REVISTA MATÉRIA
V.27 N.02
ISSN 1517-7076 articles e13182, 2022

Effect of polyurethane ratio on mechanical behavior of banana fiber/polyurethane-vinylester matrix composites

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ABSTRACT

A customary ratio of vinyl ester (VER) and Polyurethane (PU) resin were chosen as the matrix material (blend) to attain the complete Interpenetrating Polymer Networks (IPN). In this course of research, the mechanical properties of the Banana fiber reinforced IPN (blend) matrix were thoroughly investigated by precisely varying the loading of polyurethane into vinylester as 0%, 10%, 20%, 30%, 40%, 50% PU respectively. Besides that, the fabricated banana fiber reinforced polyurethane loaded IPN laminate were experimentally investigated in order to characterize the strength of the laminate as per the ASTM standards. The test results exhibit that, strain rate of the laminate increases to many folds as compared (Tensile 0% PU - 0.45% & 50% PU - 3.1%, Flexural 0% PU – 0.62% & 50% PU – 3.73%) with the neat vinylester resin based banana fiber reinforced laminate. In addition to that, it also increases the impact strength and moisture resistance (Impact 0% PU – 2.93 kJ/m^2 & 50% PU - 8.01 kJ/m^2, Moisture 0% PU – 0.42% & 50% PU – 0.96%) of the IPN laminate considerably depends upon the loading of the polyurethane. As well as to validate further, the fractured surfaces were assessed through Scanning Electron Microscope (SEM). Finally the experimental values were also cross-verified by analytical simulation software by using ANSYS. Finally, the cross-verification proved that both the results of experimental and FEA analysis of the material were in good co-relation with each other.

Keywords: Vinylester, polyurethane, interpenetrating polymer networks (IPNs), banana fiber, scanning electron microscope, ANSYS.

1. INTRODUCTION

Nowadays researchers have undertaken continuous search of new materials in order to overcome the present day problems, faced by the currently available conventional materials such as steel, cast iron and alloying materials etc. Mostly the presently exisiting material satisfies the requirement of the society in turn it leads to irrepressible issues such as rusting, weight to stiffness ratio, prone to chemical reactions with the parent material. In order to overcome such an issues encountered on the conventional materials, researchers provide new set of composite materials, as the approach to replace the existing conventional materials [1-3]. To support the thrust areas of modern industrial material search, the polymeric material playing the crucial supporting role, in the emerging research field of all sectors like automobile, aerospace, sports utility etc. Generally, the composites are the mixture of two components like fiber and resin, by properly mixing the components, it is possible to achieve all set of goal arises from the modern day industrial requirement [4-6].

The commonly accepted fibers which depend upon the industrial requirements are Glass fiber, carbon fiber, aramid fiber and boron fiber etc. Though these fibers have had a very good compatibility with all set of resins, it has its own set of problems like poor recyclability, not environmentally (non bio-degradable) cooperative, like many other imperative harmful problems to the eco system. Furthermore the overall high cost of the synthetic fiber gives the alarming signal to the many manufacturing units when set to sell the product in customer end in due course of time [7-9]. From an environmental standpoint, it would be quite interesting, if natural fibers could be used instead of glass fibers as reinforcement in various structural elements. The industries are now currently focused on alternative material sources that are both environmentally friendly and compostable. Because of the growing environmental concerns, bio composites made of normal fiber and polymeric resin are among the most recent breakthroughs in the industry and the current focus of research. In the realm of technology, the use of composite materials is gradually growing. In line to the above, natural fibers,

Corresponding Author: Gopi Suresh Received on: 14/07/2020 Accepted on: 31/01/2022

10.1590/S1517-707620220002.1382

which is derived from the plants and animals often offers a very good advantageous effect, in terms of high strength to weight ratio, bio-degradable, low density, low cost etc., even though it possess half the value of the synthetic fiber strength. However, these natural fiber are also have several practical challenges, when this combination of these materials subjected in the areas of high load bearing components and in the areas of high moisture sensitivity zones. Nevertheless many attempts have been made by the researchers to enhance the mechanical property of the natural fiber reinforced composite material by incorporating the nanoclay, graphite and carbon nano tubes in order to achieve the comparable performance as similar as that of the synthetic fibers [10-12]. Many researchers have made their significant contribution of research in the area of natural fiber reinforcement in the polymeric materials. Out of all natural fibers, the oil palm, coir, jute, hemp, kenaf, coconut, sisal, banana has given their extensive contribution in the area of replacement of the synthetic fibers reinforcement.

Among them, banana fibers compatibility with different resin matrix material has been very vigorously studied by the researchers, since easier availability and environmental degradation property etc. Brazil, India and South Asian countries are the largest producers of the banana fibers. It is being cultivated in an area of 900 hectares found in the recent study in India alone. Similarly such a large production of banana fiber also yields the high magnitude of bio-waste and its dumping as well decomposing. To overcome such an unparalleled environmental impact of this banana plant waste, concept of banana fiber usage has been envisaged. These banana fibers posses the property of high weight to stiffness ratio hence it can enhance the better physical factors of the product being developed out of this exploration [13, 14]. Resins are a set of chemicals that is used in the composite material fabrication in order to bind together the fiber texture.

