Preparation and Optimisation of Sheesham Wood Natural Fiber Composite using Box-Behnken Technique

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Abstract: **In the present work natural fiber composites (NFCs) were prepared. Sheesham wood was used as a natural fiber and Poly propylene was used as a base material. Now-a-days natural fibers have been used by the researchers due to its various advantages such as renewability, biodegrability & low material price etc. In this study material such as Sheesham wood dust, NaoH pallets & Polypropylene were used and NFCs were prepared and optimized using Injection molding technique. Tensile strength, Impact strength, Hardness, Flexural Strength were analysed and the experimental results showed a higher tensile strength, Flexural strength, Hardness with less impact strength where optimized values for Tensile strength, Flexural strength, Hardness and impact strength were found to be 26.95,46.15, 80 & 11.12 respectively.**

Keywords: **Composite, Natural fibers, Polypropylene, Polymer, Sheesham wood.**

I. INTRODUCTION

Nowadays there are number of problems facing by the people of world due to various factors such as speedy growth in population which results in the shortage of resource and ultimately leading to environmental pollution that causes harm to the earth and society(Rahman & Bhoi, 2021). In our daily life we are using a large number of non-renewable and non-biodegradable materials such as metal, glass, plastic products, petroleum derivatives etc although these products are beneficial in our routine life when they are but consumed in large amount leads to deterioration of environment(Agarwal, 2020). So in order to protect our environment from pollution and side effects associated with it use of biodegradable (Subramanian et al., 2021)materials are suggested(Wang, Liu, Ding, Zhang, & Yu, 2021)**.** A huge variety of fibers of natural origin are obtainable that are paying attention to the scientists, technologists and researchers for example cotton, banana, coir, jute , wood powder and many more(da Silva Barbosa Ferreira, Luna, Araújo, Siqueira, & Wellen, 2021) . These natural fibers can be utilized because of various advantages such as beneficial for the production of consumer goods, low housing cost and for buliding other structures associated with civil(Khalid et al., 2021). These natural fibers can be formulated into composites(Karim, Tahir, Haq, Hussain, & Malik, 2021) which possess various properties like improved electrical resistance, high-quality thermal and acoustic insulating properties and advanced resistance to fracture(da Fonseca, Rocha, & Cheriaf, 2021). If we compare natural fibers with synthetic fibers(Begum, Fawzia, & Hashmi, 2020) than they show numerous advantages fibers such as low weight, low density, low cost, recyclable, biodegradable, renewable, comparatively high strength and stiffness and causes no irritations to skins(Venkateshwaran, Elayaperumal, & Sathiya, 2012). Therefore they can be used for fabricating wood plastic composites (WPCs). These are the composites that include plant, wood or non wood fibers, thermosets and thermoplastics(Post, Susa, Blaauw, Molenveld, & Knoop, 2020). Thermosets are the plastics whose melting is not possible by repeated melting process once cured for example resins (epoxies and phenolics)(Peters, 2002) whereas the plastics which can be melted repeatedly are known as thermoplastics due to these properties they can allows other materials like fibers obtained from wood, are to be mixed with plastic so as to form a product known to be composite product(Adeniyi et al., 2016; Wilczyński, Buziak, Lewandowski, Nastaj, & Wilczyński, 2021). Examples of thermoplastics are Polypropylene (PP), polyethylene (PE) and polyvinyl chloride (PVC) that are extensively used for WPCs and at present they are very widespread in building work, construction sites, furniture manufacturing and for making automotive products(Ashori, 2008). There are various factors that effects the properties of WPCs such as content of wood dust, type of wood species used, coupling agent properties, and matrix material(Vedrtnam, Kumar, & Chaturvedi, 2019). WPCs lessen the green house effects and known to be eco-friendly. A appropriate filler for WPCs is Wood flour (WF) it because of its ease in availability, density is also low , biodegradable in nature , renewable, stiffness is high , and moderately low cost(Kumar, Vedrtnam, & Pawar, 2019)

Extrusion and injection molding are the important methods used in the manufacturing of plastics and wood fiber filled with plastic parts(Alam, Kaur, Khaira, & Gupta, 2016). In extrusion process unbroken linear profiles are produce where melted thermoplastic is forced via a die whereas injection molding process prepares three-dimensional things with least post-manufacturing stages(Migneault et al., 2009).

