

CHARACTERSATION ANALYSIS OF HARDNESS, IMPACT, WATER ABSORBTION NANO CARBON FIBER REINFORCED POLYMER MATRIX COMPOSITES [NCFRPC]

T. Vinod Kumar

Assistant Professor, Department of Mechanical Engineering, Vels Institute of Science, Technology and Advanced Studies (VISTAS), Chennai, Tamilnadu, India.

M.Chandrasekaran*

Professor and Director, Department of Mechanical Engineering Vels Institute of Science, Technology and Advanced Studies (VISTAS), Chennai, Tamilnadu, India.

*Corresponding Author

ABSTRACT

The trend of years has focused the fiber reinforced polymers have removed the conventional and metal materials in the modern engineering. This is more important because of the merits of fiber reinforced polymers over the outcomes materials. Its informly and evaluated in FRPC are light, stiff and allow both large and minimum scale production at minimum cost and however, the strength of these composites are maximum it's not founded. The performance of the mechanical properties of the expisting FP composites , a minimul amount of Nano carbon powder have been intraduced in the different weight ratios.In this experimental study of nano carbon powder with three different natural fibers of water hyacinth,areca nut and hen feather (0 ,1,2,3,4,5,6 weight %) Polylactic acid (Bal weight %) are mixed together and 3 specimens of NCFRP composites were fabricated by using polymer compression injection molding machine. After the fabrication process and specimens to take molding to preapred ASTM standards to evaluated the hardness test and impact strength.

KEYWORDS: Mechanical properties, fiber, polymer, nano composites.

Cite this Article: T. Vinod Kumar and M.Chandrasekaran, Charactersation Analysis of Hardness, Impact, Water Absorbtion Nano Carbon Fiber Reinforced Polymer Matrix Composites [Ncfrcp], International Journal of Mechanical Engineering and Technology, 9(13), 2018, pp. 147–157

<http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=13>

1. INTRODUCTION

Two or more dissimilar polymer composite materials unite together to form a better and sole material. High-temperature creep, impact damage, chemical attack and water absorption are

processed by PMC (Polymer Matrix Composite) which was decided by the property of the matrix. Thermosets or thermoplastics either derived from the resins of the matrix of PMC. 60% reinforce fiber is there in PMC in a volume form. Graphite, fiberglass and aramid are the fibers commonly found and used in Polymer Matrix Composite. Alternative synthetic fillers are generally utilized in PMC which also have a natural fibers / particles reinforcement in it. These fillers have low density, abundant availability, mechanical properties, and biodegradability. Different types of fibers like aircrafts, marine boats, and sporting equipment's such as golf shafts, tennis rackets, etc., all are reinforced with the application of Polymer Composites. The main objectives for the implementation of polymer composite in lot of applications are weight reduction, which have rather properties like non-conductive, non-corrosive, flexible, low maintenance, long life, and design flexibility.

1)By using the hand leaves, stem and foreign matter were removed which make it as a clean burr fraction and as a fine particle by knife-type cutting mill [1].

2) By pressing the Sugarcane to take the extract of sugar Ba- gasse, the residue fiber remains [2].

The triggered new one material which are able to exist along with the environment like environmental regulations and social concerns. Biodegradable, renewable and recyclable and material re-source is the bio-fillers based on agriculture products [3]. To add with been along the environment few hazardous and few biodegradable materials like medical and dental applications are need- Ed. All the bio-fillers has numerous benefits in renewed interest in low cost fillers, bulk supply, constant availability of resources, and the consumption of energy is low when it is compared with the fabricated/ synthesized fillers. From the view of researcher's these eco-friendly bio fillers in 21st century it will get the potential to be the new material for the global environmental problem it be a partial solution. The Cotton harvesting is used to obtain the by-product of ginning cotton burr. It is often used in boilers as fuels or as mulch. The material is not much expensive, and availability is high. From the harvest cotton stripper, cotton burr was collected as a trash from the field. By the cross-linked nature of thermoset resins that unable to remold but it consists polymer matrix, glass fibers and variety of inorganic fillers. Still, by con- sidering many of the thermoset based on GFRP (glass fiber reinforced plastics) waste continuously incinerated or land filled for- warded to undesirable effects to the environment and in addition it increased cost. When there is an increase in environmental matters as awareness and the subsequent need to protect the assets, redo process may transform a costly waste removal into a gainful one to use again as a material. For this it is used as a filler material [4]. Fillers increase the controlling strength up to the high at 10 wt%. Some of the researchers analyzed that Nano improves the shear and tensile strength, fracture toughness and stiffness of the composite. Still the Nano filler chooses as an impinged into the polymer matrix which improves the Mechanical properties [5]. Plant fibers are usually consists of hemicelluloses, cellulose and lignin Cellulose that improves the mechanical properties of all the natu- ral fiber. This is in order by micro-fibrils which enclose by two other main components like lignin and hemicelluloses. Cellulose micro fibrils easily find in an intertwined microfibril in the cell wall, which is confirmed by the amorphous regions and nanocrystalline peaks. Only the acid hydrolysis able to separate both the things driving to crystalline domains by using the elastic mod- ulus of 150Gpa [6]. The filler calcium carbonate has good physi- cal properties, melting, glass transition, and crystallization behav- ior of 80 PHR polypropylene (PP) with different weights of linear low density polyethylene were studied [7]. Nylon filled Poly- caprolactone (PCL) creates good improvement in stiffness with a continuously increase in ductility. Nylon fiber diameter is decreased by electrospinning process it coated a good interfacial ad-hesion between filler and matrix [7]. To improve the mechanical properties, Spiky nanostructured никels are used as fillers[8]. the research which was going on for few decades few decades on dispersing of ceramic

