

Optimum process parameters were considered and the 3D response surface graphs were displayed in figures 8-10 and contour plots are displayed in figures 11-13. The values of the tensile strength, percentage elongation, and flexural strength were unveiled by the proper 3D surfaces and the same are displayed in figs 8-10. While the contour plots for the same are displayed in figs 11-13. From the fig 8 and fig 9, it can be observed that the values of the tensile strength and flexural strength are found to increase with increase in the size of the metal particle reinforcement while the same were found increase initially up to a certain weight percent of particle reinforcement (up to 2wt%) and then started to decrease with increase in the weight percent of the particle reinforcement (beyond 2 wt%). However, 3D response plot in fig 10, the percentage elongation was found to decrease continuously with the increase in the particle reinforcement weight percentage while the same was found to increase with the increase in the size of the particle reinforcement.

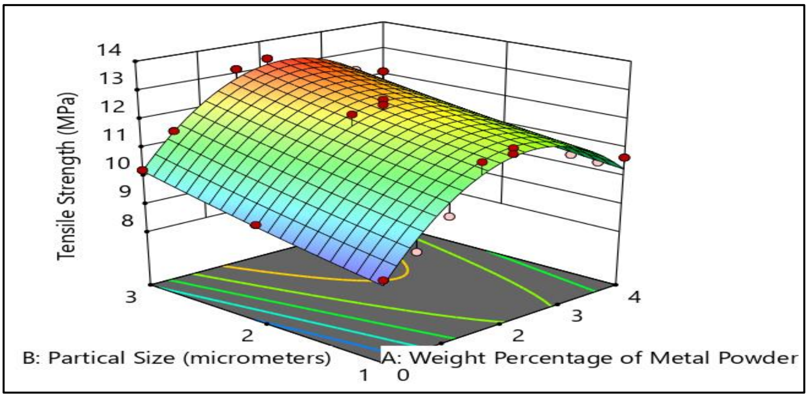


Fig 8: Surface plot detailing the effect of change in weight percentage of metal powder (wt %) of particle reinforcement, and particle size (µm, micrometres) on the Tensile Strength (MPa)

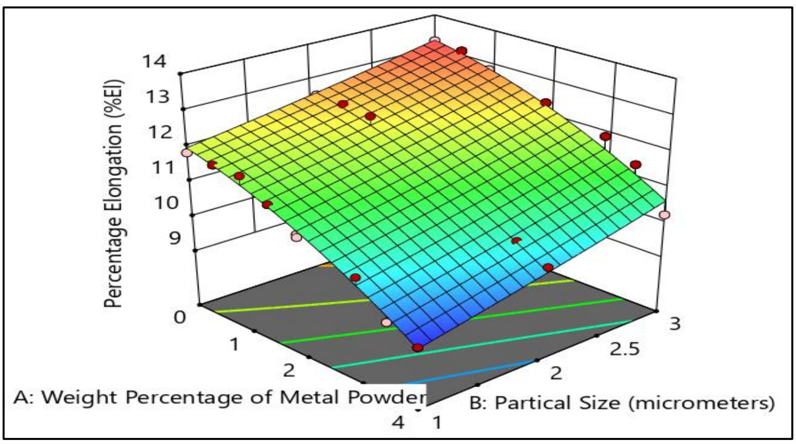


Fig. 9: Surface plot detailing the effect of change in weight percentage of metal powder (wt %) of particle reinforcement, and particle size (µm, micrometres) on the percentage elongation (%El)

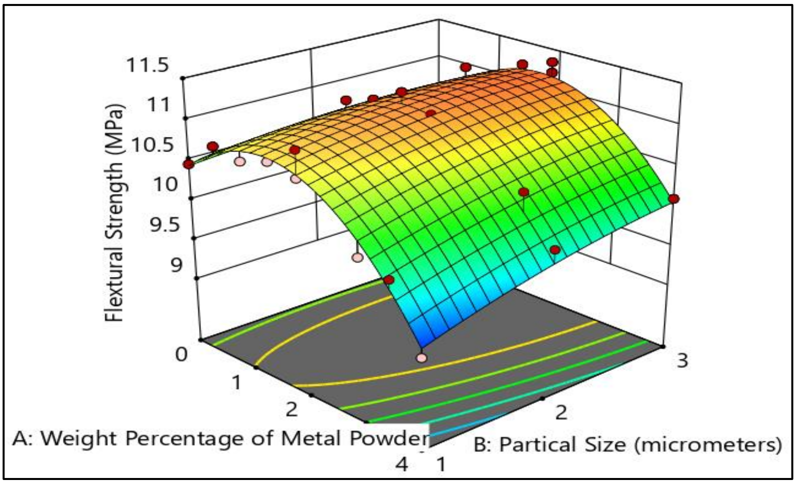


Fig. 10: Surface plot detailing the effect of change in weight percentage of metal powder (wt %) of particle reinforcement, and particle size (µm, micrometres) on the flexural strength (MPa)