In this study a unique class of resin is being incorporated, which is known as IPN (Interpenetrating Polymer Networks) resin. It is the combination of two or more resins, together to form a new variety of resin is known as IPNs. This new type of resin, that absolutely incorporates the required amount of binding force without reacting with each other constituent resins, rather it provides better entanglement among the constituents. This research work focuses on making of a banana fiber reinforced IPN laminate and testing its mechanical behavior such as tensile, flexural, impact test and moisture absorption test. In the end, the ANSYS software is used to carry out the numerical test and finally the results are compared [15].

2. MATERIALS AND METHODS

2.1 Materials

In this present research of study, the nendran variety of banana plant were chosen, because of its excellent strength and better cost as compared with the other set of banana fibers. Initially the pseudostem was removed from the banana plant following the twelve days of its post harvesting. Besides that, the cortex region was extracted from the banana tree and the same was feed into the retting machine to completely extract the fibers. Subsequently, the fiber extracted from the retting machine was sun dried for a period of 9 to 11 days in order to completely take away the moisture content.

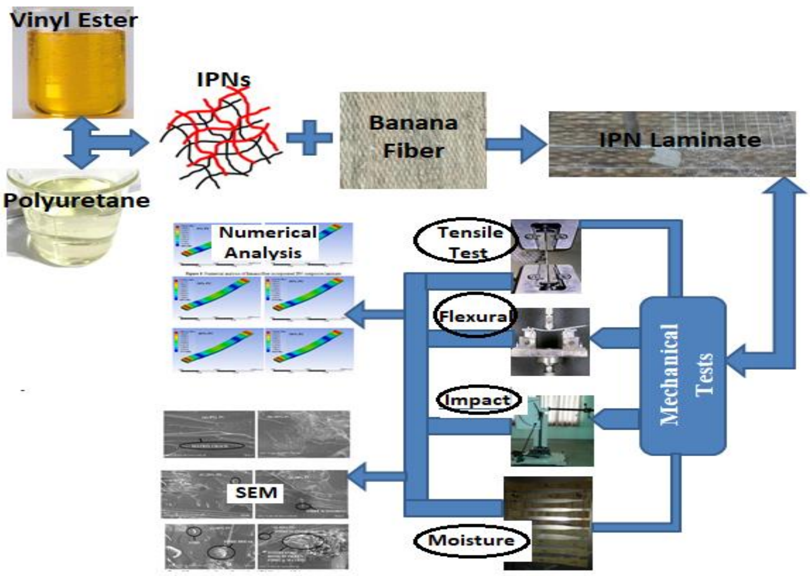

Figure 1. Schematic presentation of experimental analysis of banana fiber reinforced IPN laminate

At last, these sun dried fibers were kept in a hot air oven by maintaining the temperature between 50 deg to 80 deg for the period of 14 to 16 hours to completely dry out the moisture content to ensure the humidity free banana fiber [16]. The prepared fiber then weaved through the weaving machine to avail the uniaxial woven mat for further reinforcement. Figure 1 shows the complete schematic representation of banana fiber reinforced IPN laminate and its physical attribution and characterstics to evluate the mechanical strength for various applications.

2.2 Preparation of IPN Resin

The required amount of polyurethane (PU) and vinylester (VER) was taken in a separate beaker. In order to mix with polyurethane and Vinylester to have the better compatibility, the high density polyurethane viscosity must be reduced to have the better miscibility with the blending resin; to promulgate this, polyurethane (Shore 60 GA) was heated up to 60-70ºC before processing, then 6% of methylene bis-ortho choloroaniline was added to the polyurethane as hardener agent. Normally the PU prepolymer consists of methylene diphenyl diisocyanate (MDI) and equal amount of polyether polyols to for the PU prepolymer [17, 18].

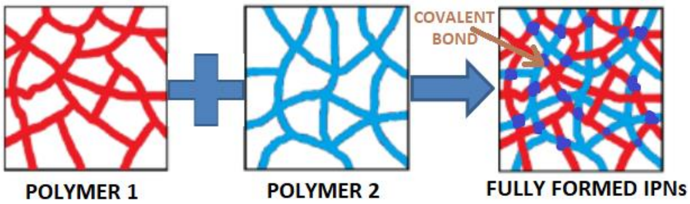

Figure 2. Schematics of the formation of fully formed IPNs

Finally the vinyl ester was being added to the polyurethane along with hardener and promoter to increase the rate of curing acceleration [19]. Thus the blend of IPN resin (PU and VER) was prepared as per the table 1. The individual polymer was synthesized in front of the another polymer and it forms the complete covalent bond with each other, thus forms the fully formed interpenetrating polymer networks as shown in the figure 2, and their properties of each individual (matrix) constituents were mentioned in the table 2.

