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Investigation on water absorption and wear characteristics of waste plastics and seashell powder reinforced polymer composite

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KEYWORDS

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Taguchi method

ABSTRACT

The need for alternate materials and the development of newer composites are increasing nowadays. The demand for specific characteristics leads to the development of the composites with various reinforcements. Reinforcements are selected based on the required properties and their field of applications. The composites need to have more resistance to wear and water absorption to use these materials under friction and underwater applications. The reinforcements added to the composite must provide hardness and wear resistance and it must repel the moisture. In this work, to acquire the required properties, the epoxy matrix is reinforced with waste plastic particulates and also filled with seashell powders. The composites are produced by mixing these reinforcements and fillers and tested for its wear and water resistance. The results showed the addition of the waste plastics and seashell powder improved the wear resistance and reduced the moisture absorption property of the composites. The results are also analyzed to study the most affecting parameter, which influences the water absorption, and wear property of the composites.

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1.0 INTRODUCTION

Generally, the seashells have better moisture resistance property as they are always inside the seawater. They have better corrosion resistance and hardness properties by nature, which in turn makes them tough against wear also. This is the main reason behind the selection of the seashell powder as a filler material for this composite. Also, as the seashell powders are ball-milled and made into powders, they fill the micropores of the composites produced during production and curing. It makes the composites to be a defect-free and when a material is defect-free, it possesses better physical and mechanical properties. Shettigar et al., 2018, fabricated and tested glass fiber reinforced epoxy composite filled with seashell and found that the composite can be used for making auto parts, helmets, etc, and also established that the addition of the seashell fillers minimizes the tensile properties of the composites.

Jena & Kumar et al., 2019, studied the influence of different factors in the drilling of composite filled with clamshell powders and determined that filler inclusion has a considerable effect on the surface roughness. Gopal Krishna et al., 2020, experimented in determining the characteristics and properties of the glass fiber and seashell added epoxy composite and says that the elements in the seashell and the fiber binding with the matrix is responsible for the hardness and the tensile strength. Balan & Ravichandran, 2019, investigated the tribological and osmosis properties of the hybrid composite and concluded that by adding silica to the composite, the water intake and wear rate gets reduced. Balan et al., 2019, worked on the osmosis property of the jute fiber-reinforced composite and found 10 wt.% of jute fiber and waste plastics of 30 wt% will lead to reduced water intake. Vigneshwaran et al., 2018, experimented on polymer composites by dispersing Dosinia exoleta powder and studied its influence on thermal properties and revealed that the filler dispersion improved the properties.

Ananthu et al., 2018, conducted experiments on wear and mechanical properties of the PMMA seashell nanocomposites and observed that wear resistance and hardness were enhanced due to the addition of the seashell nanopowders. Rakshit et al., 2017, revealed that the vibration and mechanical properties of mother of pearl filled polymer composites improved results in vibration and flexural tests at 15% of fillers. Subagia & Suardana, 2019, worked on brake lining and found seawater absorption on corrosion and hardness properties, the composites showed better hardness with an increase in basalt powder addition, and in seawater testing the composite found to be corrosive. Owuamanam & Cree, 2020, observed the tensile, flexural, and the impact toughness of composites reinforced with waste eggshell and seashell fillers and revealed that egg and seashells treated with surface modifiers improve the physio-mechanical characteristics of the composite.

Mindivan & Goktas, 2020, added seashell wastes along with reduced graphene oxide to the PVC matrix and found that seashell and RGO would be effective as they showed better interfacial interactions with the matrix and also seashells showed better distribution if added between 15% to 20 %. Moustafa et al., 2015, prepared a composite with fillers from seashells in ABS and studied the thermal and mechanical properties and revealed that thermal stability and better flame retardant properties were achieved with the addition of the seashells. Nallusamy et al., 2017, made an investigation on composite with different filling agents reinforced with coir and found that seashell powder provided better flexural and tensile strengths than bone powder which gives good impact and compressive strengths. Panigrahi et al., 2018, analyzed the effect of Clams shell in jute reinforced epoxy composite for its impact properties and found that the hardness value increases, and the strength reduce as the addition of the filler is increased. Rajan et al., 2019a, observed the effect of surface treatment by silane on physical and mechanical characteristics of powdered shell reinforced composite and found that the shell powder acts as a probable friction material for the application in pads used for braking of commercial vehicles.

