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Characterization of Plantain Fiber Reinforced High Density Polyethylene Composite for Application in Design of Auto Body Fenders

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Abstract: High density polyethylene composite reinforced with natural plantain fiber was produced using injection moulding technique. The production process utilized the popular L18 Taguchi experimental design which allowed for investigating the effects of the major production variables (the machine parameters) such as; barrel(melt) temperature, mold temperature, injection pressure, holding pressure, back pressure, clamping force and shaft speed in the final mechanical property of the product. Moreover, the need to use improved fiber volume fraction/particle size and appropriate compactibilizer mass was verified. The various mechanical tests conducted on the new composite material reveal that fiber volume fraction of 0.1, particle size of 75μm and compactibilizer mass of 0.00024kg yields a high quality composite material with improved mechanical properties suitable for auto body fender application. The Taguchi robust design technique was applied for "the greater the better" to obtain the highest signal-to-noise ratio (SNratio) for quality characteristics (strengths) in the determination of optimum factor levels. The improved PFRHDPEC was found to have optimum tensile strength of 87.44MP_a, yield strength of 76.6MP_a, Flexural strength of 77.03J, Rockwell Hardness strength of 756.99, Impact strength of 16.21J and density of 993kg/m^3. The result shows that the auto body fender produced based on compactibilized PFRHDPEC has an advantage of reduced density compared to that of steel and alternative composite materials.

Keywords: Plantain fiber, Polyethylene resin, Compactibilizer, Machine parameters, Taguchi methods.

1.0 INTRODUCTION

Natural fiber thermoplastic components in the automotive industry can afford the advantages of weight/cost reduction, recyclability, abrasiveness and biodegradability compared to conventional materials. Handlings of natural fibers in automotive exterior and interior components are essential to recover eco-efficiency and renewability. Natural fibers have recently become affordable to automotive industry as an alternative reinforcement to glass fiber reinforced thermoplastics. The best way to boost the fuel efficiency without sacrificing safety is to employ fiber reinforced composite materials in the body of the cars so that weight reduction can be achieved.

The main advantages of using the annual-growth natural plantain fibers in thermoplastics along with polyethylene are improved mechanical/thermal properties and recyclability (Sanadi et al., 1994). Plantains are plants producing fruits that remain starchy at maturity (Robinson, 1996) and need processing before consumption. Plantain production in Africa is estimated at more than 50% of worldwide production (FAO, 1990,). Nigeria is one of the largest plantain producing countries in the world (FAO, 2006). The custom of the plantain fiber reinforced plastics can be extended up to the fender, bumper beams, front end modules, instrument panel carrier, door modules and under body shields of the automobiles. They have an edge over traditional materials such as steel and aluminum due to their high specific strength, good damping capacity, simple manufacturing process and corrosion resistance (Cheon et al., 1995). The efficiency of the natural fiber reinforced composites depends on the fiber to matrix interface and the capability to adhesion over the matrix to the fiber. This can be maximized by increasing the bonding between fiber and matrix.

Numerous studies has been carried out by researchers in the area of natural fiber composites optimization and applications, Ihueze, Achike and Okafor (2016) examined the optimal performance characteristics and reinforcement combinations of coconut fibre reinforced high density polyethylene (HDPE) polymer matrixes, Ihueze, Achike and Okafor (2016) modelled and optimized the performance characteristics of coconut fibre particles reinforced high density polyethylene, Okafor and Godwin (2014) evaluated the compressive and energy adsorption characteristics of natural fiber reinforced composites. Ihueze and Okafor (2014) carried out Response Surface Optimization of the impact strength of plantain fiber reinforced polyester for application in auto body works. Ihueze and Okafor (2014) optimally designed for flexural strength of plantain fibers reinforced polyester matrix. Influence of fiber length and fiber distribution having more impact while developing natural fiber thermoplastics composites using injection molding or extrusion process (Davoodi et al., 2008).

Very little is known about the mechanical responses of high density polyethylene matrix reinforced with particulate plantain fibers. This is especially true when a compactibilizer is used. In general, there is dearth of study on performance of plantain fiber reinforced high density polyethylene composites automotive industries. Therefore, there is need to find out the characteristics of plantain fiber reinforced high density polyethylene composites for application in auto body fenders.

2.0 MATERIALS AND METHODS

The high density polyethylene resin labeled HBG00356 manufactured by Indorama Eleme Petrochemicals Limited with density of about 0.96g/cm^3, purchased from Onitsha, Anambra state was used as the matrix. The plantain fiber used as reinforcement was obtained from a local plantation in Awka, Anambra State. Sodium Hydroxide, Acetic Acid and Acetic Anhydride used for the chemical treatment of plantain fiber was purchased from Dantex Chemical Ltd, Onitsha, Anambra State. The Compactibilizer, Maleic Anhydride Grafted PE(MAPE) was imported from China.

Plantain Pseudo Stem Fiber was obtained by immersing the Plantain stems in water for 28 days for rotting process to occur. The fibers were distinct from pectins, hemicellulose and other impurities and finally dried to constant weight in an ovum for 150 minutes at an oven temperature of 80 °C.