Table 1: Typical combination of IPN – Formulation

SAMPLE NO.	VER (gms)	PU (gms)
1	100	0
2	90	10
3	80	20
4	70	30
5	60	40
6	50	50

2.3 Fabrication of composite laminate

The fiber and resins used to perform experimental analysis in these study was banana fiber uniaxial woven mat, vinyl ester, polyurethane. The polyurethane and vinyl ester resins were purchased from Vasavi bala resins, Chennai, Tamilnadu. The banana fiber was purchased from local fiber manufactures. All the resins were not mixed with any reagents during the course of study. The fabrication of banana fiber reinforced IPN composite laminate was done along with the various proportions of 0%, 10%, 20%, 30%, 40%, 50% PU loading. Initially the 0% PU content with banana fiber incorporation was being made [20]. Then the rest of the fiber reinforced laminates were made by using hand layup technique.

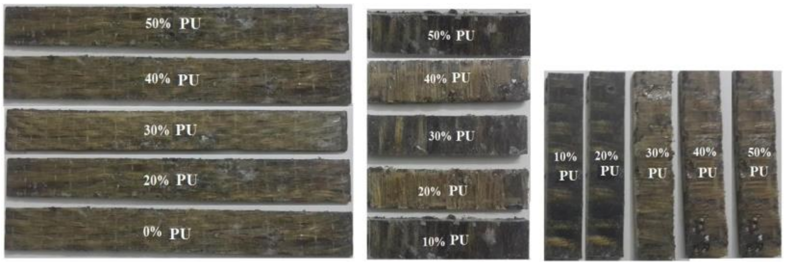

Figure 3. (a) Tensile Test Specimens (b) Flexural Test Specimens (c) Impact Test Specimens

The poly vinyl alcohol (PVA) was applied over the smooth surface plate; following this the IPN resin was applied over the PVA coat. The (weighted) banana fiber mat was placed over the surface mat and it was wetted with IPN resin coat. The placing of the mat with subsequent resin coating was continued till the level of 3 mm achievement. Similarly, the various laminate structures were formed by the load of 10%, 20%, 30%, 40%, and 50% PU. The specimens were properly shaped as per the ASTM standard with help of the diamond saw as shown in the figure 3.

Table 2. Technical specification of vinyl ester and polyurethane

Properties	Vinyl ester	Polyurethane
Peak Exotherm (150g @ 25°C)	45	40-45
Shrinkage % (Volume)	0.28	0.25
Shore D hardness	80	60
Tensile strength	55 MPa	35
Compressive strength	70 MPa	60
Deflection temperature	85°C	45°C
Co-efficient of expansion	45 - 55 ppm/°C	55 - 75 ppm/°C
Water absorption	0.18%	0.09%
Elongation at break	0.9-1.2%	1.4-2.1%
Flexural strength (MPa)	70-90	40-60

2.4 Experimental analysis

2.4.1 Tensile test

Intially the tensile test was carried out as per the ASTM D3039 standard. According to this standard the dimensions of the sample specimen were standardized as 250 mm × 25 mm × 3 mm, following this the specimen was tested in universal testing machine (Hounsdsfield 50 kN – Model – 1150 UTM) with the cross speed of 2 mm/min.

2.4.2 Flexural test

Following the tensile test, flexural test was carried out based on the ASTM standard ASTM D790-30. The dimensions of the sample were maintained as 127 mm × 12.5 mm × 3 mm. The cross head was about to 2 mm/min maintained as per the ASTM standard.

2.4.3 Impact test

In line of the tensile and flexural, impact test was performed on impact tester machine. This charpy impact test was done, by following the ASTM standard D256. As per this standard the dimensions were maintained as 68 mm × 12.5 mm × 3 mm.

2.4.4 Impact test

In addition to the above tests, moisture absorption test was also performed as per the ASTM D570 standard [12], to do this test the work pieces were maintained with the dimension of 25.4 mm x 76.2 mm x 3 mm with edge sealed condition. As well, the percentage of water absorption was calculated by using the equation (1).

$$W(\%) = \{((W_w - W_d) / W_d) \times 100\} \quad - \quad (1)$$

Where, W_w – weight of the wet specimen; W_d – weight of the dry specimen.

2.4.5 Morphological analysis

In order to completely understand the micro structure of banana fiber reinforced IPNs of various proportionate of PU loaded laminate, fractured surfaces of the specimens were validated by using the scanning electron microscope [21].

2.4.6 Numerical analysis: concepts of FEM methods

The simulation software ANSYS software was used for FEA analysis. The dimensions were set as 127 mm × 12.5 mm × 3 mm, similar to that of the laminates maintained in the experimental analysis. At the beginning, the 3D models of the laminates were created by using CATIA V5 software. Later, it was imported to ANSYS workbench for further analysis. The shell type element was used in this analysis. Similar to the loading conditions of flexural strength, the loading and the restraining conditions of the element specified. For different proportions of fiber content, the young's modulus and poison ratio are obtained by doing the physical verification test on the laminate as per the standards (ASTM D638), the same material properties was tabulated in the table 3. The same operation of meshing, restraining and loading conditions were carried out for different proportions of the laminate structures. At the end, numerical analysis were observed and compared with the results of experimental analysis [22].

Table 3. Material properties for Banana fiber/IPN laminate.