Several researchers investigated different wood powder polypropylene composites but limited studies was conducted using shisham wood powder (Graebling, 2002)polypropylene by variation of injection moulding pressure, weight percentage of fiber and fiber size are limited.

II. MATERIALS AND METHOD

A. Materials

1) Matrix Material

The polypropylene is higher temperature battling material, because of this significant property, it is appropriate for some, things like plate, jugs and instrument shakes that must be usually utilized for therapeutic conditions.

Polypropylene of low density (0.9 g/cm^3) in pellet form was obtained from Bansal plastic private limited from Firozabad,

2) Fiber Materials

This research work employs sheesham wood powder (sawdust) as natural fibers in the polypropylene matrix to fabricate different set of composites. Saw dust was obtained from local wood industry Lucknow.

During blending of clumps, 1% by weight silane, coupling specialist S-69 is included the blend for good holding of fiber in polypropylene grid..

A. Preparation of composites

Before composite fabrication, there are several treatments have been done on the fiber, separately. This kind of waste molecule size is in ranges from 20 to 5000 µm. The selected size of shisham wood powder (SWP) particle sizes are 300,740,1180 µm. Treatment of wood powder was carried out by using NaOH (Sodium Hydroxide) solution. The NaOH pellets 900 grams were put in 15 liters water in the bucket. NaOH pellets are soluble in water and make a 6% NaOH solution. To begin with, the wood powder is washed with the typical water for three-four times to evacuate dust and different materials, at that point dried in daylight at 43-45 0C four days at room temperature to expel the dampness. At that point wood powder (WP) was ground to fine powder and went through sifter shaker. .wood powder was submerged in NaOH answer for 24 hours, where the room temperature was kept up. The rewarded wood powder at that point completely flushed in ordinary faucet water a few times to evacuate the overabundance NaOH, at long last washed with refined water twice. After washing in water, the wood powder was kept in trays homogeneously for its drying in oven at 110^{0}C for 48 hours.

B. Fabrication of Composites

The SWP composite are fabricated by injection moulding technique due to varying moulding pressure, weight percentage of fiber and fiber size than the optimum set fabrication of parameters are achieved by Box-Behnken Technique.

In Extrusion examination work, the twin extruder was utilized for exacerbating (blending) the strands and polypropylene. For aggravating the composites Siemens Ltd extruder, model Simatic HMI was utilized. Twin Screw Extruder Operating Conditions parameters are Melting pressure 30 bar, Temperature 30^{0}C, Screw rotation speed 50 RPM, Screw temperature 170,180,190,200,210^{0}C. After the compounding of all the batches, these were cut separately in small pieces. Infusion shaping machine (Electronica 70-90 ton machine model number 1656) Electronica Plastic Machine Ltd, Pune, India, was utilized for the sample preparation. Operating parameters of the injection molding machine are Screw rotation speed 40 RPM, Cycle time 30S, Nozzle temperature range (149,180,190,200,210)^{0}C and Mould temperature 50^{0}C. Trim temperature scopes of the infusion chamber are 149, 180, 190, 200 and 210, these range are discovered ideal in the back, center, front, and spout zones, individually.

The form temperature is 500^{0}C. Process duration for infusion is 30 second. At the overheating temperature, the polypropylene can be vanishing so it is important to keep up temperature beneath 2500^{0}C.

III. CHARACTERISATION, OPTIMISATION AND TESTING

A. Tensile Strength of Developed Composites (ASTM D638)

The Tensile specimens with measurement 68.2 × 12.70 ×3.18 mm^3 are acquired from the infusion forming machine. The pliable trial of various created composites were completed in the agreement with the standard ASTM D638 utilizing a standard material testing framework with cross head speed 50 mm/min. In this examination work, this test is acted in the widespread testing machine Instron USA 3382. The outcomes are utilized to examine the rigidity and tractable modulus of the composite examples. Here, the example tests are rehashed multiple times on each created composite sort and mean qualities is accounted for as the rigidity and tractable modulus of that composite.

B. Flexural Strength (ASTM D790)

The flexural example tests with measurement 50 × 12.40 × 3.30 mm3 were created by utilizing the infusion shaping machine. The flexural tests are acted in the understanding with the ASTM D790 utilizing a standard material testing framework with cross head speed 1.50 mm/min. The flexural properties of the created composites are determined in three point twisting tests.