The plastic particulates naturally have the water repulsion quality and they also offer better resistance to wear. If the reinforcement well adheres to the matrix, then the mechanical properties will be better. As there are no natural fibers that are used in this, there is no hydrophobic and hydrophilic mismatch between matrix and reinforcements. Daramola et al. worked on the tribological behavior of polylactic acid reinforced with crab-shell micro particles and found that 10 wt% of chitosan particles contribute to maximum wear resistance. Singaravelu et al., 2019, developed and evaluated the performance of brake pads made from crab shell powder and found that thermally processed crab shell brake pads showed improved thermal stability and fade characteristics. In the chase test, it showed better performance. Rajan et al., 2019b, evaluated the tribological performance of silane treated shell powder in composites and found that treatment improved the brake pad performance as per IS 2742 standards and overall tribological performance.

From the above literature survey, the present work aims to develop the epoxy-based composite reinforced with waste plastic and seashell powder and analyze the water absorption and wear behavior of the produced composite.

2.0 MATERIALS AND METHODS

The waste plastics are collected from domestic waste. Mostly the waste plastics of the same type are segregated for adding as reinforcement. The waste plastics collection comprises of waste Cd’s and DVD’s, which are made up of polycarbonate material. The collected plastics are cleaned with water to remove the dust and the sediments and the dried. Then the plastics are made into particulates by crushing them and the crushed particles are then sieved to maintain uniform particulate size. As the southern part of India is covered by seas and oceans on its three sides, the sea products available in abundance. The seashells are available in plenty of numbers and in various shapes and sizes. They are rich in calcium carbonate and other minerals. They are collected from the seashore near Kanyakumari and cleanse using freshwater. Cleaned shells are dried, crushed and ball milled to produce filler powders. The epoxy resin and the stiffener are purchased at Aiswarya polymer company, Coimbatore. As per the manufacturer’s instruction, the resin and the hardener are mixed in 50:50 ratios by weight. The crushed and sieved plastic particulates, raw seashells, and seashell powders are shown in Figure 1.

Mostly, the polymer composites are manufactured by hand layup or spray layup methods. The composite has the reinforcement and the fillers in the particulate and powder form, so the stir method is followed. Like the stir casting process, without applying heat, the reinforcements and fillers are added to the resin in steps and stirred well for a particular time and then the mixed slurry is poured into the mold. The whole process takes place at room temperature without the application of heat. The resin slurry is mixed well to ensure the homogeneity and uniform spread of the reinforcement and the fillers. The mold is coated before a gel coat for the easy removal of the composites. The resin and the hardener are mixed in a separate beaker in a prescribed ratio. The plastic waste and the seashell filler powder are weighed and then mixed along with the resin mixture with constant stirring action. The reinforcement and the fillers are added one by one in steps to avoid the clustering of the particles. Then after 10 mins of constant stirring, the mixed content is emptied onto the template. The slurry is made to spread all over the mold and then allowed to cure. The top portion of the mold is covered to avoid direct air contact. The mold is then compressed with the male part slowly which makes the excess resin content to be spilled out. Then the composite part is cured and finished for perfection.

Figure 1: Experimental work plan.

2.1 Water Intake Test

Plastics are organic polymers which has hydrophobic ends over its structure. The organic groups have affinity to organic species and polar groups have affinity to polar species. Water is naturally polar and hence it is repelled by the organic group plastics. To test the moisture intake properties of a material, the ASTM D590 testing method is followed. After curing, the specimens are cut to the required shape and size using water jet cutting technology. The nine specimens which are manufactured as per the Taguchi's orthogonal experimental design are weighed to find their mass before the test. Then the specimen peripheries are insulated with waterproof tape to avoid water percolation through the sides of the specimen. This will allow the water through the specimen surface alone. After weighing, the specimens are dipped into distilled water which was placed in a beaker. The specimens are ensured that they are kept immersed during the testing period. The test was carried out for 24 hours and after that, the pieces are dried with a cotton cloth and insulations were removed. Then the specimens are weighed to find out the weight gain due to the immersion test. The deviation of the final weight from the initial weight gives the moisture absorption percentage.