Mechanical Properties	Mixture ratio of banana fiber reinforced PU loaded IPN composite					
	0%	10%	20%	30%	40%	50%
E_1 (MPa)	48.43	46.24	44.12	42.19	39.14	37.45
E_2 (MPa)	22.42	21.44	20.12	19.11	18.10	17.12
υ_{12}	0.32	0.31	0.31	0.32	0.31	0.32
G_{12} (MPa)	24.67	23.12	22.91	21.81	20.12	19.11

E_1 & E_2 – Young's modulus; IPN: Interpenetrating Polymer Network; PU – Polyurethane

3. RESULTS AND DICUSSION

This chapter depicts the mechanical strengths of the various proportionate of PU loaded banana fiber reinforced IPN (VER/PU) laminate.

3.1. Influence of tensile stress behavior of various proportionate of PU loaded banana fiber reinforced IPN laminate

The figure 4 shows the tensile stress behavior of the banana fiber/IPN matrix composites. In this analysis, as per the ASTM D3039 standard, both the ends of the specimen were completely clamped in the universal testing machine, following this, the load was applied gradually until the specimen fracture observed.

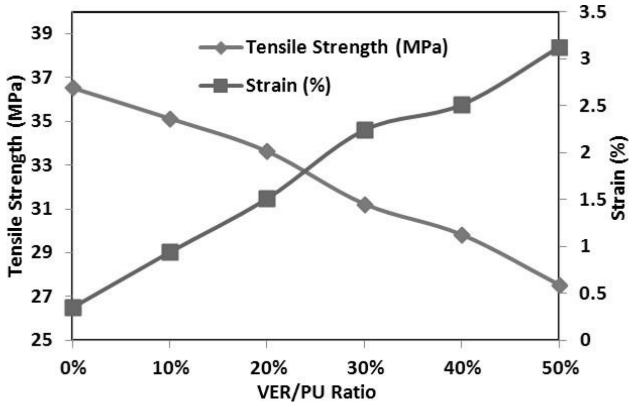

Figure 4. Tensile stress analysis of banana fiber/IPN composites

The tensile strength value of the 0% PU loaded specimen had shown as 36.54 MPa and their corresponding strain rate was 0.35. Whereas the 10% PU loaded specimen shown the strength value of 35.14 MPa, the obtained value was nearly 4% lesser than the original value of 0% PU loaded specimens. But the attained strain value for the 10% PU loaded laminate was nearly three times higher than the neat banana fiber reinforced vinylester resin (0% PU). During the fracture of the specimen, the common mode of failure fiber pullout was commonly seen for all the laminates irrespective of PU loading. Normally the fiber takes the maximum stresses, once threshold limit of the fiber attains the maximum level, it starts distribute the same stresses to the matrix, upon transfer the stresses the interfacial adhesion between the fiber and matrix breaks and atlast the crack initiates, propagates finally fracture occurs. This system of failure was commonly seen in all the laminate fracture mechanism. Apart from that, the 20% PU loaded specimens were shown tensile stress value as 33.64 MPa, this value was 4.5% lesser than the value of 10% PU loaded specimens, at the same time their strain rate was 1.51%; this value was nearly 60% higher than the 10% PU loaded specimens. In the same way 30% PU loaded specimen had shown the tensile strength of 31.23 MPa with the strain rate value of 2.24%. These values were 7.7% lesser with respect of considering the 20% PU loaded specimens, as well the strain rate was 48% higher than the 20% PU. This kind of decreasing trend of tensile stress and increase inclination of strain rate was continually witnessed in all set of PU loaded specimens, this effect evidences that, the soft segment (SS) presence of polyurethane was completely makes the permanent entanglement with the hard segment (HS) presence of vinylester. Further to this, the soft segment presence deep intrudes into the vinylester's hard segment and makes the brittleness nature of the vinylester into partially ductile nature. So as much as loading of PU into the IPN system, it completely dilutes the brittleness characteristics of the vinylester into the much appropriate way of brittle to ductile transition. Hence the laminate gives very good strain rate as compared with the neat vinylester resin based composite material. The soft segment presence enables the much elongation and gives the ductile property to the laminate before fracture occurs, as well as the polyurethane was good familiar for the shape memory polymer property, hence the PU loaded laminates retain its initial position once the load was removed from the specimen. Moreover as such observed in the PU loaded specimens of 30% PU loading, the 40% PU loading also gives the similar kind of decreasing trend of tensile stress value, the observed value was 29.83 MPa this value was nearly 5% lesser than the value of 30% PU loaded specimens. Their corresponding strain rate also observed as 2.51%, this value was nearly 12% higher than the 30% PU loading. Besides the obtained value of the 50% also evidenced such a decreasing trend of 27.54 MPa and increasing strain rate value of 3.12%. Therefore from the test results, it was concluded that the as much as PU loading increases into the IPN system along with reinforcement of banana fiber, the tensile stress value keep decreases and substantially increases the strain rate to the maximum level. It seems the soft segment (SS) presence of polyurethane was made better entanglement with the vinylester's hard segment (HS) and thus the way increases the strain rate by reducing the brittleness characteristics of the vinylester [23].

3.2. Influence of flexural stress behavior of various proportionate of PU loaded banana fiber reinforced IPN laminate

The figure 5 shows the flexural stress behavior of the banana fiber/IPN matrix composites. In this flexural stress analysis, the three point bending analysis procedure was followed as per the ASTM D790 standard.