Chemical treatment of plantain fibers at 2% solution of sodium hydroxide at optimum soaking time of 2:30 hours removes the moisture content from the fibers, thereby increasing its strength. 1% acetic acid was applied to neutralize the sodium hydroxide solution. The fibers were thoroughly washed until a PH of 7 was obtained and finally dried to constant weight in an oven at 80 ° C. The mercerized and dried fibers were treated with acetic anhydride solution at 10% with optimally derived soaking time of 1 hour to stabilize the cell walls against moisture, environmental degradation and improve dimensional stability. The fibers were thoroughly washed to neutrality. The compactibilizer, Malaeic Anhydride Grafted PE(MAPE) was employed at 1.5% in order to increase compatibility between fiber and matrix and to decrease hyrophilicity of fibers.

The Treated fibers were ground to a fine powder using Electric Milling Machine and finally sieved unto a set of sieves of 75 micron meter (ASTM 200) and 150 micron meter (ASTM100) arranged in descending order of fineness using Sieve Shaker. Employing Taguchi L_{18} Design of Experiment, the samples were cast in a collapsible mild steel mould in accordance with ASTM standard D638-10 for Tensile tests, ASTM D790-10 for Flexural, ASTM A370 for Charpy Impact and ASTM E10-12 for Hardness using injection molding process. In accordance to ASTM (American Society for Testing and Materials) standards, Tensile strength, Flexural strength were tested using Universal Testing Machine while Impact strength was carried out using Charpy impact tester and Hardness strength using Hardness Tester.

2.1 Signal to noise ratio and application of Taguchi methodology

Taguchi Robust design technique was applied for greater the better option of signal to noise ratio (eqn 1) using the measured properties as quality characteristics and choosing three factor levels (Low, medium, high) for an L_{18} array design matrix. The computed SN ratio for the quality characteristics were evaluated and optimum control factor levels established for the parameters.

The S/N ratio for maximum which comes under larger is better characteristic, was calculated as logarithmic transformation of the loss function as shown in eqn 2 below (Ross, 1993 , Roy, 1990).

The signal to noise ratio measures the sensitivity of the quality investigated to those uncontrollable factors (error) in the experiment. The higher value of *S/N* ratio is always desirable because greater *S/N* ratio will result in smaller product variance around the target value. In order to perform

S/N ratio analysis, mean square deviation (*MSD*) for "the bigger- the-better" quality characteristic and *S/N* ratio were calculated from the following equations:

$$(MSD) = \left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (1)$$

$$S/N\ ratio = -10Log(MSD) \quad (2)$$

Where, y_i is the mechanical property under constant load for *i*th replicate experiment.

2.2 Estimation of expected responses

The confirmation of experiment is the final step in Taguchi design of experiment and analysis technique. The confirmation of experiment is conducted to validate the inference drawn during the analysis phase. For conducting the confirmation experiments the optimum conditions are set for the significant parameters and selected numbers of experiments are carried out under specified conditions. The average of the confirmation experiments results is compared with the anticipated average based on the parameters and levels tested (Ross, 1993).

According to Radharamanan and Ansui, the expected response is estimated using the optimum control factor setting from the main

effects plots; by employing the response table for signal to noise ratio and the response table for mean, the expected response model is as in equation 3:

$$EV = AVR + (A_{opt} - AVR) + (B_{opt} - AVR) + (C_{opt} - AVR) + \ldots + ({n^{th}}_{opt} - AVR) \quad (3)$$

Where EV = expected response, AVR = average response, A_{opt} = mean value of response at optimum setting of factor A, B_{opt} = mean value of response at optimum setting of factor B, C_{opt} = mean value of response at optimum setting of factor C.

3.0 RESULTS AND DISCUSSION

In this study the tensile, flexural, hardness and impact strengths of PFRHDPEC were investigated for optimum reinforcement combinations to yield optimum response employing Taguchi methodology. The signal to noise ratio and mean responses associated with the dependent variables of this study are evaluated and presented. Injection molding technique on replicated samples of PFRHDPEC were used to obtain the value of quality characteristics of the four mechanical properties using different levels of control factors levels as in table 1. The response table for means shows that for uncompactibilized P1, the screw speed has the highest contribution in influencing the composite tensile strength, followed by volume fraction as depicted in table 5. In compactibilized P1, volume fraction has the highest contribution in influencing the composite tensile strength as depicted in table 6 while barrel temperature has the highest contribution in influencing the composite tensile strength as depicted in table 7. Other contributions of control factors in influencing the mechanical properties of different particle sizes are recorded in tables 9,10,12,13,14,16,17 and 18.

Table 2 and Table 3 show the Taguchi DOE orthogonal array and Design matrix implemented for the larger the better signal to noise ratio (SN ratio) that led to results of figures 1-11 and tables 4,8,11 and 15 for optimum control factor levels.

The expected responses are therefore computed with equation 3 and presented in Table 19.