2.2 Wear Test

The crab shell exoskeleton is made up of protein known as calcium carbonate and chitin which are hard in nature. As the carb shell powder is added to the polymer composite, it provides the resistance to the wear and abrasion due to the hard nature of the shells. To test the wear resistance of a material, ASTM G99-17 procedure is observed. A wear evaluating machine which comprises of a steel disk of known wear rate which rotates at different speed levels. The pin on disc wear tester is shown in figure 1. The top of the disk is placed with a pin in which the specimen to be tested has to be placed. As the disk rotates, the pin will be forced to contact the disk by a known weight. A load of 5 N is applied and the disk is rotated at 600 rpm and the experiment was conducted for 15 mins. The specimens are cut to fit the pin of the wear testing machine. Before testing, the initial weights of the specimens are noted. The gliding length was computed by equation 2 and the wear rate and the rate at which wear takes place were estimated by equations 3.

$$\text{Gliding length (m)} = 3.14 \times \text{Diameter of the wear track (mm)} \times \text{speed of the disk (rpm)} \times \text{Test time (Seconds)} / 60000 \tag{1}$$

$$W = K / D \tag{2}$$

W = Rate of wear in Kilograms / meter
K = Amount of wear in Kilograms
D = Gliding length in meters

$$W_{specific} = W / F \tag{3}$$

$W_{specific}$ = Specific wear rate in Kilogram / Newton meter
F = Normal force in Newton

2.3 Taguchi's Orthogonal Array

Taguchi orthogonal array is being used to find the optimum conditions of parameters for the responses. The L9 orthogonal array is used to understand the impact of 4 independent parameters with 3 factor levels of values. In this work, three independent parameters with three levels are analyzed for the 2 responses. Hence L9 orthogonal array is well suited and used for the analysis. In this work, the interaction plot is provided to understand the interaction between parameters for the two different material properties such as water absorption and wear rate.

3.0 RESULTS AND DISCUSSION

To determine the optimum levels for maximum mechanical properties and to interpret the most influencing factor which decides the characteristics of the material, optimization techniques assists. Taguchi's orthogonal array technique is followed which is a traditional method and provides accurate results. In Taguchi's experimental design, three level design with three number of factors were chosen and the input parameters are provided. L9 Orthogonal array design was chosen, and the factors and their levels were given as input. The MINITAB software will generate a work sheet in which the levels of each factor will be indicated, and the experiments have to be conducted as per the proposed design. In this work, three factors and three levels are chosen for the DOE. Table 1 conveys the chosen factors and their levels. Table 2 provides the details of L9 experimental plan with the findings. Figure 2 displays the water absorption (%) and the specific wear rate for the fabricated samples as per the experiment number. The lowest water absorption has resulted in experiment number 9 and the plastic particulate percentage is 30 and the seashell powder percentage is 15 while the stirring time is 10 minutes. Similarly, the low wear rate is obtained for the same experiment number. The reason is that more inclusion of plastic particles and seashell powder. These inclusions would act as resistant to the wear and water absorption characteristics of the composites. The addition of seashell powder improved the mechanical properties for the glass-reinforced epoxy composite (Shettigar et al., 2018) and thus here also these seashell powder contributed to the improvement wear resistance of the proposed epoxy composite.

Table 1: Process characteristics and their levels.

Sl. No.	**Parameters**	**Units**	**Levels**		
			1	**2**	**3**
1	Constitution of waste plastic particulates	Wt.%	10	20	30
2	Constitution of Seashell powder	Wt.%	5	10	15
3	Stirring time	Mins	5	10	15

Table 2: L9 experimental design with results.

Experiment No.	**Process parameters**			**Water absorption (%)**	**Specific wear rate ×10^{-6} Kg/Nm**
	Constitution of Plastic particulates (A) (Wt.%)	**Constitution of Seashell powder (B) (Wt.%)**	**Stirring time (C) (Mins)**		
1	10	5	5	1.65	10.85
2	10	10	10	1.43	8.63
3	10	15	15	1.07	6.27
4	20	5	10	1.10	9.32
5	20	10	15	0.99	7.19
6	20	15	5	0.82	5.02
7	30	5	15	0.73	9.90
8	30	10	5	0.61	5.83
9	30	15	10	0.46	4.61

