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Effects of Fiber Type, Weight Percentage Loading and Fiber Size on Impact Strength and Hardness of Wood and Rice Husk Hybrid Composite

Rajendra Kumar[1*]
Research Scholar, Mechanical Engineering Department,
I.K. Gujral P.T.U. Jalandhar, Punjab, India.

Dr. Tejeet Singh[2]
Saheed Bhagat Singh Technical Campus,
Ferozpur, Punjab, India.

Dr. Harwinder Singh[3]
Guru Nanak Dev Engineering College,
Ludhiana, Punjab, India.

Abstract

The production of wastage from various industries, agriculture, mining and domestic households are increasing day by day. The disposal problem of these wastages becomes a challenge to safeguard the environment. Researchers suggested that these waste materials may act as a good filler for making natural fiber polymeric composites to improve mechanical properties. In this regard, wood powder and rice husk are selected to study in the present work. Three composites viz., a wood powder + talc powder + polypropylene called as WP composite, a combination of rice husk powder + talc powder + polypropylene called RHP and hybrid composite of WP+RHP called as WPRHP, are prepared and tested for impact strength and hardness. Moreover, the three parameters, fiber type, fiber loading and fiber size are considered for investigating the effects of these parameters on impact strength and hardness. Taguchi experimental design method is used to analyzed the effects on impact strength and hardness properties of the selected parameters of the composites. Results shows that the impact strength of hybrid WPRHP composite is

[*] Corresponding Author

increased, with increased fiber loading up 20 weight percentage age of fiber then decreased. Moreover, the hardness is decreased with increase in the filler loading up to 20 weight percentages then increased. However, the hardness is increased with increase in the filler size from 300, 600 and 1180 µm.

Keywords: Hybrid Composite, Waste Material, Natural Fibers, Polypropylene, Impact Strength and Hardness

INTRODUCTION

Over the past few decades, composites, plastics and ceramics have a great deal of attentions by researchers. Composite is the dominating engineering material having rapidly increasing applications. The development of eco-material is the need of hour to save the environment. As well as, various factors such as working life, shape complexity, cost and weight of material are equally important [Bogoeva- Gaceva, G., et al. 2007; Kumar, et al. 2015].

Composites made of natural fibers and biopolymers are completely biodegradable and are called ‘‘green composites” because of their environmentally beneficial properties. Natural fibers as reinforcement for petrochemical polymers like polypropylene (PP) have added a great value in the automotive industries [Bax, B. and Mussig, J., 2008]. Social, environmental and economic advantages to design “green” automotive components [Zhun, J., Zhu, et al., 2013]. The search for alternative fibers as a replacement for manmade fibers has had continued. The well-known advantages of natural fibers are low density, low cost, its availability, renewability, ease of production, low process energy, non-abrasive, good acoustic property, acceptable specific strength and modulus, low cost, easily available, and easy recyclability [Sapuan S. M., et al. 2003 and Jawaid, M., et al. 2011]. Some other important advantages of natural fibers are low specific weight, environmental friendly, carbon dioxide sequestration, producible low investment, good thermal and acoustic insulating properties, and no skin irritation, thermal recycling [Alves, C. et al. 2010].

PP is the most useful polymer which have outstanding physical, mechanical, chemical, thermal and electrical properties. PP has superior working temperature and tensile strength over the other polymers. Generally, many PP has applications such as sheet rolls, toys, tubing, piping, house wares, furniture, appliances, batteries cases, tables etc. [Biswas, S. 2010]. The most common natural plant used in applications is blast fibers, such as hemp, jute, flax, kenaf, and sisal can be reinforced in PP [Saheb, D. N. and Jog, J. P. 1999]. These fibers are composed mainly of cellulose, hemicellulose and lignin, with the composition varying according to the type of plant and geographic region. The final properties and, therefore, the potential applications of the obtained composite materials, depend on the composition of the fiber, the interfacial adhesion with the matrix, the size of the particle and the aggregate weight percentage [Cintia S. Navas, et al., 2015]. The combination of two or more natural and synthetic fibers into a single matrix has led to the development of hybrid composites [Jawaid, M. et al., 2013].