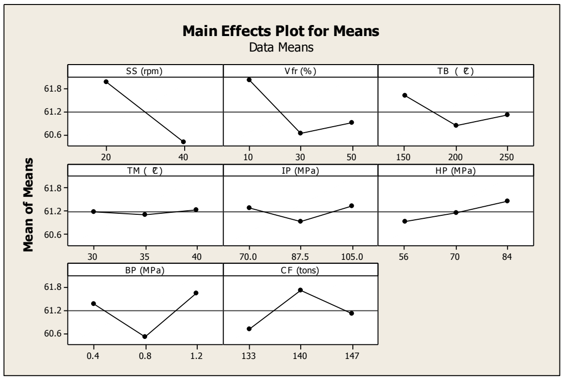

Figure 1: Main effects plots for Mean-Tensile Strength Response of Uncompactibilized Particle size 1

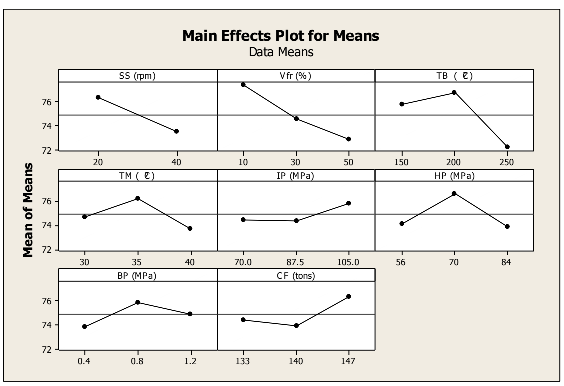

Figure 2: Main effects plots for Mean-Tensile Strength Response of Compactibilized Particle size 1

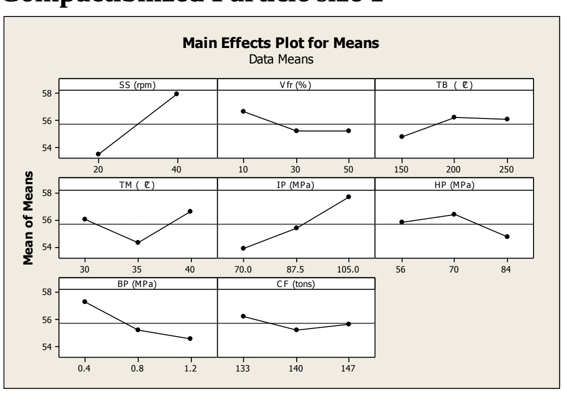

Figure 3: Main effects plots for Mean-Tensile Strength Response of Compactibilized Particle size 2

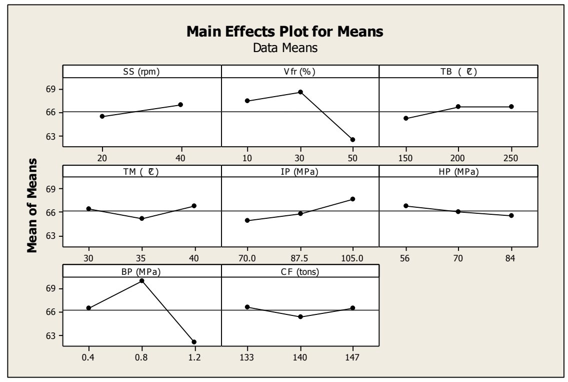

Figure 4: Main effects plots for mean-Flexural Strength Response of Compactibilized Particle size 1

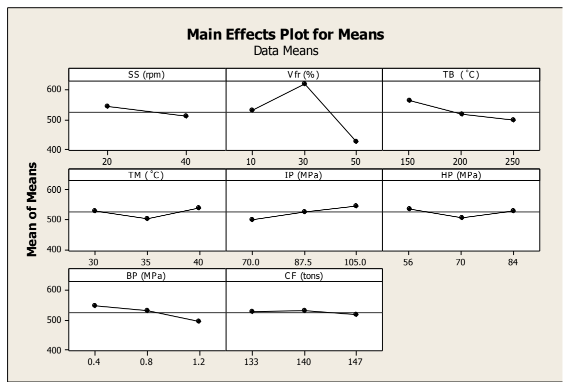

Figure 5: Main effects plots for mean-Flexural Strength Response of Compactibilized Particle size 2

The tensile strength and the young's modulus of the compactibilized partcle size 2 fibers were higher than compactibilized partcle size 1 fibers and uncompactibilized partcle size fibers

This is due to the good adhesion and bonding between the fibers/matrix interfaces in the material. Under a tensile load, the improved adhesion results in a more efficient stress transfer from the matrix to the reinforced fibers.

The compactibilized partcle size 2 fibers shows challenging values in flexural strength compared to the compactibilized partcle size 1 fibers and uncompactibilized partcle size fibers. This implies that the compactibilized partcle size 2 fibers had better strength and the fiber distribution is good.