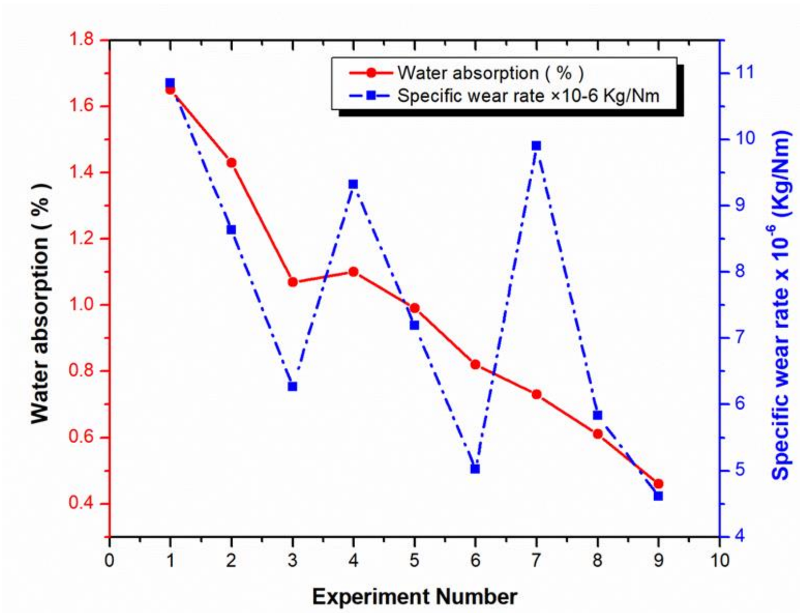

Figure 2: Water absorption percentages and Specific wear rate for the experiments**.**

From the above results, it is clear that an increase in the addition of the waste plastics make the composite to resist the intake of moisture. As the plastics have the water repulsion nature, these help in increasing the water resistance. The inclusion of the seashell powder, which is comprised of calcium carbonate fills the interface between the matrix and the reinforcements (Gopal Krishna UB et al., 2020). It also reduces the formation of the pores and blowholes which increases the water resistance property.

The main effect plot for low moisture intake and minimum wear rate are shown in figures 3 and 4. The plot is plotted based on smaller is better objective (Alagarsamy & Ravichandran, 2019), the lengthy line indicates the most affecting factor, and the inclusion of the filler powder stands next to that. From the plot for lower moisture intake, the addition of the plastics and the filler powders must be maximum with 10 minutes of stirring time. From the plot for lower wear rates, the inclusion of the seashell filler powder must be maximum, and it stands as the most influencing factor when compared with the other factors. For lower rates of wear, the inclusion of plastics must be 30 wt.%, the addition of fillers must be 15 wt. % and the stirring time must be 5 mins. The stirring time does not affect the properties much, it can be given the least importance. These plots displayed the most effective content which affecting the water absorption is waste plastic and wear rate is seashell (Ananthu et al., 2018).

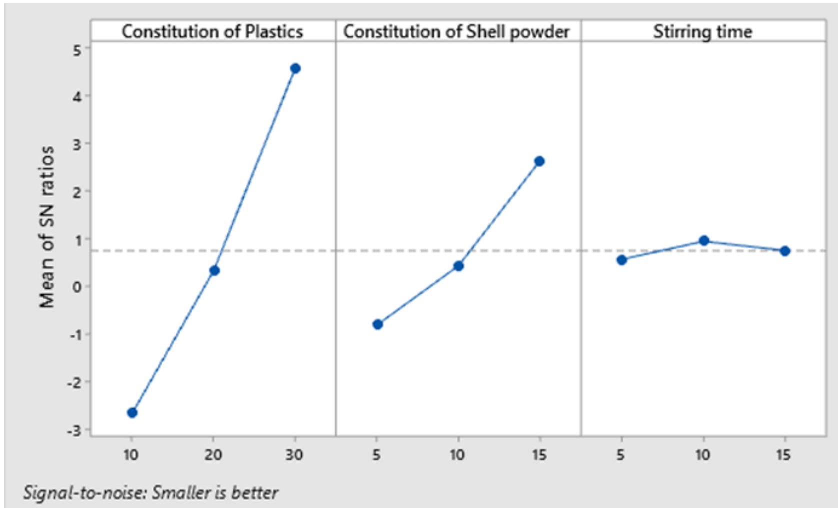

Figure 3: Main effect plot for water absorption.