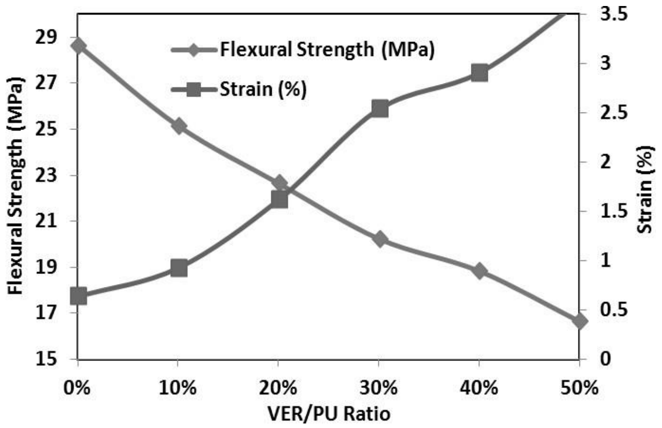

Figure 5. Flexural stress analysis of banana fiber/IPN composites

From the figure 5, it was observed that, the flexural stress value of the IPN laminate was kept decreasing upon the loading of polyurethane into the IPN system. To evidence that, the 0% PU loaded specimen had shown the value of 28.64 MPa and their corresponding strain rate was 0.64%. Further to this, the 10% PU loaded specimen was shown the flexural strength value as 25.13 MPa and their subsequent strain rate value was 0.93%. The obtained values were 12.25% lesser than the 0% PU loaded specimen, similarly their corresponding strain rate was 45% higher than the 0% PU loaded specimens. The negative surge in the flexural strength was purely because of the soft segment presence of PU, that makes the better entanglement with hard segment presence of VER and forms complete covalent bond between them, because of that the breaking of the PU loaded happens after much elongated strain rate. Additionally, the loading of the PU kept decreases the flexural strength value in substantiate way and contrarily increases the strain rate to the higher level. The further obtained values of the remaining proportionate also evidences positive surge in the strain rate value and negative surge in flexural strength values. The 20% PU loaded specimen shown the value of 22.64 MPa and their related strain rate value was 1.62%. The attained value was 9.91% lesser (flexural stress) than the 10% PU loaded specimens, alike as the strain rate was nearly 74.2% higher than the 10% PU loaded specimen. In addition, to give more strength on the obtained value of the 20% PU loaded specimens, the 30% PU loaded specimen also given the flexural strength value as 20.23 MPa and their corresponding strain rate value was 2.54%. Additionally the 40% and 50% PU loaded specimens also had shown the similar trend of value as 18.83 MPa and 16.64 MPa respectively, and their subsequent strain rate also shown as 2.91% and 3.63%. Out of all tests, it was clearly observed that the PU loading completely increases the strain rate value to many folds with the slight negative deviation of flexural strength value. This was because of the effect of physical entanglement between the polyurethane and vinylester. During this entire study, it was observed that, there was proper fiber pullout before specimen breaks. This seems that, there was proper fiber and matrix adhesion; consequently it completely enhances the distribution of the flexural stresses uniformly along the fiber direction before the specimen breaks [24].

3.3 Influence of Impact strength behavior of various proportionate of PU loaded banana fiber reinforced IPN laminate

The figure 6 shows the Impact strength behavior of the banana fiber/IPN matrix composites. In this Impact strength analysis, the ASTM D256 standard test procedure was followed. The impact strength of the material shows the capacity of the material against the shocks and loads, also capability of the material to dissipate the energies under the impact or else shock loading. From the figure 6, it was observed that, the 0% PU loaded specimen was shown the impact strength value as 2.93 kJ/m^2. Contrarily against the tensile and flexural test results, the impact strength specimens were shown tremendous increases in their strength value as much as PU loading content increase into the IPN system. To prove the statement of the above, the 10% PU loaded specimen had shown the impact strength value as 3.54 kJ/m^2. This value was nearly 21% higher than the 0% PU loaded specimen. This was because of the loading of the polyurethane into the IPN system. Again to give further proof for that, the 20% PU loaded specimen also given the impact strength value as 4.64 kJ/m^2. The obtained value was 31% higher than the 10% PU loaded specimen.