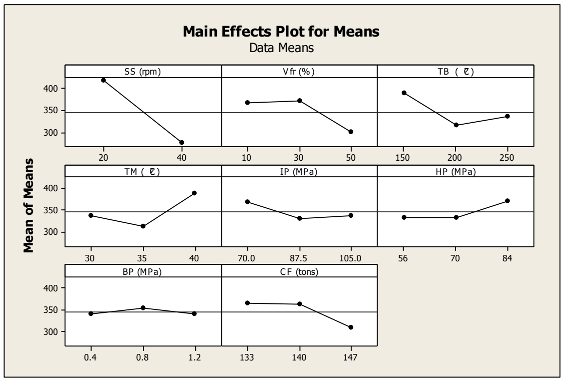

Figure 6: Main effects plots for mean-Rockwell Hardness Strength of Uncompactibilized Particle size 1

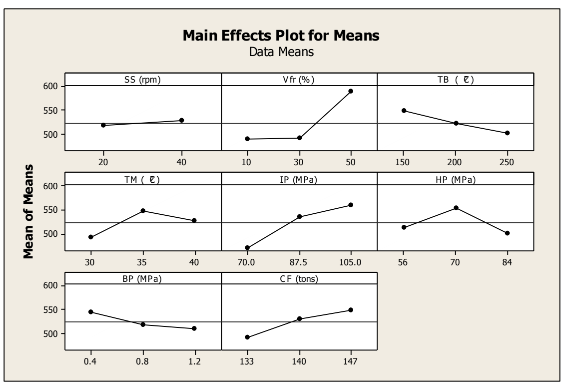

Figure 7: Main effects plots for mean-Rockwell Hardness Strength of Compactibilized Particle size 1

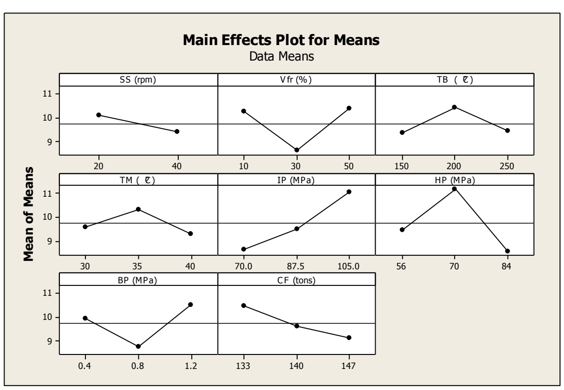

Figure 8: Main effects plots for mean-Rockwell Hardness Strength of Compactibilized Particle size 2

Rockwell hardness strength in compactibilized particle size 2 fibers were higher than compactibilized partcle size 1 fibers and uncompactibilized particle size fibers.

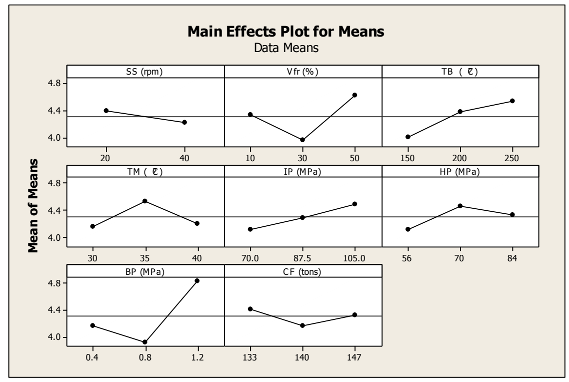

Figure 9: Main effects plots for mean-Charpy Impact Strength of Compactibilized Particle size 2

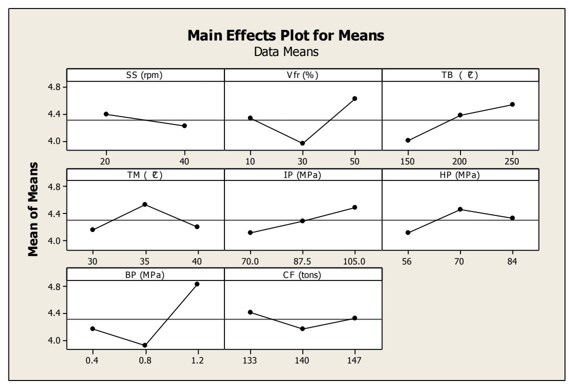

Figure 10: Main effects plots for mean-Charpy Impact Strength of Compactibilized Particle size 1

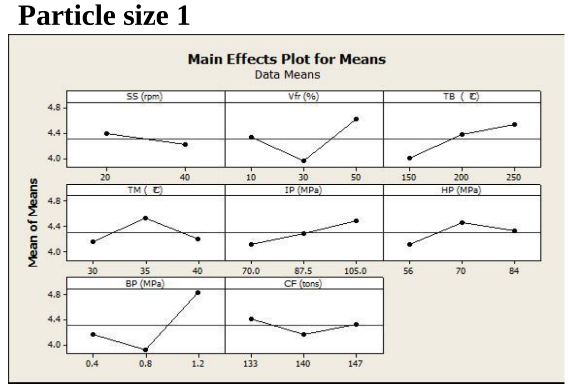

Figure 11: Main effects plots for mean-Charpy Impact Strength of Uncompactibilized Particle size 1

While comparing the Charpy Impact test results, it is proven that the compactibilized partcle size 2 fibers has demanding strength to compactibilized particle size 1 fibers and uncompactibilized particle size fibers. The fender materials should have higher impact strength to absorb heavy shock loads during collision.