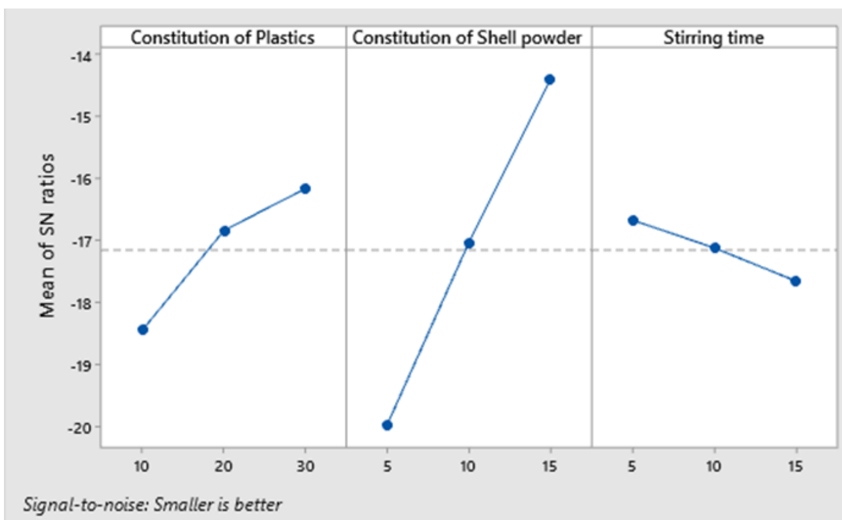

Figure 4: Main effect plot for specific wear rate.

Figures 5 and 6 indicate the interconnection between the factors in determining the water absorption and wear properties of the material. From the plot shown in figure 5 for minimum water absorption, the plot shows an interaction that prevails between the addition of the fillers and the stirring time. In figure 6, the interaction plot for the minimum wear rate explains there is a dependency between the inclusion of plastics and stirring time. The high level of interaction is observed between the seashell powder and waste plastic which evident these two fillers improve the resistance for wear and water absorption (Subagia & Suardana, 2019).

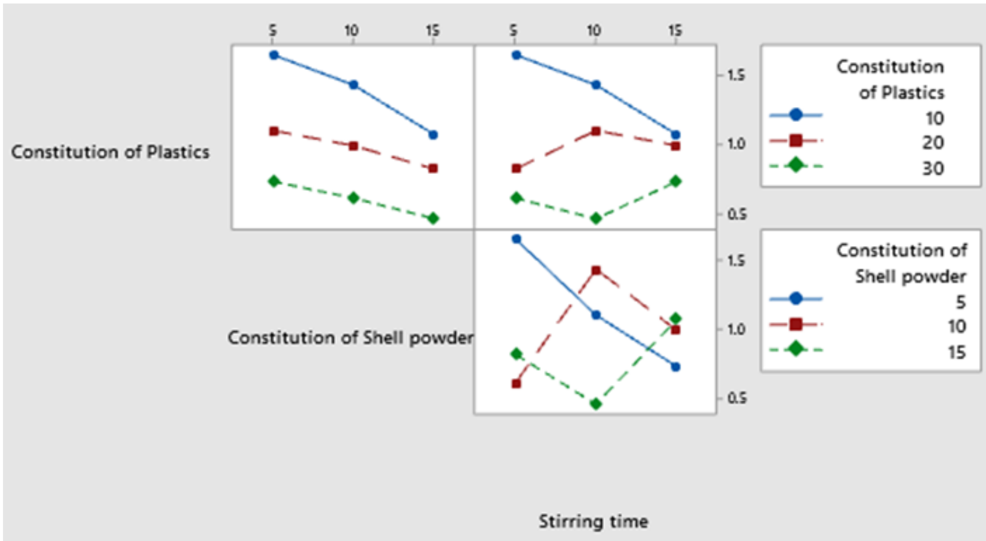

Figure 5: Interaction plot for water absorption.