Contour plots were displayed in figures 11-13 represent the response (Tensile Strength, percentage elongation and flexural strength) plotted against the combination of input factors (particle size and weight percentage of the metal powder) and clearly state the relation between the response and the factors. The tensile strength and the flexural strength were increased with the increase in both the input parameters, particle size as well as weight percentage of metal powder up to certain limit and thereby decreasing with increase in the weight percentage of the metal powder. While percentage elongation was considerably decreased with increase in the weight percentage of the metal powder and shown significant rise with increase in particle size.

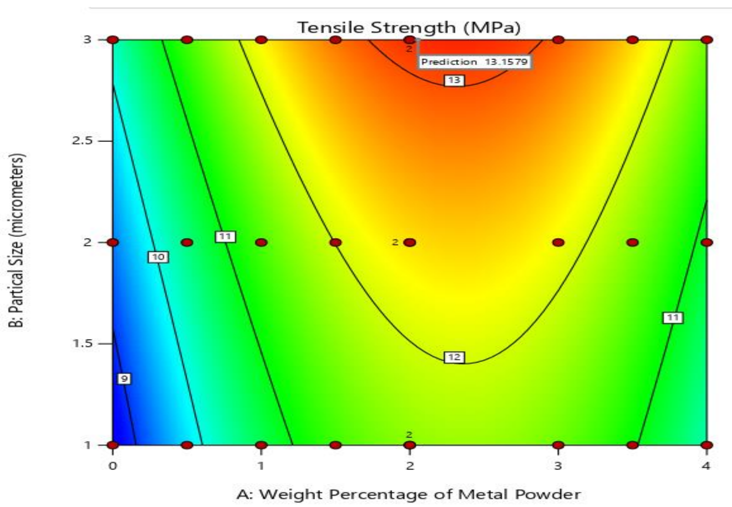


Fig 11 Optimization for Tensile Strength

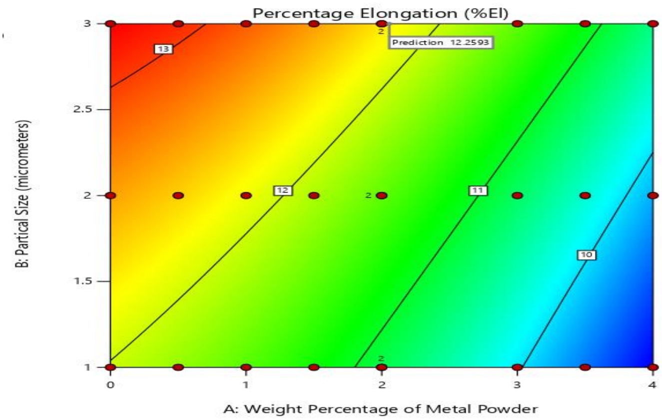


Fig 12 Optimization for % elongation

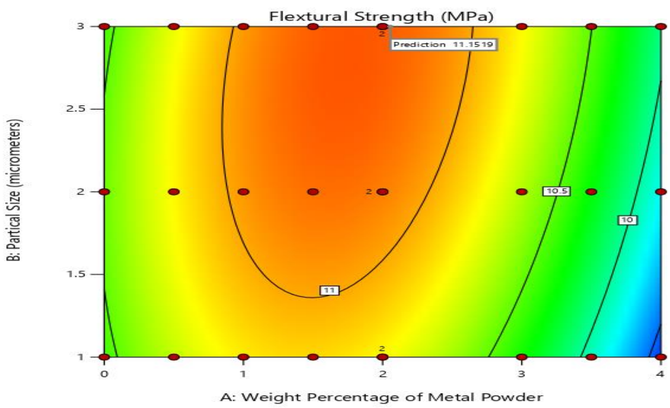


Fig 13 Optimization for Flexural Strength

RSM helps to reach the optimum value using Design Experts software which leads to 1.114% metal powder reinforcement loading with an optimum particle size to be 1.65 μm.