Natural–synthetic fiber hybrid composites are increasingly used in a wide range of applications [Atiqah A, 2014]. The advantages of hybridization are fully utilized to reduce the use of synthetic fibers which are generally non-environmentally friendly. Hybrid composites can be made from artificial fibers, natural fibers and with a combination of both artificial and natural fibers [Nunna S. et al, 2012]. Hybrid composites material provide high tensile strength and impact resistance properties [Yahaya, R. et al., 2016]. Hybrid nanocomposites with PP/clay/wood flour by melting compounding was prepared and observed that the tensile modulus and strength of most hybrids increased with the increased loading of clay, MAPP, and wood flour [Maldas, D. et al., 1988]. Mechanical and thermal properties of wood flour and talc filled polylactic acid composite investigated successfully [Lee et al. 2008]. Good improvement in mechanical properties of hybrid (wood flour/talc PP) composites [Singh et al., 2010]. The improvement in mechanical properties depends on the fiber loading, on the particle size of the fiber, on the concentration and chemical structure of the coupling agents [Venkateshwaran, N. et al., 2012]. Hybrid composite prepared using banana/sisal fibers and thermosetting resin experimentally found the tensile strength and modulus are good agreement [W Qui, at al., 2000]. Effect of hybrid filler wheat straw and inorganic filler (heavy calcium carbonate, silicon dioxide and fly ash) reinforced in recycle polypropylene investigated and reported that the water absorption properties improved from wheat straw and inorganic fillers [Min, et al. 2016]. The mechanical and thermal properties of single fiber and hybrid filler PP composites determined which have generated very interesting results that demonstrate the effectiveness of hybrid fillers in enhancing the properties of PP [Zhun, J. et al. 2013]. Hybridization effect has successfully increased the resistance of the composite to severe environmental degradation. The hybrid filler PP composite show better retention in mechanical properties [Wai yie Leong et al. 2004]. Therefore, in the present work, a hybrid composite of wood and rice husk is developed and tested for effects of various parameters such as fiber type, weight percentage loading and fiber size on the impact strength and hardness.

The subsequent sections discuss about the preparation of composite, experimental design, results and discussion and conclusion drawn from the current work.

PREPARATION OF COMPOSITE

Polypropylene polymer 700MJ is purchased from Bansal Plastic Private Limited, Firozabad, Uttar Pradesh, INDIA. The density of polymer is 0.9 g/cm^3. Filler materials, wood powder and rice husk are collected from local market of Firozabad.

Talc powder supplied by Goyal Private Limited, Rajasthan INDIA. Silane (S-69) coupling agent is obtained from Mahaveer Chemical Private Limited, New Delhi, INDIA.

The rice husk is washed thoroughly using the running tap water and dried for 24 hours in sunlight of June month at a temperature of 43-45°C in district Firozabad, Uttar Pradesh, recorded as per a national news channel broadcast. The dried rice husk crushed in crushing machine and converted into Rice Husk Powder (RHP). Wood Powder (WP) is a sawdust produced in plenty as a waste of sawmills. In the present work, Indian Shisham tree is used as wood powder. It is also named as Dalbergia Sissoo [Nunna S. et al. 2012].

The WP and RHP powders are washed 3-4 times in normal running water for further removal of dust particles and then the powders are immersed in NaOH solution for 12 hours. Moreover, the treated fibers washed by tab water for 3-4 times to remove excess NaOH. Also, WP and RHP as well as the Talc powder are oven dried at 110 ^{0}C for 24 hours to remove the moisture content and then stored in an air tight container.

A sieve is used to separate desired elements from unwanted material. Sieving is a simple and convenient method of separating particles of different sizes. In the present work, the sieves with different types of holes are used for the classification of the WP and RHP separately. The WP and RHP ground to finer flour using seven different sieves analysis. The sizes of translation sieves available for the separation of the raw particle fibers are 4750, 3350, 2360, 1180, 600, 300 and 150 µm. The present work considered diameter ranges of 300 µm, 600 µm and 1180 µm (0.3 mm, 0.6 mm and 1.18 µm) for both fibers. The fiber length is not considered as far as fine in short length.

EXPERIMENTAL DESIGN

In the present work, Taguchi method is utilized, which is well-known systematic and efficient approach for experimentation to determine near optimum settings of design parameters for best performance. This method involves laying out of the experimental conditions using particularly constructed table known as orthogonal arrays [Biswas, S., 2010]. Table 1 present the operating conditions under which fabrication are carried out. This indicates the factors and their levels in the compounding experiment of composite having three factors and each factor has 3 levels. Three parameters viz., fiber type, fiber loading and fiber size, are considered as a controlling factor. As per Taguchi method, if there are three parameters and three levels for each parameter then L_9 orthogonal array has been suggested for the experimentation [Biswas, S., 2010].