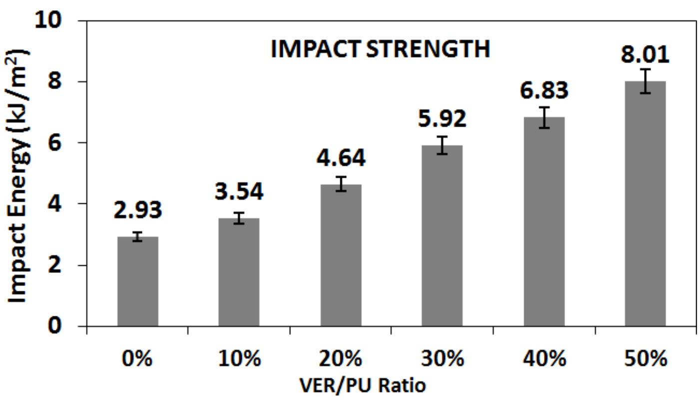

Figure 6. Impact strength analysis of banana fiber/IPN composites

As much as increase of PU loading into the IPN system had been shown considerable amount of increase in impact strength value. It shows that the soft segment presence of PU taken much amount of the impact force as compared with neat vinylester based banana fiber reinforced composite laminate. Hence it was proved that the complete entanglement was taken place between the PU and VER. Besides that the 30% PU also shown the impact strength value as 5.92 kJ/m^2, the relative variation between the 20% PU to 30% PU was 27%. Almost all the samples subjected with impact force, had shown the similar kind of matrix fracture as such observed in tensile and flexural, followed by fiber matrix debonding consecutively ends with fiber breakage/fiber pullout. In other words, the load applied on the specimens' shears the interfacial bond between the fiber and matrix, thus the way finally leads to the specimen fracture. Moreover the 40% PU loaded specimen as well shown the impact strength value as 6.83 kJ/m^2, with hike of 15.4% of earlier (30% PU) loading. The 50% PU loaded specimen shown the strength value of 8.01 kJ/m^2. It was completely 17% higher than the earlier loading of PU. On an average all the specimen had shown the significant amount of hike in impact strength as much as PU loading increases [25].

3.4 Influence of moisture absorption behavior of various proportionate of PU loaded banana fiber reinforced IPN laminate

The figure 7 shows the moisture absorption behavior of the banana fiber/IPN matrix composites. In this moisture absorption analysis, the ASTM D750 standard test procedure was followed.

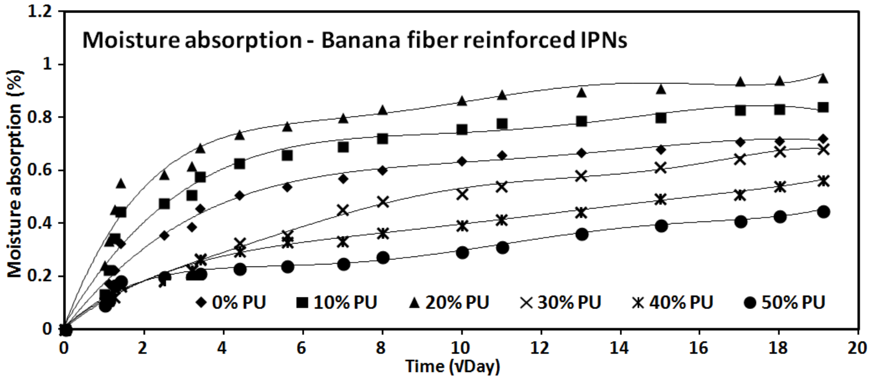

Figure 7. Moisture absorption analysis of banana fiber/IPN composites

The 0% PU loaded specimen was shown the moisture absorption as 0.95%. Though vinylester resin considered as the best known material against the moisture absorption characteristics, still their relative study against the PU loaded specimens had shown the contrary results. To give proof to this, the 10% PU loaded specimens had shown the 0.84% absorption rate. Further to this, this value was 11.57% higher than the 0% PU loaded specimens. It seems that the PU loaded specimens had shown predominant value against the pure vinylester based composite. Similarly the 20% PU loaded specimen shown the 0.72% of moisture absorption rate. Moreover this value was nearly 14% higher than the 10% PU loaded specimen. As much as PU loading into the IPN subsequently reduces the moisture absorption rate to the adornment level. Additionally the 30% PU loaded specimens also had shown the value of 0.68% of moisture absorption level. Consequently the 40% and 50% PU loaded specimens had also shown the moisture absorption rate of 0.56% and 0.45% respectively. In the context, it had showed that as much as PU loading into the IPNs, it reduces the moisture absorption rate in sizeable level, the PU loading completely diffuses deep into the VER by creating the noteworthy covalent bond, it abruptly creates better interfacial adhesion and lessens the void content in the IPN composite specimens in turn reduces the hydrophobic nature of the composite. Hence moisture absorption rate was very less as much as PU incorporation into the IPN composite [26].

3.5 Scanning electron microscopy (SEM) analysis

The (Impact) fractured surfaces of the banana fiber/IPN matrix composite was observed through SEM analysis. The main purposes of the SEM micrographs were to observe the Fiber – matrix de bonding, matrix dislocation, banana fiber fracture and pull-out, delamination and surface cracks. The SEM micrographs of the impact tested specimens were shown in the figure 8. The SEM photograph of 0% PU shows the matrix cracking in the Fractographing image. Though the vinylester were meant to absorb the high impact force as compared with remaining set of matrix material, still it gives the impact strength value as 2.93 kJ/m^2 as lesser than the value of the PU loaded specimens. This energy absorption was evident with the matrix cracking and common fiber pullout in the specimen of 0% PU. The 10% PU specimens had shown the better interfacial adhesion with fiber and matrix material, it seems that the slight adhesion of polyurethane matrix material into the IPN creates strong adhesion between the fiber and matrix, this was the reason why the impact strength value increases (3.54 kJ/m^2) in considerable way as explained in impact strength analysis. The better compactness between fiber and matrix was evident in the 0% PU. This adhesion of matrix with the fiber significantly increases the specimens impact energy absorption rate as compared with the 0% PU. Similarly in the 20% PU loaded specimen had shown the smaller amount of void presence in the fractrographic image. Along with that it shows the fiber matrix delamination during the high energy absorption. In addition to that the IPN creates strong interfacial adhesion between the constituents. It could be clearly seen from SEM image of 20% PU loaded specimens, in turn gives improved impact strength of 5.92 kJ/m^2. The 30% PU loaded specimen had been absorbed with fiber scissoring followed with fiber pull out from matrix, in turn it adversely affects the matrix interfacial adhesion. Moreover the 40% PU loaded fractured specimen shown the fiber breaking and void presentation, and findings of the loosening of interfacial adhesion was not seen in the images. The 50% PU loaded specimens had shown the improved interfacial adhesion between the fiber and matrix and finding of void was not seen in the fractrographic image.