C. Impact Strength (ASTM D256)

The effect tests examples were set up as per the standard ASTM D256. All the effect test examples were tried utilizing the Izod sway analyzer. Above all else, an indent (2.5 mm) at 450 point was cut by the manual step shaper. The testing device was pendulum sway testing machine Tinius Olsen, Model Impact 104.

D. Hardness (ASTM D2240)

The hardness testing examples were formed from the infusion shaping machine. In the current work, the hardness properties are estimated utilizing a Durometer Shore D, DIN 53505 model hardness analyzer. The ASTM standard test technique for estimating the hardness properties of fiber sap composite ASTM D2240. The particular estimations of the hardness of various examples are noted straightforwardly from the dial pointer. The each assessment is rehashed multiple times on the lattice and every composite kind and the normal worth is accounted for as the hardness of that composite.

IV. RESULT AND DISCUSSION

A Box-Behnken Technique design was adopted to optimize the formulation and an overlay plot was obtained using design expert software (Design-Expert software, version 8.0) which provides theoretical values of optimized batch. Design Parameters and Their Levels are shown in Table 1. The Results of Mechanical Properties of pure Polypropylene (PP) are shown in table 2. The data responses in terms of flexural strength, tensile strength, hardness and impact strength are recorded in Table 3. The overlay plot displays the values of impact strength, tensile strength, hardness, flexural strength.

Table I. Design Parameters and Their Levels.

Number of parameters	Selected parameters	Levels			Unit
		1	2	3	
1	Injection Moulding pressure	35	40	45	bar
2	Fiber percentage	9	18	27	Wt.%
3	Fiber size	300	740	1180	µm

Table II. Results of Mechanical Properties of Polypropylene (PP)

Material	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (J/m)	Hardness ShoreD
PP	23.15	43.21	13.9	73

Table III. Investigated Mechanical properties of Sheesham wood polypropylene composite

Std	Run	Factor 1 A:Injection M... Bar	Factor 2 B:Fiber perc... Wt%	Factor 3 C:Fiber size µm	Response 1 Tensile Stren... MPa	Response 2 Flexural Stre... MPa	Response 3 Hardness SHD	Response 4 Impact Stren... J/m
8	1	45.00	18.00	1180.00	27.62	50.11	82	11.56
2	2	45.00	9.00	740.00	24.33	48.87	81	8.85
6	3	45.00	18.00	300.00	24.65	50.34	82	8.34
11	4	40.00	9.00	1180.00	25.26	46.76	75	9.95
1	5	35.00	9.00	740.00	25.21	48.92	82	7.78
3	6	35.00	27.00	740.00	24.55	47.26	75	10.23
13	7	40.00	18.00	740.00	26.75	45.67	82	11.3
9	8	40.00	9.00	300.00	25.22	47.12	81	7.97
7	9	35.00	18.00	1180.00	24.86	48.98	76	10.45
10	10	40.00	27.00	300.00	24.26	44.32	82	8.83
4	11	45.00	27.00	740.00	24.28	50.58	77	9.3
12	12	40.00	27.00	1180.00	24.51	44.88	75	9.48
5	13	35.00	18.00	300.00	26.51	44.25	81	8.18
14	14	40.00	18.00	740.00	26.68	45.55	81	11.35
15	15	40.00	18.00	740.00	26.71	45.34	81	11.27

A. Tensile Properties Of Composites

The results of Tensile strength of developed composites from Table 3 are given in Table 4.

Table.IV. Tensile Properties Results

Exp.No.	A	B	C	Tensile Strength (MPa)
1	3	2	3	27.62
2	3	1	2	24.33
3	3	2	1	24.65
4	2	1	3	25.26
5	1	1	2	25.21
6	1	3	2	24.55
7	2	2	2	26.75
8	2	1	1	25.22
9	1	2	3	24.86
10	2	3	1	24.26
11	3	3	2	24.28
12	2	3	3	24.51
13	1	2	1	26.51

In Table IV, A= Injection moulding pressure in Bar, B= Fiber Percentage (Wt %), C= Fiber Size (µm) and 1= Min value of factor , 2= Medium value of factor, 3= Max value of factor.