nanoparticles in to polymer matrix which is proved effective. It has enhanced ionic conductivity that challenges to form the network very efficiency[9]. the thermal stability of the polymer matrix and mechanical strength are improved by the core–shell silica particles[10, 11].This article gives an overview of the current and previous research work carried out in the topic of polymer composite materials with different type of fillers used. Firstly, the polymer composite fillers are reviewed and the methods to synthesis of particular fibers are discussed. The properties after incorporating these fibers are discussed and compared. Finally, the main challenges relating to synthesis of polymer composite with different category of fibers are discussed.

2. EXPERIMENTAL

Assessment of PLA Polymer amalgamations are critical when a new materials are synthesized or a solid material needs to be designed, or the strength of the material ought to be recognized. PLA Polymer composites characterization is analytical branch of PLA Polymer science which can produce a final material which is cost effective. The purpose of characterization is to ultimately improve the performance of the material. Desirable properties of the materials such as strength, thermal stability and optical properties are to be characterized with the relevant techniques. These characterization techniques are employed to determine the structure, molecular mass, thermal and mechanical properties. There are two phases during the time spent acquainting with plastics.

2.1. Impact Behaviour of Composites

Tests of brittleness make use of impact tests. The main causes of brittle failures in materials are found to be (1) triaxiality of stress, (2) high strain rate and (3) low temperatures. Test methods developed for determining the impact behaviour of materials thus involve striking a notched bar with a pendulum. This is the most convenient way of subjecting the material to triaxiality of stress (at the notched tip) and a high strain rate so as to promote a brittle failure.



Figure 1. Impact tested specimen [ASTM: D256]

The standard test methods are the Charpy and Izod tests, which employ the pendulum principle. The specimen has a standard notch on the tension side. In the Charpy test, the specimen is supported as a simple beam and is loaded at the midpoint. In the Izod impact test, the specimen is supported as a cantilever and is loaded at its end. The standard energy absorbed in breaking the specimen is recorded. The results of impact tests are often scattered, even with the more careful test procedure. A normal practice in such cases is to quote the median strength rather than average strength because the median is more representative of the bulk of the results if there is a wide scatter of results from very few to very high. The choice of notch depth and tip radius will affect the impact strength observed. A sharp notch is usually taken as 0.25 mm radius, a blunt notch as 2 mm radius. It is evident that the use of a sharp notch may even rank plastic materials in an order different from that obtained by using a blunt notch. This fact may be explained by considering the total energy absorbed to break the specimen, as

consisting of energy is necessary for crack initiation. When a sharp notch (0.25 mm radius) is used, it may be assumed that the energy necessary to initiate the crack is small and the main contribution to the impact strength is the propagation energy. The specifications of impact testing machine is shown in Table.1.

Table 1 Specifications of Impact Testing Machine [2]

Model	XJU-22
Maximum capacity	500 J
Minimum scale graduation	2 J
Overall size	1.1 m x 0.45 m x 1.65 m (H)
Net weight	375 kg

2.2. Rockwell Hardness Test

The hardness of a material may be defined in several ways: (1) resistance to indentation, (2) rebound efficiency and (3) resistance to scratching. The first method is the most commonly used technique for plastics. Numerous methods are available for measuring the resistance of a material to indentation, but they differ only in detail. Basically, they all use the size of an indent produced by a hardened steel or diamond indenter in the material as an indication of its hardness ; the smaller the indent produced, the harder will be the material and hence greater the hardness number. Hardness tests are simple, quick and non-destructive which account for their wider use for quality control purpose. In this research, Rockwell test differs from other tests mentioned, because, the depth of the indenter rather than its surface area is taken as a measure of hardness. The hardened steel ball is used as an indenter. A major advantage of Rockwell test is that no visual measurement of the indentation is necessary and the depth of the indents read directly as a hardness value on the scale. A minor load of 10 kg is applied on the steel ball and the scale pointer is set to zero within 10 sec of applying the load. In addition to this minor load, a major load is applied for 15 sec. A further 15 sec after removal of the major load (with the minor load still on the ball), the hardness value is read off the scale. Since creep and recovery effects can influence readings, it is essential to follow a defined time cycle for the test. The scale letter is quoted along with the hardness number e.g., Rockwell R60. Scale R and L are used for low hardness number and scales M and E when the hardness value is high. In addition to the Rockwell Hardness Test, there is a Superficial Rockwell. For each test, a minor load is applied to either a diamond cone or a steel ball indenter positioned on the test material's surface to establish a zero reference position.