The tests were conducted as per experimental design presented in table 1, which is designed as per orthogonal array L_9 for data collection under room temperature. The collections of data are searched by 9 conditions. Moreover, the pure polypropylene (PP) is used to fabricate the samples and no any other type of filler material is used. The plan of the experiments is as follows: the first column is assigned to fiber type (A), the second column to fiber loading (B) and third column to fiber size (C). Table 2 present the experimental layout based on L_9 orthogonal arrays adopted in this work.

Table 1. Design parameters and their levels considered in the present work

Factors	**Selected parameters**	**Levels**		
		1	2	3
1	Fiber type	WP	RHP	WPRHP
2	Fiber loading	10 wt. %age	20 wt. %age	30 wt. %age
3	Fibers size	300 μm	600 μm	1180 μm

Legends: WP: Wood Powder; RHP: Rice Husk Powder; WPRHP: Wood Powder and Rice Husk Powder

Table 2. Experimental layout based on L_9 Orthogonal Arrays

Exp. No.	**Design Parameter Levels**			**Parameters Setting**
	Fiber type (A)	Fiber loading (B)	Fiber Size (C)	
1	WP+TP+PP (Level 1)	10 (Level 1)	300 (Level 1)	A1B1C1
2	WP+TP+PP (Level 1)	20 (Level 2)	600 (Level 2)	A1B2C2
3	WP+TP+PP (Level 1)	30 (Level 3)	1180(Level 3)	A1B3C3
4	RHP+TP+PP (Level 2)	10 (Level 1)	600 (Level 2)	A2B1C2
5	RHP+TP+PP (Level 2)	20 (Level 2)	1180 (Level 3)	A2B2C3
6	RHP+TP+PP (Level 2)	30 (Level 3)	300 (Level 1)	A2B3C1
7	WP+RHP+TP+PP (Level 3)	10 (Level 1)	1180 (Level 3)	A3B1C3
8	WP+RHP+TP+PP (Level 3)	20 (Level 2)	300 (Level 1)	A3B2C1
9	WP+RHP+TP+PP (Level 3)	30 (Level 3)	600 (Level 2)	A3B3C2

Legends: WP: Wood Powder; RHP: Rice Husk Powder; WPRHP: Wood Powder and Rice Husk Powder

The selected three parameters would require 3^3 i.e. 27 experiments each at the three levels in the full factorial experiment whereas Taguchi's experimental method reduces it to 9 runs only offering a great advantage. A twin-screw extruder (made of Siemens Ltd.) is used for the compounding as shown in the figure 1. The extruder barrel temperature is 190, 200, 210, 220, 230 and 240 ^{0}C of six zones from feeding to die zone. Moreover, the compounds are blended at a screw rotational speed of 50 RPM and the melting pressure of extruder is set at 30 bars. The extrudates are cooled in a water bath pulled which is attached with extruder body and pelletized. Pelletized compounding is shown in figure 2.

Figure 3 showing the moulding machine used in the present work. Test specimens are injection moulded using a 70-90 Tonne Electronica Injection Moulding Machine. The screw rotational speed and injection cycle time are calibrated as 40 RPM and 30 seconds, respectively. The injection molding nozzle temperature range are 149, 171, 200 and 240 ^{0}C. The injection pressure and mould temperature are set as 50 Bar and 50 ^{0}C, respectively.

The impact tests are performed as per ASTM D 256 using a standard material testing system. All measurements are performed at ambient conditions and three specimens are tested for each composite formulation. The impact test results are noted directly from digital screen of Izod impact tester. Figure 4 shows the samples for hardness testing, molded from the injection molding machine and as per ASTM D 2240. Figure 5 shows the samples for hardness testing.

Figure 1. Twin Screw Extruder Machine used in the present work

Figure 2. Pellets of compounding

Figure 3. Electronica Injection Moulding Machine used in the present work.

Figure: 4. Impact testing samples after V- Notching.

Figure: 5. Hardness testing samples.