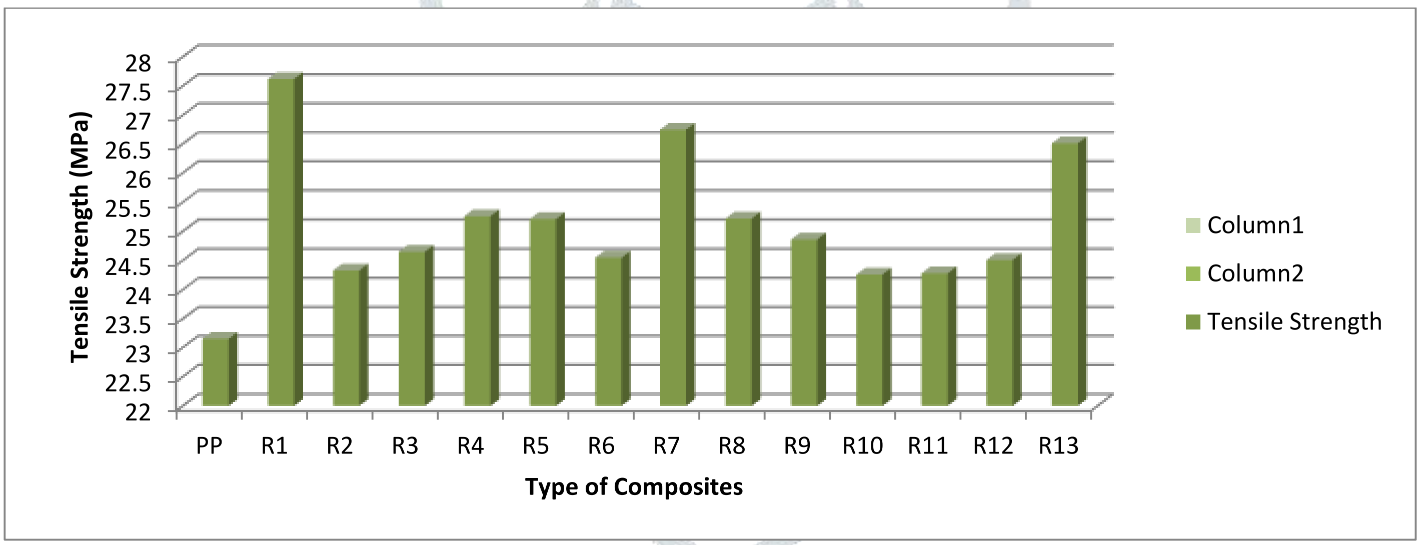

Fig 1 Tensile Strength of Developed Composites

It has been observed that the tensile strength of R1-R13 composites lie in the range 24.26 – 27.62 MPa All variations in the values are depends upon composites formulations according to design methodology. It has been observed that around maximum 19% improvement in the tensile strength of SWPPP composite takes place by the adding of 18% wt% of wood powder as compared to pure polypropylene. However, in respect of 27 wt% of the reinforcing materials, the tensile strengths of wood powder polypropylene composites are found to decrease as the filler increased. With the variation of filler loading in the increasing order, the tensile strength . It is maximum at 45 bar injection moulding pressure, 18% fiber and 1180 µm fiber size.

B. Flexural Properties of Composites

The flexural quality is identified with twisting of materials. On the off chance that a composite material fizzles in twisting, the advancement of the new composite material is basic to improve the flexural properties. The variations of the flexural properties and hardness and impact strength of different composites are seen in Table 3 & Table 5.

Table V. Flexural Properties, Hardness and Impact Strength of Composites

Exp. No.	A	B	C	Flexural Strength (MPa)	Hardness (SHD)	Impact Strength (J/m)
1	3	2	3	50.11	82	11.56
2	3	1	2	48.87	81	8.85
3	3	2	1	50.34	82	8.34
4	2	1	3	46.76	75	9.95
5	1	1	2	48.92	82	7.78
6	1	3	2	47.26	75	10.23
7	2	2	2	45.67	82	11.30
8	2	1	1	47.12	81	7.97
9	1	2	3	48.98	76	10.45
10	2	3	1	44.32	82	8.83
11	3	3	2	50.58	77	9.3
12	2	3	3	44.88	75	9.48
13	1	2	1	44.25	81	8.18

In Table V, A= Injection moulding pressure in Bar, B= Fiber Percentage (Wt %), C= Fiber Size (µm) and 1= Min value of factor , 2= Medium value of factor, 3= Max value of factor.