4.0 CONCLUSION

This study concentrates on the characterization of plantain fiber reinforced high density polyethylene composites for application in auto body fenders .The compactibilized particle size 2 fibers composite which is fabricated by injection moulding process, presents a superior mechanical property. The overall result suggests that a natural plantain fiber reinforced composites could be utilized in automotive structural components such as fenders, bumper beams, front end modules and also in interiors of automobiles.

5.0 ACKNOWLEDGEMENTS

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REFERENCES

Cheon, S.S., Choi, J.H. and Lee, D.G. (1995). Development of the composite bumper beam for passenger cars. J. Comp. Struct. 32:491-499.

Davoodi, M.M., Sapuan, S.M. and Yunus, R. (2008). Conceptual design of a polymer Composite automotive bumper energy absorber. Mater. Des. 29:1447-1452.

Food and Agriculture Organization.(1990). Production Year Book 1990. FAO, Rome.

Food And Agriculture Organization.(2006). Production Year Book 2006. FAO, Rome.

Ihueze, C.C., Okafor, E.C. and Ujam, A.J. (2012). Optimization of Tensile Strength Response of Plantain Fibers Reinforced Polyester Composites. Applying Taguchi Robust Design. Innov. Syst. Des. Eng., 3(7): 64-76.

Joseph, S., Sreekala, M.S. and Thomas, S.(2002). "Studies on resol matrix resin", *Composites 62,1857*.

Robinson, J.C. (1996). Banana and Plantain CAB International, UK. pp. 238

Sanadi, A.R., Caulfield, D.F.and Rowell, R.M. (1994). Reinforcing polyethylene with natural fibers. Plast. Eng. 4:27

Ihueze, C. C. Achike M. K. and Okafor C. E. (2016). Optimal Performance Characteristics and Reinforcement Combinations of Coconut Fibre Reinforced High Density Polyethylene (HDPE) Polymer Matrixes. *Journal of Scientific Research & Reports 9(3): 1-10*

Ihueze, C. C. Achike M. K. and Okafor C. E. (2016). Modelling And Optimization Of Performance

Characteristics Of Coconut Fibre Particles Reinforced High Density Polyethylene. *Journal of Basic and Applied Research International*. 17(1): 32-48,

Okafor C. E and Godwin H. C (2014). Evaluation of Compressive and Energy Adsorption Characteristics of Natural Fiber Reinforced Composites (NFRC). *World Journal of Engineering and physical Sciences 2 (3) pp. 036-048.*

Ihueze C. C. and Okafor E. C. (2014) Response Surface Optimization of The Impact Strength Of Plantain Fiber Reinforced Polyester For Application In Auto Body Works. *Journal of innovative research in engineering and sciences*. 4(4), pp. 505-520.

Ihueze C. C. and Okafor C. E. (2014). Optimal Design for Flexural Strength of Plantain Fibers Reinforced Polyester Matrix. *Journal of Innovative Research in Engineering and Sciences* 4(4), pp. 520-537.

Table 1: Design factors and Levels

S/N	**FACTORS**	**LEVELS**		
		1	**2**	**3**
1	Volume fraction Vfr, (%)	10	30	50
2	Barrel(Melt) temperature TB, (°C)	150	200	250
3	Mold temperature TM,(°C)	30	35	40
4	Injection pressure IP, (MP_a)	70	87.5	105
5	Holding pressure HP, (MP_a)	56	70	84
6	Back pressure BP, (MP_a)	0.4	0.8	1.2
7	Clamping force CF, (tons)	133	140	147
8	Shaft speed SS, (rpm)	20	40	40

Table 2: Taguchi L_{18} Orthogonal array

Experiment Number	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3

15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

Table 3: Populated Taguchi L_{18} Orthogonal array

EXPT.	**SS (rpm)**	**Vfr (%)**	**TB (°C)**	**TM (C)**	**IP (MP_a)**	**HP (MP_a)**	**BP (MP_a)**	**CF (tons)**
1	20	10	150	30	70	56	0.4	133
2	20	10	200	35	87.5	70	0.8	140
3	20	10	250	40	105	84	1.2	147
4	20	30	150	30	87.5	70	1.2	147
5	20	30	200	35	105	84	0.4	133
6	20	30	250	40	70	56	0.8	140
7	20	50	150	35	70	84	0.8	147
8	20	50	200	40	87.5	56	1.2	133
9	20	50	250	30	105	70	0.4	140
10	40	10	150	40	105	70	0.8	133
11	40	10	200	30	70	84	1.2	140
12	40	10	250	35	87.5	56	0.4	147
13	40	30	150	35	105	56	1.2	140
14	40	30	200	40	70	70	0.4	147
15	40	30	250	30	87.5	84	0.8	133
16	40	50	150	40	87.5	84	0.4	140
17	40	50	200	30	105	56	0.8	147
18	40	50	250	35	70	70	1.2	133