RESULTS AND DISCUSSIONS

In the present work, the developed composite samples are tested for hardness and impact strength. In figures, WP represent the composite of wood, talc and polypropylene, similarly, RHP represent the composite of rice husk, talc, and PP. Also, the WPRHP represent the proposed composite containing wood, rice husk, talc and polypropylene as discussed in experimental design section.

a) Impact Strength

Figure 6 is illustrating the comparative results obtained for impact strength of selected composites in this work. Results shows that with the 20-wt. percentage of fiber loading the impact strength of WP composite is increased and consecutively decreased. In addition, the impact strength of RHP composite is increased up to 20-wt. percentage of fiber loading and thereafter decreased significantly. It has been seen that, the impact strength is improved with increase in the filler loading weight percentage for the developed WPRHP composite. Also, the impact strength is increased with increase in the filler size up to 600 µm then decreased. As compared to obtained results of impact strength to PP with hybrid filled PP composites, it is found that hybrid filled PP composites impact strength results are not so good.

Results revealed that the impact strength of WP composite is increased with both the fiber loading up 20 wt. %age and fiber size range 300 to 600 µm but then shows decreased. It is found that the impact strength of RHP composites is increased with fiber loading up 20 wt. %age but impact strength increased with increased fiber size from 300, 600, 1180 µm. But in case of hybrid WPRHP composites, the impact strength increased with increased fiber loading from 10, 20, and 30 weight percentage. It is also observed that the impact strength of hybrid WPRHP composite is increased, with increased fiber loading up 20 wt. %age fiber then decreased.

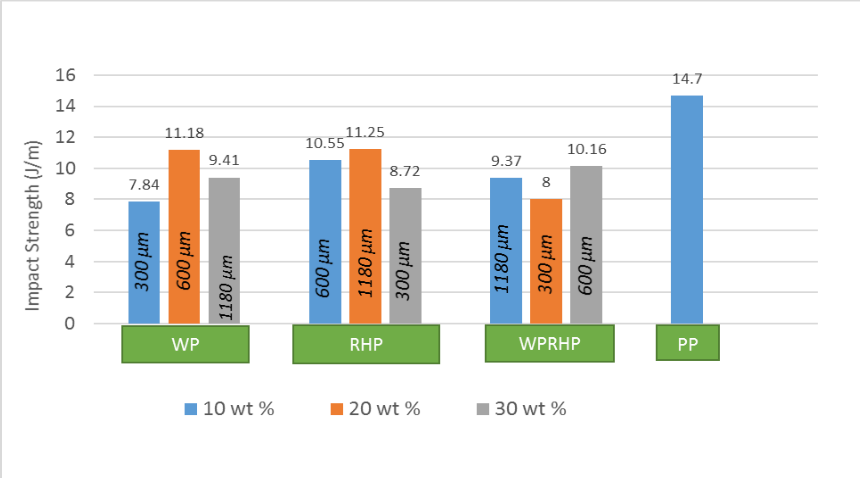

Figure 6. Comparison of Impact strength of different type of composites considered in present work.

b) Hardness

The comparative results of hardness for developed composites are illustrated in figure 7. It is observed that the hardness of WP composite increased with the increase of 20 wt. percentage of fiber loading. Moreover, the hardness increased up to 600 µm fiber size and then decreased drastically. Experiments revealed that the hardness of RHP composite is increasing corresponding to fiber loading from 10, 20 and 30 weight percentage continuously. Also, for RHP composite the hardness is slightly improved at fiber size 300 µm. From the proposed hybrid WPRHP composite results, the hardness is decreased with increase in the filler loading up to 20 weight percentages then increased. However, the hardness is increased with increase in the filler size from 300, 600 and 1180 µm. it is can be seen that hardness results are excellent of developed PP composites in the comparison to PP.

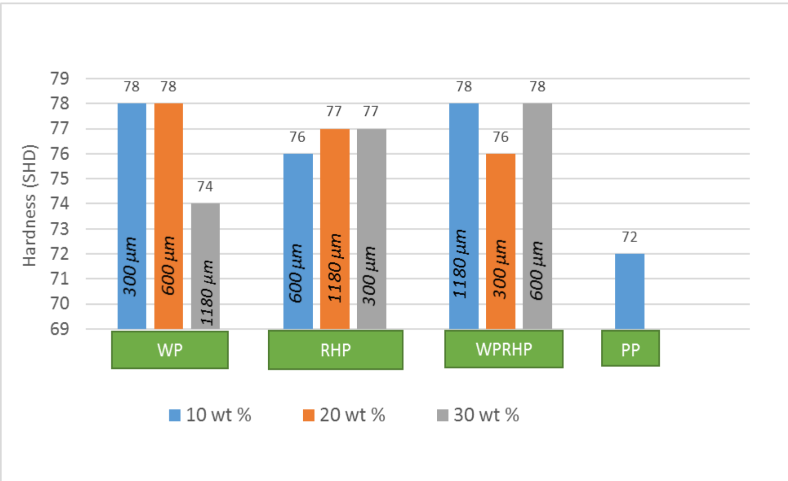

Figure 7. Comparison of hardness of different type of composites considered in the present work.