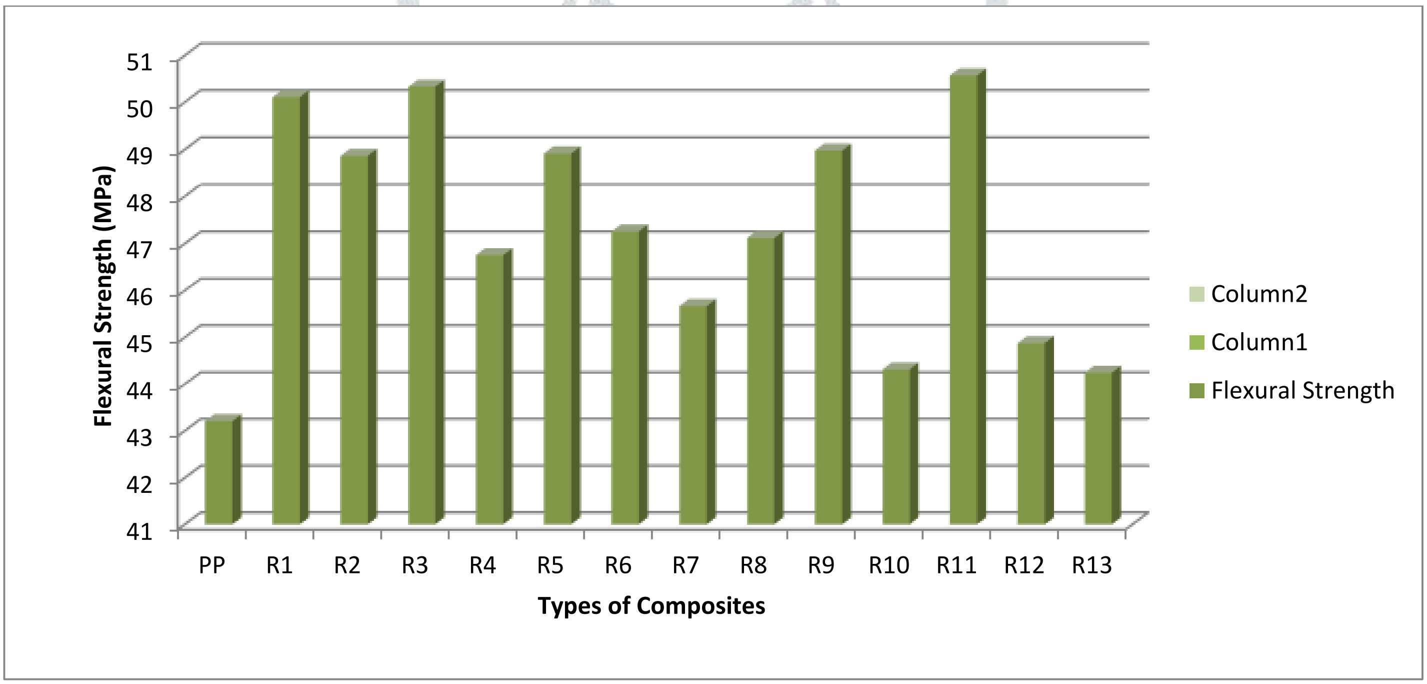

Fig. 2 .Flexural Strength of Composites

The trend of flexural strength of all developed SWPPP composites are shown in Figure 2.

From the Table 5, it is seen that the scope of the flexural quality of R1-R13 composites lies between 44.25–50.58 MPa. The flexural quality of the R1-R13 wood powder polypropylene composites expanded up to the expansion of 18 wt% of fiber substance. Be that as it may, further expanded up to 27 wt% of fiber prompts decline in the flexural quality. It was discovered that the most elevated flexural quality is seen with 45 bar pressure, 27 weight level of fiber and 740 µm fiber size. The further increment in fiber stacking in the composite prompts decline in the flexural quality.

C. Impact Strength of Composites

The impact strength is the capability of a material to soak up and dissipate energies under the shock or impact loading. The difference in the values of impact strength measured under this investigation of all developed composites and pure polypropylene are presented in Figure 5.

The experimental values of the impact strength of different developed composites are also presented in the Table 3 & 5. The Figure 3 shows the variation of measured values of the impactstrength.