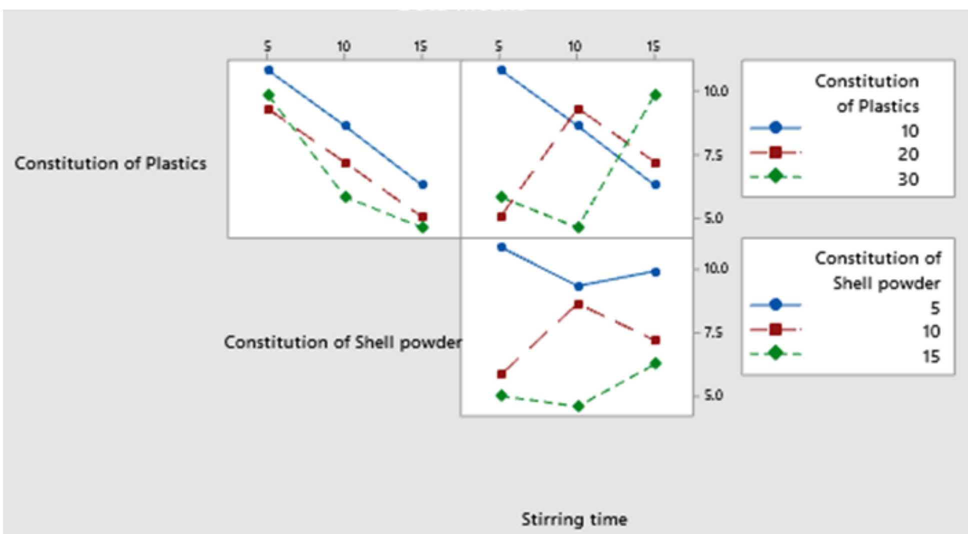

Figure 6: Interaction plot for specific wear rate.

The contour plots are shown in figures 7 and 8 indicates, the levels at which the water absorption and the wear rates will be minimum. In both cases, the addition of the plastics and the incorporation of the fillers are to be maximum. Figures 7 and 8 indicate the contribution of each factor to determine the properties of the material. For minimum moisture absorption, the inclusion of the plastics must be high and for lower wear rates, the inclusion of the filler powders should be maximum.

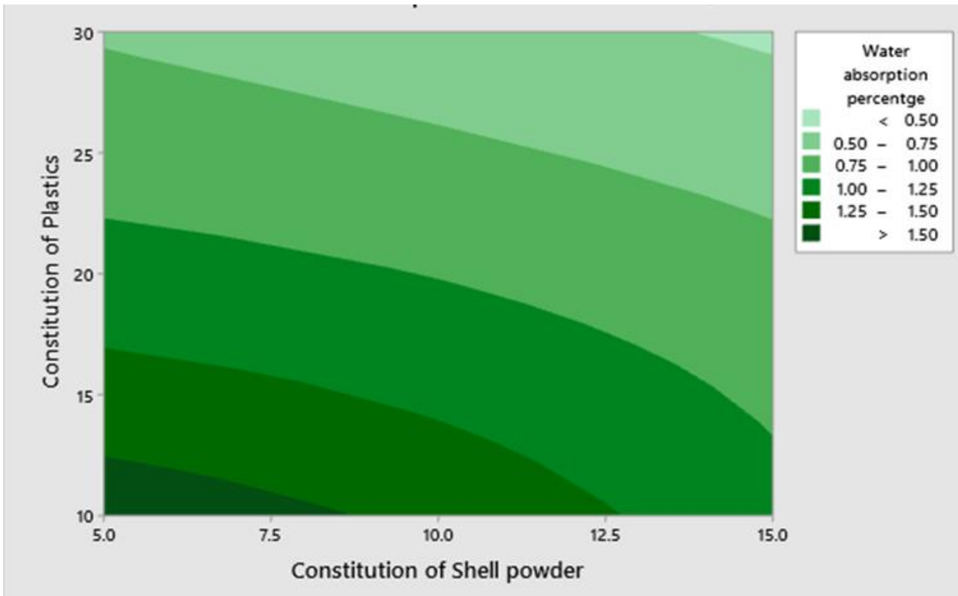

Figure 7: Contour plot for water absorption.