TAGUCHI EXPERIMENTAL ANALYSIS

In the present study, all the designs, plots and analysis have been carried out using MINITAB 17 statistical software. Since, impact strength and hardness properties are the criterion that were preferred to find the optimum parameters on the bases of determined S/N ratio, the larger is better quality characteristic has been selected. The following sections are presenting the Taguchi analysis for various mechanical properties considered in the present work.

a) Impact Strength

Table 3 and 4 present the mean and S/N data for impact strength respectively. In these tables, the ranks and delta values show that fiber loading has the greatest effect on the impact strength. To study the significance of the process variables towards impact strength, analysis of variance (ANOVA) is performed. From table 5, it can be observed fiber type ($p = 0.072$), fiber loading ($p= 0.149$) and fiber size ($p = 0.000$). It is found that point C that's represent fiber size, is significant process parameters for impact strength where, point A and point B, represent fiber type and fiber loading is not significant process parameter. The response tables 3 and 4 shows the average of each response characteristic (means and S/N data) for each level of each factor. The tables include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor.

As per mean data, the second level of fiber type (A_2), second level of fiber loading (B_2) and second level of fiber size (C_2), provide maximum value of impact strength as presented in figure 8. Similarly, from figure 9, the S/N data analysis suggests the same levels of the variables (A_2, B_2 and C_2) as the best levels for maximum impact strength in composite characterization. These values are optimal level of selection for flexural modulus.

It can be seen from figures 10 that the residuals follow an approximately straight line in normal probability plot and approximate symmetric nature of histogram indicates that the residuals are normally distributed. Residuals possess constant variance as they are scattered randomly around zero in residuals versus the fitted values. Since residuals exhibit no clear pattern, there is no error due to data collection order.

Table 3. Response table for means of impact strength

Level	A	B	C
1	9.487	9.152	8.148
2	10.179	10.100	10.633
3	9.020	9.433	9.904
Delta	1.159	0.948	2.486
Rank	2	3	1

Table 4. Response table for S/N ratios of impact strength

Larger is better

Level	A	B	C
1	19.39	19.05	18.13
2	19.98	19.91	20.36
3	18.95	19.36	19.83
Delta	1.03	0.86	2.23
Rank	2	3	1

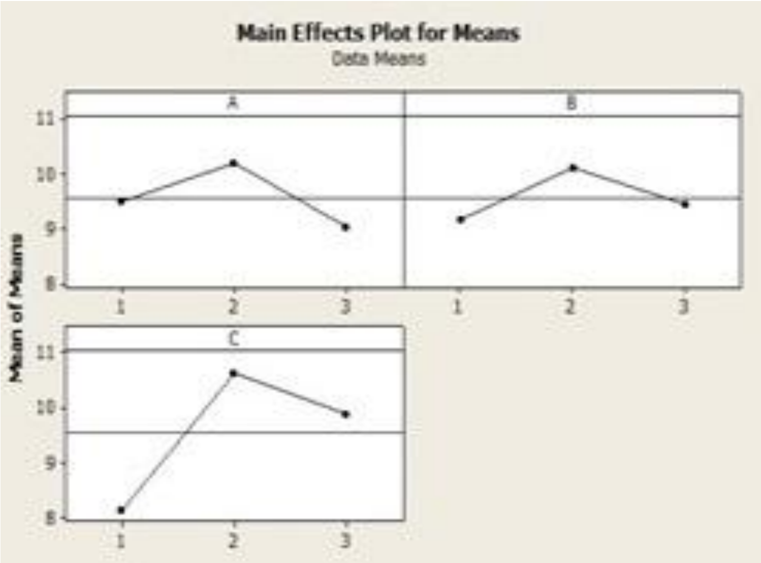

Figure 8. Mean response for effect of process parameters on impact strength for different composites