3.6 Solutions

The optimization at the input level and ramp reports were exhibited in Figure 14. The red and blue dots seen in the ramp report indicate the optimum input and output response for the composite material. The tensile strength value of 11.3002 MPa, flexural strength of 11.0196 MPa, and percentage elongation of 11.3383 were the optimum suggested values using RSM for 1.114% metal powder reinforcement loading with 1.65 μm particle size. DOE was created through RSM using the Box Behnken technique in Design Expert software version 13 for optimization. In this optimization, 2 input parameters and 3 output response parameters were used as represented in Table 2. ANOVA test was performed before optimization and the significance of the model was found for all three responses as shown in Tables 4, 5, and 6. The significance of the model in ANOVA depends on the P value. The value of P was less than 0.001 in all the tests (for the tensile, and flexural tests) for all the models signifying the accuracy of the value. [19] According to Figure 1 (a-c), the value of every test remains within the limit range employing a second-order equation.

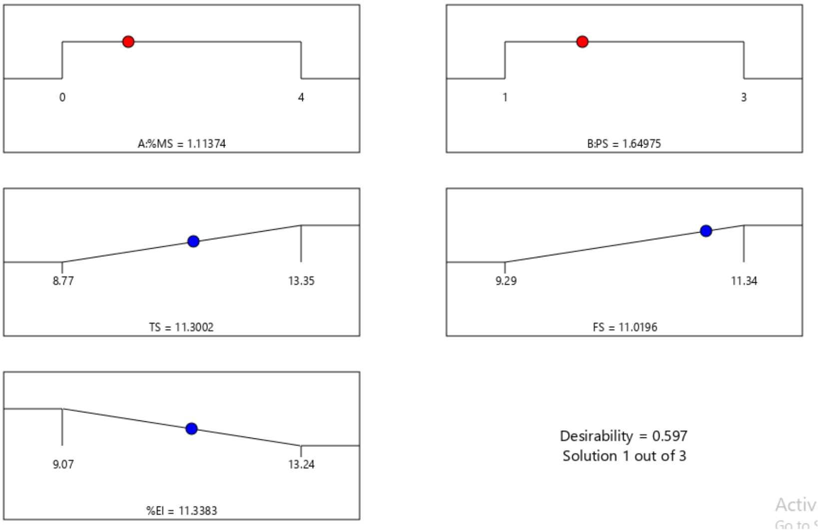


Fig 14 Optimization at Input Level

4. Conclusion

Observations suggest that with the increase in the reinforcement particle loading (weight percentage of the metal powder), the tensile strength and the flexural strength increased considerably with a sizeable decrease in the percentage elongation of the composite material. The statistical study was incorporated to optimize the results. 3D surface plots using response surface methodology were generated to find the optimum area within the designated range of process parameters. To relate the process variables to the responses, three quadratic models were developed. 1.114% metal powder reinforcement loading (weight percentage of the metal powder) with an optimum particle size to be 1.65 μm were the optimized values for input parameters. In this experimentation, 27 combinations of the samples were prepared and tested for tensile strength, percentage elongation, and flexural strength as per ASTM standards. Optimization of the values was achieved by using response surface methodology.

In the presented study samples of polymer matrix composite material reinforced with metal powder were prepared and tested according to ASTM standards for tensile and flexural tests. There were 27 experiments conducted with the help of Design Expert software to optimize the parameters by application of response surface methodology. During the work, following conclusions were made:

- The effect of loading of the reinforcement (weight percentage of the metal powder) in the matrix by weight percentage and particle size on the mechanical properties was successfully studied using response surface methodology.
- Three quadratic models were obtained for finding the corelation of process variables to the responses.

- The maximum tensile strength, % elongation and flexural strength was found out to be 13.35 MPa, 11.33 % and 11.34 MPa respectively.
- The optimized input process parameters were found out to be 1.11374 % reinforcement of the metal powder by weight and 1.64975 μm particle size of the reinforcement material.
- The optimized value of output responses was recorded as 11.3002 MPa, 11.3383 % and 11.0196 MPa for tensile strength, % elongation and flexural strength respectively.

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