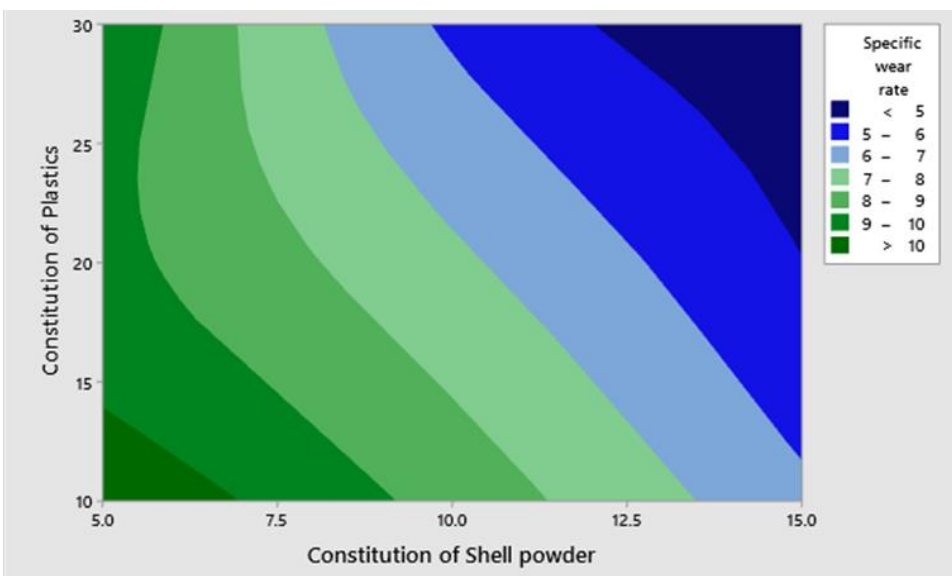

Figure 8: Contour plot for specific wear rate.

In ANOVA Fischer value decides the contribution of the parameter on the responses (Alagarsamy & Ravichandran, 2020). From Table 3, the Fischer values explain that for minimum moisture intake, the inclusion of the plastics must be increased as it repels the water rather than absorbing. Next to that, the inclusion of the filler powders influences the water resistance property of the composite. R squared value of 98.12% describes the significance of the model. From ANOVA Table 4, the inclusion of the filler escalates the wear resistance of the composite.

The wear may vary in some areas as the seashell powders are not found to be on the surface of the plastics. They are found only on the matrix and between the interface of the matrix and the reinforcements. This behavior affects the wear resistance property of the material. The R-squared value greater than 95% represents that the results of the model were significant. Equation (4) and (5) show the regression equation for minimum moisture intake and wear rate.

$$\text{Moisture absorption} = 2.2411 - 0.03917\,A - 0.03767\,B - 0.00967\,C \quad (4)$$

$$\text{Specific wear rate} = 13.487 - 0.0902\,A - 0.4723\,B + 0.0553\,C \quad (5)$$

Table 3: ANOVA results for water absorption.

Source	Degrees of freedom	Adjacent Sum of Squares	Adjacent MS	Fischer Value	Probability Value
Regression	3	1.14725	0.382417	87.02	0
Constitution of Plastics	1	0.92042	0.920417	209.45	0
Constitution of Shell powder	1	0.21282	0.212817	48.43	0.001
Stirring time	1	0.01402	0.014017	3.19	0.134
Error	5	0.02197	0.004394		
Total	8	1.16922			
Sum: 0.066291, R-Squared : 98.12%, R-squared(Adj): 96.99%, R-squared(Predicted): 93.37%					

Table 4: ANOVA results for specific wear rate.

Source	Degrees of freedom	Adjacent Sum of Squares	Adjacent MS	Fischer Value	Probability Value
Regression	3	38.8021	12.934	38.76	0.001
Constitution of Plastics	1	4.878	4.878	14.62	0.012
Constitution of Shell powder	1	33.4648	33.4648	100.28	0
Stirring time	1	0.4593	0.4593	1.38	0.294
Error	5	1.6685	0.3337		
Total	8	40.4706			
Sum: 0.577668, R-Squared : 95.88%, R-squared(Adj): 93.40%, R-squared(Predicted): 84.41%					

Figure 9 shows the contribution offered by the reinforcements and the fillers which affect the responses of the proposed material. For the water absorption and the wear rate to be minimal, the percentage addition of the waste plastic particulates and the inclusion of the fillers must be maximum. In determining the water absorption rate, the addition of plastics about 80% of the influence, and to decide the wear rate of the material, the inclusion of the seashell fillers play a vital role.