Table 4: Tensile Strength response

	Uncompactibilized Particle size one, P1			**Compatibilized Particle size one, P1**			**Compatibilized Particle size two, P2**		
	Mean ultimate tensile Response (MPa)	MSD	SNratio	Mean ultimate tensile Response (MPa)	MSD	SNratio	Mean ultimate tensile Response (MPa)	MSD	SNratio
1	62.15	0.00026	35.87	71.45	0.0002	37.08	75.11	0.00018	37.51
2	61.33	0.00027	35.75	61.34	0.00027	35.75	81.56	0.00015	38.23
3	62.95	0.00025	35.98	68.6	0.00021	36.73	74.79	0.00018	37.48
4	62.15	0.00026	35.87	59.52	0.00028	35.49	80.2	0.00016	38.08
5	61.33	0.00027	35.75	64	0.00024	35.12	78.37	0.00016	37.88
6	61.33	0.00027	35.75	58.9	0.00029	35.4	71.94	0.00019	37.14
7	62.15	0.00026	35.87	68.67	0.00021	36.74	78.22	0.00016	37.87

8	61.33	0.00027	35.75	74.24	0.00018	37.41	73.9	0.00018	37.37
9	62.95	0.00025	35.98	72.07	0.00019	37.16	72.76	0.00019	37.24
10	61.33	0.00027	35.75	79.56	0.00016	38.01	80.44	0.00015	38.11
11	62.95	0.00025	35.98	68.62	0.00021	36.73	76.71	0.00017	37.7
12	61.33	0.00027	35.75	62.65	0.00025	35.94	75.26	0.00018	37.53
13	60.93	0.00027	35.7	65.98	0.00023	36.39	73.68	0.00018	37.35
14	59.59	0.00028	35.5	59.71	0.00028	35.52	74.68	0.00018	37.46
15	58.5	0.00029	35.34	63.37	0.00025	36.04	68.33	0.00021	36.69
16	60.93	0.00027	35.7	67.63	0.00022	36.6	66.9	0.00022	36.51
17	58.5	0.00029	35.34	69.46	0.00021	36.83	75	0.00018	37.5
18	59.59	0.00028	35.5	66.11	0.00023	36.41	70.14	0.0002	36.92

Table 5: Mean Tensile Strength for Uncompactibilzed Particle Size One, P1 at Different Volume Fractions Based on Larger is Better Quality Characteristics

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (℃)	TM (℃)	IP (MPa)	HP (MPa)	BP (MPa)	CF (tons)
1	61.96	62.01	61.61	61.20	61.29	60.93	61.38	60.71
2	60.41	60.64	60.84	61.11	60.93	61.16	60.52	61.74
3		60.91	61.11	61.24	61.33	61.47	61.65	61.11
Delta	1.56	1.37	0.77	0.13	0.40	0.54	1.13	1.03
Rank	1	2	5	8	7	6	3	4

Table 6: Mean Tensile Strength for compactibilzed Particle Size One, P1 at Different Volume Fractions Based on Larger is Better Quality Characteristics

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (℃)	TM (℃)	IP (MPa)	HP (MPa)	BP (MPa)	CF (tons)
1	66.53	68.70	68.80	67.41	65.58	67.11	66.25	69.79
2	67.01	61.91	66.23	64.79	64.79	66.39	66.88	65.76
3		69.70	65.28	68.11	69.95	66.81	67.18	64.77
Delta	0.48	7.78	3.52	3.31	5.15	0.73	0.93	5.02
Rank	8	1	4	5	2	7	6	3

Table 7: Mean Tensile Strength for compactibilzed Particle Size Two, P2 at Different Volume Fractions Based on Larger is Better Quality Characteristics.

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (℃)	TM (℃)	IP (MPa)	HP (MPa)	BP (MPa)	CF (tons)
1	76.32	77.31	75.76	74.68	74.47	74.15	73.85	74.38
2	73.46	74.53	76.70	76.20	74.36	76.63	75.91	73.92
3		72.82	72.20	73.78	75.84	73.89	74.90	76.36
Delta	2.86	4.49	4.50	2.43	1.48	2.74	2.07	2.43
Rank	3	2	1	6	8	4	7	5

Table 8: Flexural Strength response

	Compatibilized Particle size one, P1			Compatibilized Particle size one, P2		
	Mean Flexural Response (J)	MSD	SNratio	Mean Flexural Response (J)	MSD	SNratio
1	52.5	0.00036	34.4	63.75	0.00025	36.89
2	51.25	0.00038	34.19	66.25	0.00023	36.42
3	53.75	0.00035	34.61	62.5	0.00026	35.92
4	53.75	0.00035	34.61	63.75	0.00025	36.09
5	57.5	0.0003	35.19	70	0.0002	36.9
6	53.75	0.00035	34.61	72.5	0.00019	37.21
7	47.5	0.00044	33.53	63.75	0.00025	36.09
8	53.75	0.00035	34.61	61.25	0.00027	35.74
9	57.5	0.0003	35.19	65	0.00024	36.26
10	63.75	0.00025	36.09	76.25	0.00017	37.64
11	57.5	0.0003	35.19	65	0.00024	36.26
12	61.25	0.00027	35.74	71.25	0.0002	37.06
13	53.75	0.00035	34.61	63.75	0.00025	36.09
14	57.5	0.0003	35.19	68.75	0.00021	36.75
15	55	0.00033	34.81	72.5	0.00019	37.21
16	57.5	0.0003	35.19	60	0.00028	35.56
17	60	0.00028	35.56	68.75	0.00021	36.75
18	55	0.00033	34.81	56.25	0.00032	35