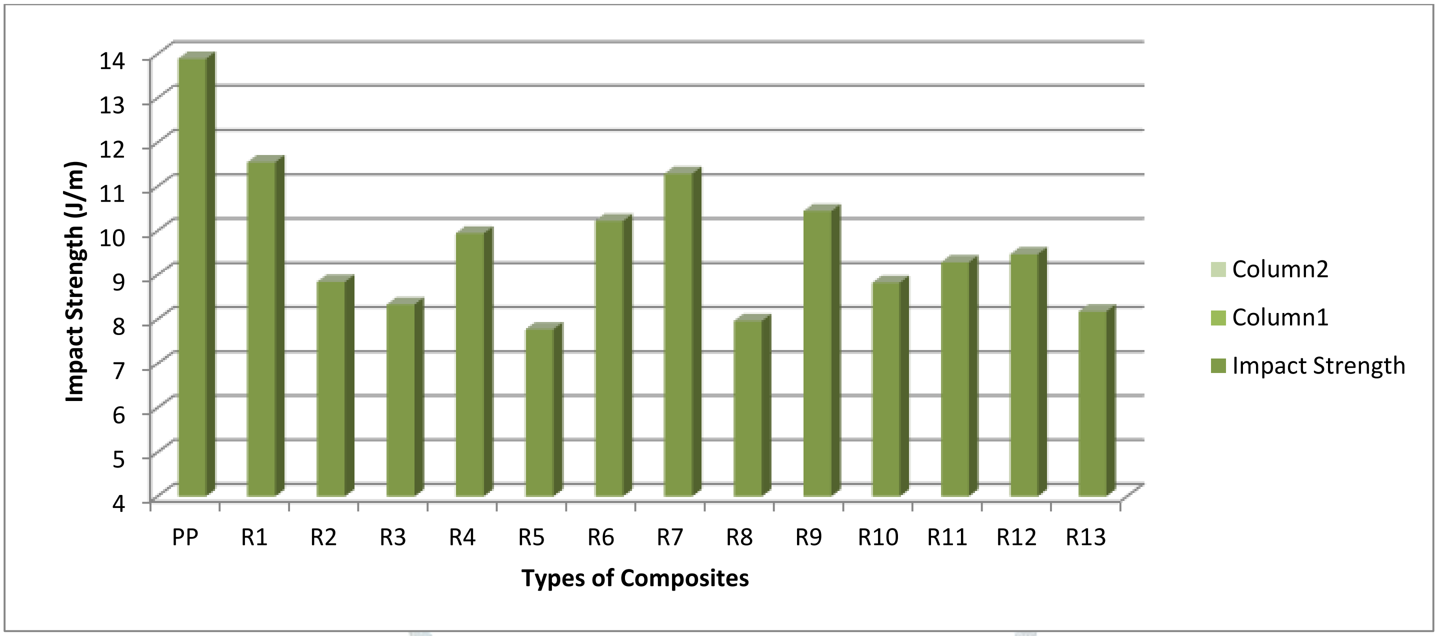

Fig. 3. Impact Strength of Developed Composite

It is observed that the impact strength of pure polypropylene (PP) matrix is very highest as compared to all developed composites. From the figure 3, it is observed that the impact strength of wood powder-polypropylene R1-R13 composites increased up to the 18 wt% of fiber loading and then decreased when fiber loading increased up to 27 wt%. The obtained value of polypropylene impact strength is 13.9 J/m. It can be observed from the Table 5 that the impact strength of WPPP composites lies in the range of 7.78 to 11.56 J/m. It is also observed that the impact strength of wood powder-polypropylene composites with 18 wt. % is very close to the value observed for polypropylene. It is clearly noticed that the R5 composite have lower impact strength than other developed composites. The most elevated impact strength is seen with 45 bar pressure, 18 weight level of fiber and 1180 µm fiber size.

D. Hardness of Composites

Variation of hardness properties of the different composites with the variation of the fiber weight percentage is shown in Figure 4. It is observed that pure PP matrix has a very lowest hardness as compared to all developed composites in this present work. It is seen that the hardness of wood powder-polypropylene composite improved up 18 wt% of fiber content addition and thereafter decreased. However, It is also seen that the hardness of R10 composite improved with 27 wt%offiber.