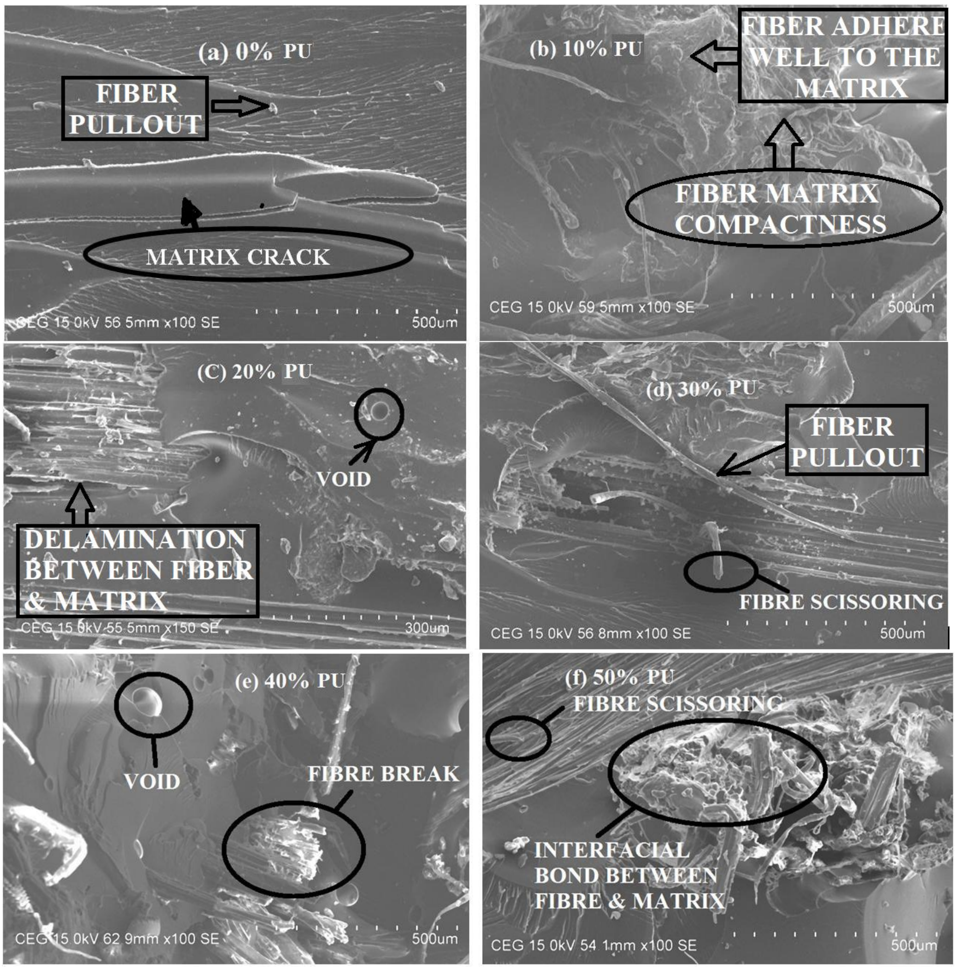

Figure 8. Fractrographs of banana fiber/IPN composites: a) 0% PU, b) 10% PU, c) 20% PU, d) 30%, e) 40% PU and f) 50% PU.

It shows that as much as PU loading increases into the IPN system it creates the better interfacial adhesion between the fiber and matrix along with that lessens the void presence, adversely exhibits noteworthy impact resistance [27].

3.6 FEA analysis

The experimental analysis on the banana fiber reinforced IPN matrix specimen revealed that, the loading of the PU into the IPN matrix was found to be increase strain rate in substantial level of the IPN laminate by subsequently lessening the flexural strength value of the laminate. From the figure 9, the laminate containing 0% PU loading into the IPN matrix had given flexural strength value of 29.52 MPa. In that sequence, laminate containing 10% of PU loading was shown the flexural strength value was around 26.59 MPa. Followed by this, the laminate with 20% PU showed up to 23.93 MPa. In the continuation of the above, the PU loading of up to 30% of PU with IPN matrix had given the value to be around of 21.27 MPa. Furthermore, the 40% PU loaded laminate produced a flexural load withstanding capacity of 18.61 MPa.