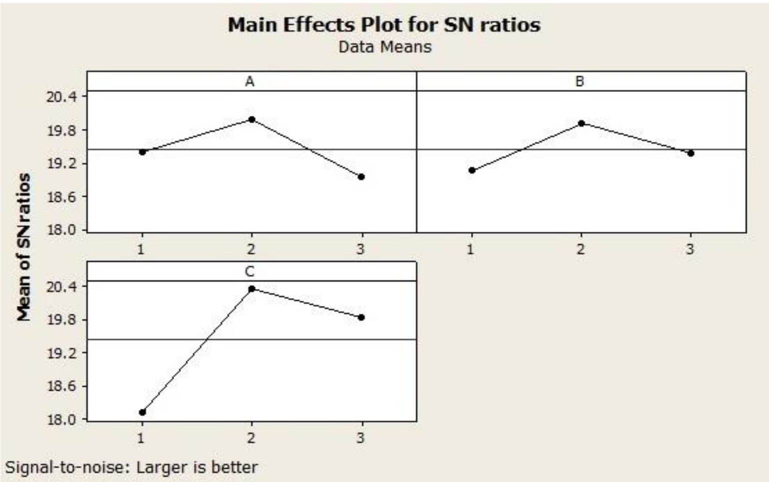

Figure 9. S/N response for effect of process parameters on impact strength for different composites

Table 5. Analysis of variance for impact strength, using Adj SS for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	6.120	6.120	3.060	3.01	0.072
B	2	4.265	4.265	2.133	2.10	0.149
C	2	29.385	29.385	14.693	14.47	0.000
Error	20	20.305	20.305	1.015		
Total	26	60.076				

Legends: DF - Degrees of Freedom, Seq SS – Sequential Sum of Squares, Adj SS – Extra Sum of Squares, Adj MS – Extra Mean Squares (Variance), F - Ratio of variance of a source to variance of error, P < 0.05 - Determines significance of a factor at 95% confidence level

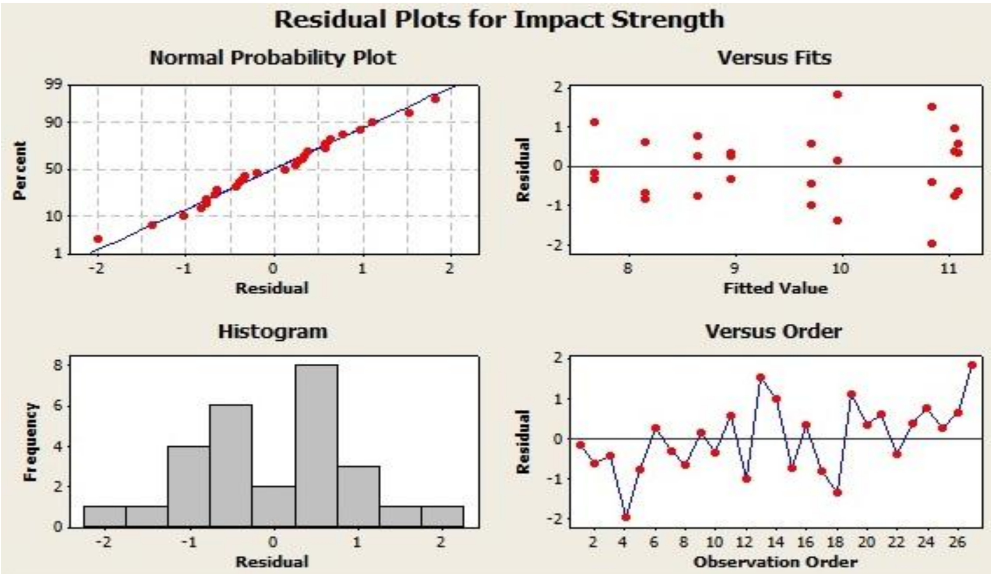

Figure 10. Residual for effect of process parameters on impact strength for different composites

b) Hardness

Table 6 and 7 present the mean and S/N data for hardness respectively. In these tables, the ranks and delta values show that fiber size has the greatest effect on the hardness. To study the significance of the process variables towards hardness, analysis of variance (ANOVA) is performed. From table 8, it can be observed that the fiber type ($p = 0.745$), fiber loading ($p = 0.550$) and fiber size ($p = 0.745$), i.e. there is not significant process parameter for hardness in process variables. It is found that fiber type, fiber loading and fiber size are non-significant process variable for hardness. The response tables 6 and 7 shows the average of each response characteristic (means and S/N data) for each level of each factor. The tables include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor.

From the figure 11, it can be seen from mean data, that the third level of fiber type (A_3), second level of fiber loading (B_2) and second level of fiber size (C_2), provide maximum value of hardness. Similarly, from figure 12, the S/N data analysis suggests the same levels of the variables (A_3, B_2 and C_2) as the best levels for maximum hardness composite characterization. These values are optimal level of selection for hardness.