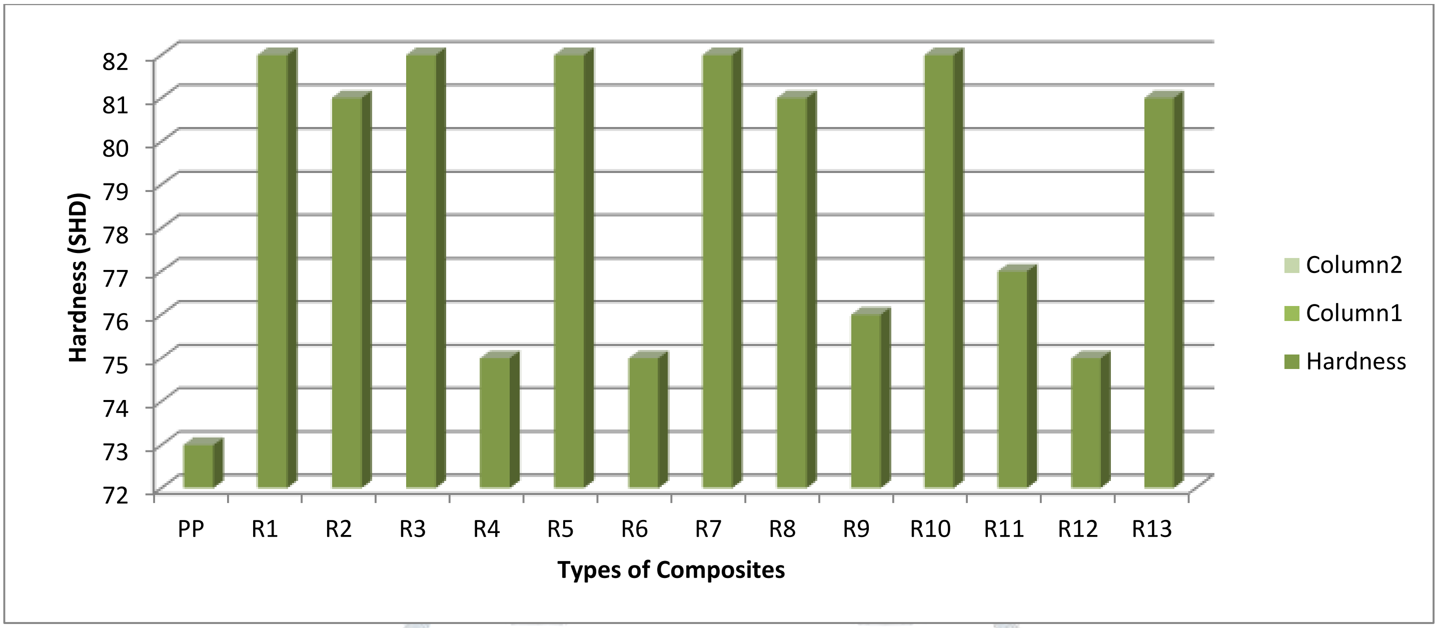

Fig. 4. Hardness of developed Composite

E. Ovarlay plot

An overlay plot was obtained using design expert software (Design-Expert software, version 8.0) which provides theoretical values of optimized batch. After analysis of each data the graphical method of optimization was adopted to find out the area of desired region (design space) and optimum formulation. Certain constants were applied on each dependent for purpose of optimization.