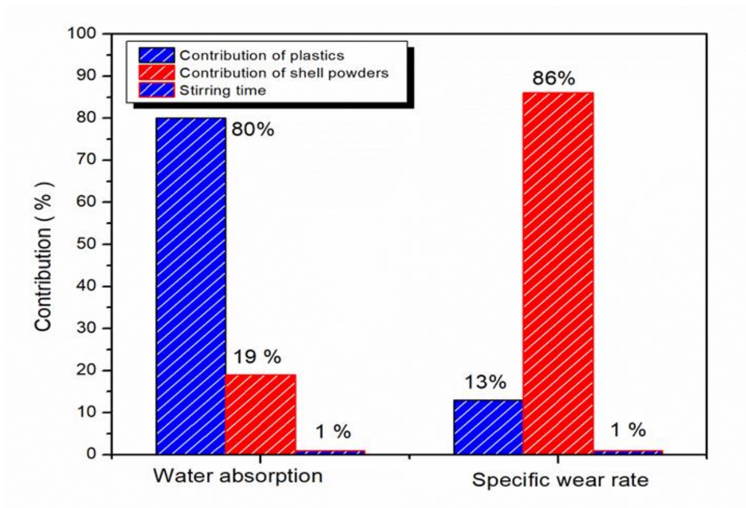

Figure 9: Contribution plot for water absorption and specific wear rate.

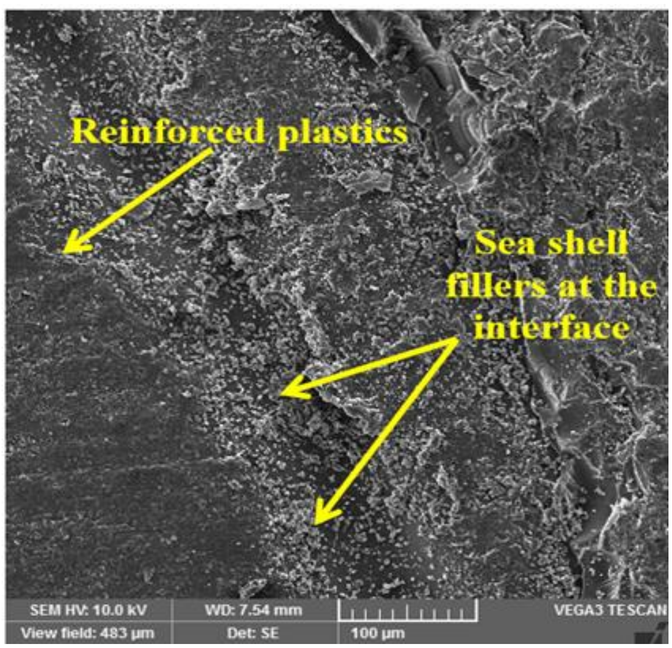

Figure 10: SEM image of the composite sample.

Figure 10 is the SEM image taken on the worn side of the developed composite as per the parameters obtained from the main effect plot. The SEM image comprises a part of reinforced plastic and the interface between the matrix and the reinforcement. It also indicates the uniform spread of the fillers all over the surface of the composite, except the reinforcement surface. But in the interface of the matrix and the reinforcement, the fillers fill the minute gaps and reduce the cracks and pores which affect the main properties of the material.

4.0 CONCLUSION

In this work by adding the waste plastics and seashell powders as reinforcement and fillers respectively, the properties like wear and moisture absorption resistance got improved to some extent. The compatibility between the matrix and the reinforcements are better which can be understood from the microscopic image. The wear resistance got improved due to the addition of the filler powders and the waste plastic inclusion reduced the water intake properties. From the results, the addition of the shell powders also contributed to the water absorption by reducing the micro pores that may form during the manufacturing of the composites. The inclusion of seashell powder lowered the emergence of small pores and micro-cracks in the composite during manufacturing, curing, and finishing operations. This enhanced the strength of the composite and reduced the defects. For the water absorption and wear rate to be minimum, the inclusion of the plastics and the fillers must be 30 and 15 weight percentages, respectively. The stirring time has a negligible impact on determining the properties of the composite. Since the wear and the moisture absorption are better in the present composite, it can be applicable in areas where more wear and water resistance are required like automobiles, doors, window panels, partition walls.

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