Table 9: Mean Flexural Strength for Compactibilized Particle Size One, P1 at Different Volume Fractions Based on Larger is Better Quality Characteristics

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (℃)	TM (℃)	IP (MPa)	HP (MPa)	BP (MPa	CF (tons)
1	53.47	56.67	54.79	56.04	53.96	55.83	57.29	56.25
2	57.92	55.21	56.25	54.38	55.42	56.46	55.21	55.21
3		55.21	56.04	56.67	57.71	54.79	54.58	55.63
Delta	4.44	1.46	1.46	2.29	3.75	1.67	2.71	1.04
Rank	1	7	6	4	2	5	3	8

Table 10: Mean Flexural Strength for Compactibilized Particle Size Two, P2 at Different Volume Fractions Based on Larger is Better Quality Characteristics

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (℃)	TM (℃)	IP (MPa)	HP (MPa)	BP (MPa)	CF (tons)
1	65.42	67.50	65.21	66.46	65.00	66.88	66.46	66.67
2	66.94	68.54	66.67	65.21	65.83	66.04	70.00	65.42
3		62.50	66.67	66.88	67.71	65.63	62.08	66.46
Delta	1.53	6.04	1.46	1.67	2.71	1.25	7.92	1.25
Rank	5	2	6	4	3	7.5	1	7.5

Table 11: Rockwell Hardness Strength

	Uncompatibilized Particle size one, P1			Compatibilized Particle size one, P1			Compatibilized Particle size one, P2		
	Mean Rockwell Hardness Response	MSD	SNratio	Mean Rockwell Hardness Response	MSD	SNratio	Mean Rockwell Hardness Response	MSD	SNratio
1	626.25	0.0000025	55.93	475	0.0000044	53.53	408.25	0.000006	52.22
2	539	0.0000034	54.63	349.75	0.0000081	50.88	552.25	0.0000033	54.84
3	550.25	0.0000033	54.81	422.5	0.0000056	52.52	495.25	0.0000041	53.9
4	596	0.0000028	55.5	393.25	0.0000065	51.89	53600	0.0000035	54.58
5	632	0.0000025	56.01	395.5	0.0000064	51.94	514	0.0000038	54.22
6	595	0.0000028	55.49	494	0.0000041	53.87	408.5	0.000006	52.22
7	441.75	0.0000051	52.9	433	0.0000053	52.73	581.25	0.000003	55.29
8	439.75	0.0000052	52.86	407	0.000006	52.19	546.5	0.0000033	54.75
9	452.75	0.0000049	53.12	377.5	0.000007	51.54	629.75	0.0000025	55.98
10	554.75	0.0000032	54.88	407.75	0.000006	52.21	553.5	0.0000033	54.86
11	445.75	0.000005	52.98	337	0.0000088	50.55	380	0.0000069	51.6
12	470.25	0.0000045	53.45	205.75	0.000024	46.27	543.25	0.0000034	54.7
13	654.25	0.0000023	56.31	316.5	0.000001	50.01	567.5	0.0000031	55.08
14	606.25	0.0000027	55.65	298.25	0.0000112	49.49	525.25	0.0000036	54.41
15	623	0.0000026	55.89	333.75	0.000009	50.47	402.75	0.0000062	52.1
16	495.25	0.0000041	53.9	300.5	0.0000111	49.56	641.5	0.0000024	56.14
17	441	0.0000051	52.89	105.5	0.00009	40.47	609.25	0.0000027	55.7
18	290.5	0.0000012	49.26	176.25	0.0000322	44.92	530.75	0.0000035	54.5

Table 12: Mean Rockwell Hardness Strength for Uncompactibilzed Particle Size One, P1 at Different Volume Fractions Based on Larger is Better Quality Characteristics

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (℃)	TM (℃)	IP (MPa)	HP (MPa)	BP (MPa)	CF (tons)
1	541.4	531.0	561.4	530.8	500.9	537.8	547.1	527.7
2	509.0	617.8	517.3	504.6	527.2	506.5	532.4	530.3
3		426.8	497.0	540.2	547.5	531.3	496.1	517.6
Delta	32.4	190.9	64.4	35.6	46.6	31.2	51.0	12.8
Rank	6	1	2	5	4	7	3	8

Table 13: Mean Rockwell Hardness Strength for Compactibilized Particle Size One, P1 at Different Volume Fractions Based on Larger is Better Quality Characteristics

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (℃)	TM (℃)	IP (MPa)	HP (MPa)	BP (MPa)	CF (tons)
1	416.4	366.3	387.7	337.0	368.9	334.0	342.1	365.9
2	275.7	371.9	315.5	312.8	331.7	333.8	354.0	362.5
3		300.0	335.0	388.3	337.5	370.4	342.1	309.7
Delta	140.7	71.9	72.2	75.5	37.3	36.6	11.9	56.2
Rank	1	4	3	2	6	7	8	5