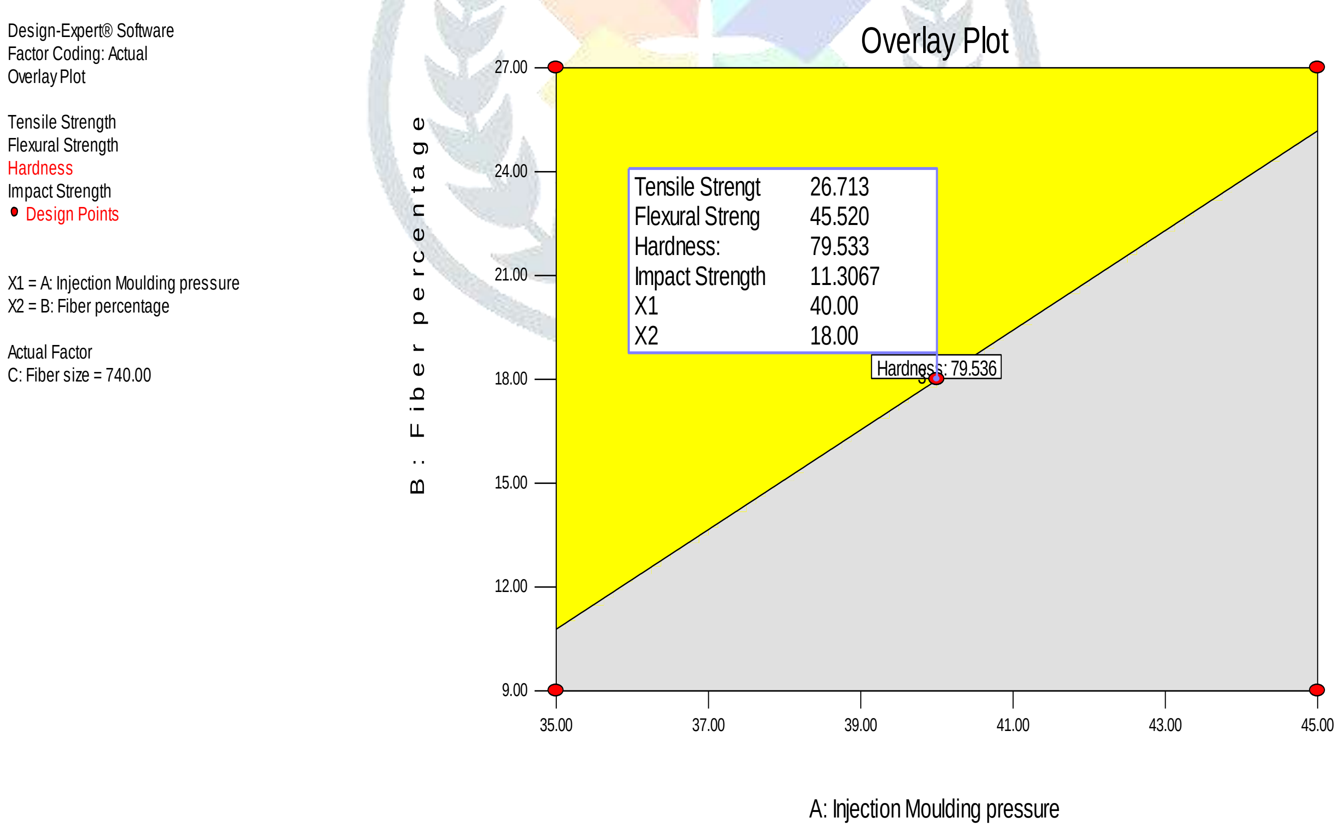

Fig 5. Overlay plot of design experiment

Table-VI. Validation of parameters by DOE/ Overlay Plot

Parameter	Predicted	Observed
Impact strength	11.3067	11.12
Tensile strength	26.713	26.95
Hardness	79.533	80
Flexural strength	45.520	46.15

As seen in overlay plot, for optimized batch the set parameters are Injection moulding pressure 40 bar, Fiber percentage 18w% , Fiber size 740 µm. we can see the Predicted value given by overlay plot in table. We fabricate specimen with these parameters and found observed value very close to Predicted value given by overlay plot optimized batch.

V. CONCLUSIONS

This study was carried out for the purpose of development and characterization of shisham wood natural fiber based polymeric composites. The composites were fabricated by mixing wood powder in polypropylene matrix using Injection molding. These composites were tested in the laboratory for various mechanical properties and optimum parameters were identified.

On the basis of above, the following conclusions have been drawn.

Tensile strength of the wood powder polypropylene composite are observed maximum (27.62 MPa) at injection moulding pressure 45 bar, 18 wt% of fiber with 1180 µm fiber size particles and when compared to pure polypropylene it is 19% more.

The flexural strength of shisham wood powder polypropylene composite is the highest flexural strength (50.58 MPa) has been observed at the 45 bar injection pressure, 27 wt. % of fiber with 740 µm fiber size and the flexural strength of SWPPP composite has increased by (17.05%) in comparison to pure polypropylene.

The maximum value of impact strength has been found to be 11.56 J/m for SWPPP composite with 45 bar injection moulding pressure, 18 wt% fiber and 1180 µm fiber size, which is close to the value for polypropylene.

The impact strength of developed natural fiber composite has decreased as comparison to pure polypropylene. The lowest value of impact strength (7.78 J/m) has been observed for shisham wood powder composite with 35 bar moulding pressure, 9 wt% fiber and 740 µm fiber size.

The hardness of developed composite has increased up to 82 SHD with different combination of input parameters like 45 bar moulding pressure, 18 wt% fiber and 1180 µm in comparison to pure polypropylene which is 73 SHD.

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