It can be seen from figures 13 that the residuals follow an approximately straight line in normal probability plot and approximate symmetric nature of histogram indicates that the residuals are normally distributed. Residuals possess constant variance as they are scattered randomly around zero in residuals versus the fitted values. Since residuals exhibit no clear pattern, there is no error due to data collection order.

Table 6. Response table for means of hardness

Level	A	B	C
1	37.62	37.69	37.64
2	37.64	37.69	37.70
3	37.70	37.59	37.62
Delta	0.08	0.10	0.07
Rank	2	1	3

Table 7. Response table for S/N ratios of hardness

Larger is better

Level	A	B	C
1	76.11	76.67	76.22
2	76.22	76.67	76.78
3	76.78	75.78	76.11
Delta	0.67	0.89	0.67
Rank	2.5	1	2.5

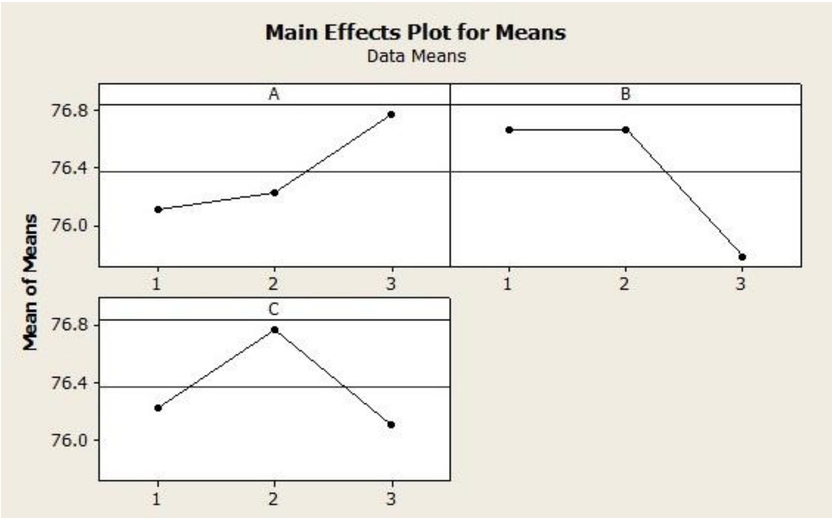

Figure 11. Mean effect of process parameters on hardness for different composites

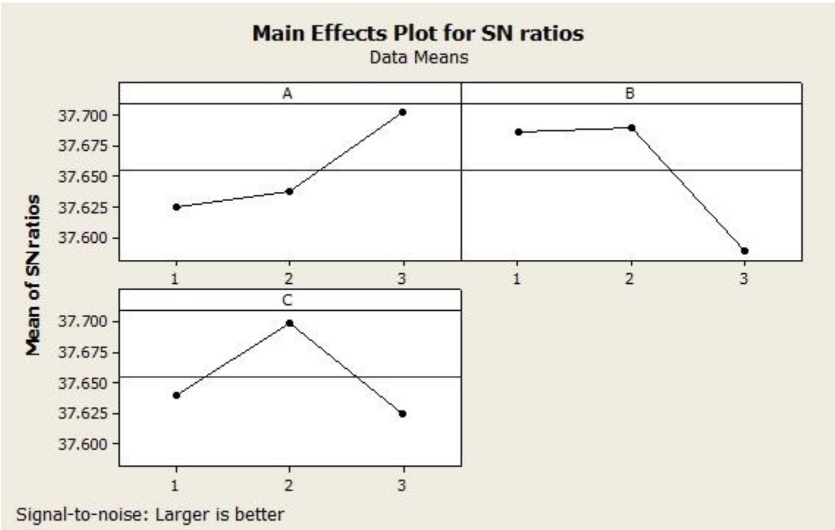

Figure 12. S/N ratio effect of process parameters on hardness for different composites

Table 8. Analysis of variance for hardness, using Adj SS for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	2.296	2.296	1.148	0.30	0.745
B	2	4.741	4.741	2.370	0.62	0.550
C	2	2.296	2.296	1.148	0.30	0.745
Error	20	76.963	76.963	3.848		
Total	26	86.296				

Legends: DF - Degrees of Freedom, Seq SS – Sequential Sum of Squares, Adj SS – Extra Sum of Squares, Adj MS – Extra Mean Squares (Variance), F - Ratio of variance of a source to variance of error, P < 0.05 - Determines significance of a factor at 95% confidence level.