Table 14: Mean Rockwell Hardness Strength for Compactibilized Particle Size Two, P2 at Different Volume Fractions Based on Larger is Better Quality Characteristics

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (°C)	TM (°C)	IP (MPa)	HP (MPa)	BP (MPa)	CF (tons)
1	519.1	488.8	548.0	494.3	472.3	513.9	543.7	492.6
2	528.2	492.3	521.2	548.2	537.0	554.6	517.9	529.9
3		589.8	501.7	528.4	561.5	502.5	509.3	548.4
Delta	9.1	101.1	46.3	53.8	89.2	52.1	34.3	55.8
Rank	8	1	6	4	2	5	7	3

Table 15: Charpy Impact Strength response

	Uncompactibilized Particle size one, P1			**Compatibilized Particle size one, P1**			**Compatibilized Particle size two, P2**		
	Mean Charpy Impact Response (J)	MSD	SNratio	Mean Charpy Impact Response (J)	MSD	SNratio	Mean Charpy Impact Response (J)	MSD	SNratio
1	3.5	0.0816	10.88	5.5	0.0331	14.81	9.5	0.011	19.55
2	4.25	0.0554	12.57	4.5	0.0494	13.06	11.75	0.0072	21.4
3	5.25	0.0363	14.4	5.25	0.0363	14.4	10	0.01	20
4	4.5	0.0494	13.06	6.75	0.0219	16.59	9.5	0.011	19.55
5	4.75	0.0443	13.53	7	0.0204	16.9	11	0.0083	20.83
6	3.5	0.0816	10.88	9	0.0123	19.08	5.5	0.033	14.81
7	4	0.0625	12.04	4	0.0625	12.04	7.5	0.018	17.5
8	5	0.04	13.98	6	0.0278	15.56	12.5	0.0064	21.94
9	4.75	0.0443	13.53	5	0.04	13.98	13.5	0.0055	22.61
10	4	0.0625	12.04	5.5	0.0331	14.81	11.75	0.0072	21.4
11	4.5	0.0494	13.06	8.25	0.0147	18.33	9	0.0123	19.08
12	4.5	0.0494	13.06	4	0.0625	12.04	9.5	0.011	19.55
13	4	0.0625	12.04	8.75	0.0131	18.84	10.5	0.0091	20.42
14	3.5	0.0816	10.88	6	0.0278	15.56	8.75	0.0131	18.84
15	3.5	0.0816	10.88	5	0.04	13.98	6.5	0.0237	16.26
16	4	0.0625	12.04	6.25	0.0256	15.92	7.5	0.018	17.5
17	4.25	0.0554	12.57	5.75	0.0302	15.19	9.5	0.011	19.55
18	5.75	0.0302	15.19	7	0.0204	16.9	11.75	0.0072	21.4

Table 16: Mean Charpy Impact Strength for Compactibilized Particle Size two, P2 at Different Volume Fractions Based on Larger is Better Quality Characteristics

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (°C)	TM (°C)	IP (MPa)	HP (MPa)	BP (MPa)	CF (tons)
1	10.083	10.250	9.375	9.583	8.667	9.500	9.958	10.500
2	9.417	8.625	10.417	10.333	9.542	11.167	8.750	9.625
3		10.375	9.458	9.333	11.042	8.583	10.542	9.125
Delta	0.667	1.750	1.042	1.000	2.375	2.583	1.792	1.375
Rank	8	4	6	7	2	1	3	5

Table 17: Mean Charpy Impact Strength for Compactibilized Particle Size One, P1 at Different Volume Fractions Based on Larger is Better Quality Characteristics

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (°C)	TM (°C)	IP (MPa)	HP (MPa)	BP (MPa)	CF (tons)
1	5.889	5.500	6.125	6.042	6.625	6.500	5.625	6.000
2	6.278	7.083	6.250	5.875	5.417	5.792	5.625	6.958
3		5.667	5.875	6.333	6.208	5.958	7.000	5.292
Delta	0.389	1.583	0.375	0.458	1.208	0.708	1.375	1.667
Rank	7	2	8	6	4	5	3	1

Table 18: Mean Charpy Impact Strength for Uncompactibilized Particle Size one, P1 at Different Volume Fractions Based on Larger is Better Quality Characteristics

	Means of Quality Characteristics							
Level	SS (rpm)	Vfr (%)	TB (°C)	TM (°C)	IP (MPa)	HP (MPa)	BP (MPa)	CF (tons)
1	4.389	4.333	4.000	4.167	4.125	4.125	4.167	4.417
2	4.222	3.958	4.375	4.542	4.292	4.458	3.917	4.167
3		4.625	4.542	4.208	4.500	4.333	4.833	4.333
Delta	0.167	0.667	0.542	0.375	0.375	0.333	0.917	0.250
Rank	8	2	3	4.5	4.5	6	1	7

Table 19: Optimal setting of control factors and expected Optimum strength of composites

Mechanical Test	**Control**	**Particle size 1**	**Particle size 2**
Tensile (MP_a)	64.68	80.26	87.44
Flexural (J)	-	65.32	77.03
Rockwell Hardness	747.1	601.15	756.99
Charpy Impact(J)	6.14	10.47	16.21