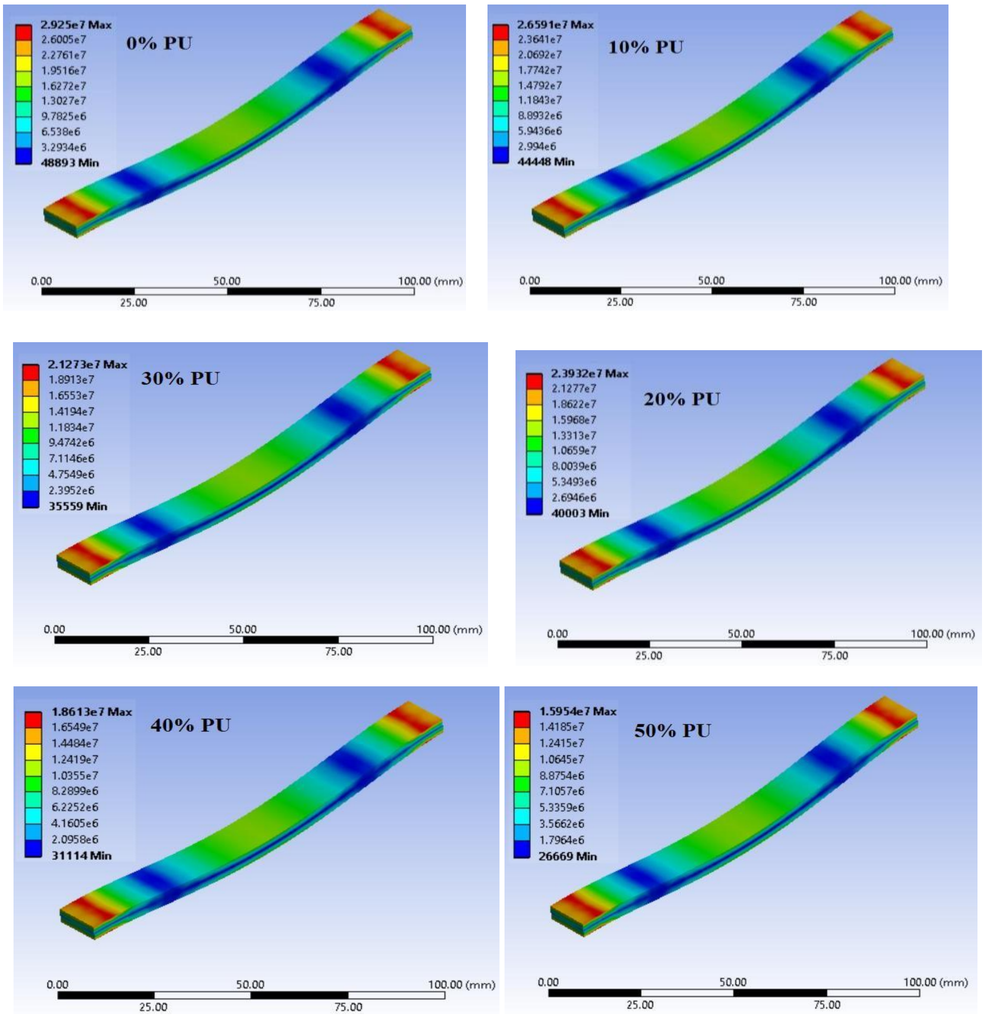

Figure 9. Numerical analysis of banana fiber/IPN composites: a) 0% PU, b) 10% PU, c) 20% PU, d) 30%, e) 40% PU and f) 50% PU

Finally, the 50% PU loaded laminate structure gave a flexural strength of about 15.95 MPa. All the mechanically tested samples had given flexural strength value which had better correlation with the numerical analysis and their corresponding differences were noted in the table 4.

Table 4. Comparison of Experimental and Numerical values.

S.No	**Polyurethane loading**	**Experimental (Flexural analysis) (MPa)**	**Numerical (Flexural analysis) (MPa)**	**Error**
1.	0%	28.64	29.25	-0.61
2.	10%	25.13	26.59	-1.46
3.	20%	22.64	23.93	-1.29
4.	30%	20.23	21.27	-1.04
5.	40%	18.83	18.61	0.22
6.	50%	16.64	15.95	0.69

4. CONCLUSION

In this work, the following conclusions were drafted upon the various proportions banana fiber reinforced polyurethane loaded IPN matrix laminate.

1. IPNs were successfully tried out in the reinforcement of natural fiber (banana fiber).
2. It was seen that the strain rate values of the tensile and flexural specimens had shown the phenomenal surge in their values by substantially reducing their stress factor.
3. The impact strength and moisture absorption values of IPN laminate had shown the extraordinary characteristics against the 0% PU loaded specimens. As much as loading of the PU into the IPN increases their above properties in considerable level.
4. Moreover to thoroughly observe the micro mechanism between the fiber and matrix, the fractured surfaces were evaluated with Scanning Electron Microscope (SEM).
5. In addition to that the finite element analysis had also been performed to validate the experimentally obtained values, as a result of this it was found that both the experimental analysis and FEA analysis had shown the meaningful correlation.

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