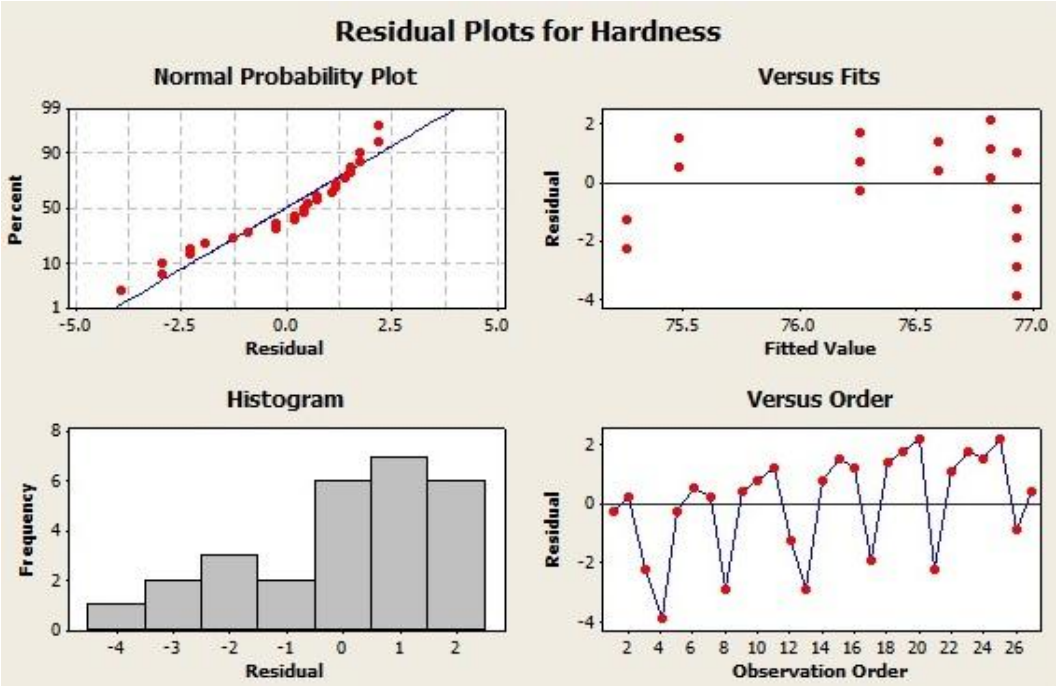

Figure 13. Residual effect of process parameters on hardness for different composites

CONCLUSIONS

The effects of selected parameters on impact strength and hardness of proposed hybrid composite are investigated as follows:

- With 20-wt. percentage of fiber loading the impact strength of WP composite is increased and consecutively decreased. In addition, the impact strength of RHP composite is increased up to 20-wt. percentage of fiber loading and thereafter decreased significantly. It has been seen that, the impact strength is improved with increase in the filler loading weight percentage for the developed WPRHP composite. Also, the impact strength is increased with increase in the filler size up to 600 µm then decreased. As compared to obtained results of impact strength to PP with hybrid filled PP composites, it is found that hybrid filled PP composites impact strength results are not so good.
- The impact strength of WP composite is increased with both the fiber loading up 20 wt. %age and fiber size range 300 to 600 µm but then shows decreased. It is found that the impact strength of RHP composites is increased with fiber loading up 20 wt. %age but impact strength increased with increased fiber size from 300, 600, 1180 µm. But in case of hybrid WPRHP composites, the impact strength increased with increased fiber loading from 10, 20, and 30 weight percentage. It is also observed that the impact strength of hybrid WPRHP composite is increased,

with increased fiber loading up 20 wt. %age fiber then decreased.

- It is observed that the hardness of WP composite increased with the increase of 20 wt. percentage of fiber loading. Moreover, the hardness increased up to 600 µm fiber size and then decreased drastically. Experiments revealed that the hardness of RHP composite is increasing corresponding to fiber loading from 10, 20 and 30 weight percentage continuously. Also, for RHP composite the hardness is slightly improved at fiber size 300 µm. From the proposed hybrid WPRHP composite results, the hardness is decreased with increase in the filler loading up to 20 weight percentages then increased. However, the hardness is increased with increase in the filler size from 300, 600 and 1180 µm. it is can be seen that hardness results are excellent of developed PP composites in the comparison to PP.

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