Next, a major load is applied for a specified amount of time, leaving the minor load applied upon release. The Rockwell hardness number will be the difference in depth between the zero reference position and the indent due to the major load. The choice of the indenter is dependent upon the characteristics of the test material. The Rockwell Hardness Test applies larger minor and major load values than the Superficial Rockwell, yet both tests offer three different major load options. More than thirty different scales are used between Rockwell and Superficial Rockwell hardness testing due to the various choices and combinations of tests, indenters, and major loads. Table.2. shows the specifications of Rockwell hardness testing machine.

Table 2 Specifications of Rockwell Hardness Test Machine [2]

Model	2000 R
Preliminary load	10 kgs
Total test force	60 kg, 100 kg and 150 kg
Test scales	A, B, C, D, E, F, G, H, K, L, M, P, R, S, V
Test load control	Closed-loop electronic load cell

3. MATERIALS

In this present investigation water hyacinth stem powders (*Eichhornia crassipes*), Hen feather shell powder (*Phasianidae*), areca nut shell powders (*Areca catechu*), Nano Carbon powders (Carbon oxide) and PLA are used for fabricating the Nano Carbon and natural fiber reinforced polymer matrix composite specimens. The water hyacinth stem powders, hen feather powder sand, areca nut shell powders are obtained from Erode District, Tamil Nadu, and India. PLA is obtained from Kovai Seenu & Company Ltd., Coimbatore, India. Carbon powder is obtained from M/s Star Scientific Traders, Erode, Tamilnadu, India.

3.1. Natural fibers

In the last two decades, there has been a impressive enhancement in the use of natural fibers such as fiber extraction from sisal, arecanut, water hyacinth, jute, coir, flax, hemp, pineapple and banana for making a new environment friendly and biodegradable composite materials (somehow these composites are called “Green Composites”). Recent studies in natural fiber composites offer significant improvement in materials from renewable sources with enhanced support for global sustainability. These natural fiber composites possess high/moderate strength, thermal stability when they are recycled, but the problems of using pure biodegradable polymers are their low strength and transition temperature.

3.2. Water hyacinth stems powders

Water hyacinth stem powders (Figure 2.A) are prepared from the stems of water hyacinth plant. The plants are cultivated in the banks of the Bhavani River, Bhavani, Erode District, Tamilnadu, India. The weight of the plants used in the experimentation is 27kg. After the cultivation of the plant, leaves are removed from the plant using knife. Then the stems of the water hyacinth are washed by pure water and allowed to dry at room temperature in an open space for one week to eliminate the moisture content. Then the dried water hyacinth stems are taken into the flour mill hopper and grinded by the flour mill grinder with different grid size blades to change the long strand stems into desirable grain sizes powder form with the processing time of one hour. In order to reduce the grain size of the water hyacinth stems powder the grinding process is repeated until it is converted to fine grain sized particles. Finally the desired grain size water hyacinth stems powders are made with the flour mill grinder.

3.3. Hen feather powders

Hen feather powders (Figure.2.B) are prepared from the well dried stems of waste. 5 kg of the Hen feather stem are obtained from the Vinayaga Oil Mills, Bhavani, Erode District, Tamilnadu, India. After that the shells of the Hen feathers are allowed to dry at room temperature in an open space for one week duration to enhance its powder form ability. Then the dried hen feather shell are taken into the flour mill hopper and grinded by the flour mill grinder with different grid size blades to change the shells into desirable grain sizes powder form with the processing time of two hours. In order to minimize the grain size of the hen feathers stem powder the grinding process is repeated until they are converted to fine grain size particles. Finally the desired grain size hen feather powders are made with the flour mill grinder.

3.4. Arecanut shell powders

Arecanut shell powders (Figure.2.C) are prepared from the fine dried shells of arecanut. 10kg of well dried arecanut shells is obtained from the thirumurugan arecanut products, Thalaivasal, Salem District, Tamilnadu, India. After that the shells of the areca nuts are allowed to dry at room temperature in an open space for three weeks duration to eliminate the complete moisture content present in its shells. Then the well dried arecanut shells are taken into the flour mill hopper and grinded by the flour mill grinder with different grid size blades to change the shells into desirable grain sizes powder form with the processing time of four hours. In order to reduce the grain size of the arecanut shells powder the grinding process is repeated until it is converted to fine grain size particles. Finally the desired grain size arecanut shellpowders are made with the flour mill grinder.

3.5. Nano Carbon powder

Carbon is a versaile material used as refractory, engineering ceramics material, abrasive and in various other applications where chemical inertness coupled with its high hardness and abrasiveness is of primary importance. The micron size particles of Carbon powder are purchased from M/s Star Scientific Traders, Erode, Tamilnadu, India. Then themicron size particles of the Carbon powders are changed into nano size particles by using ball milling process at Sona College of Technology, Salem, Salem District, Tamilnadu, India. The particle size confirmation test is carried out at K.S.Rangasamy College of Technology, Tiruchengode, Namakkal District, Tamilnadu, India. The Nano Carbon powder is shown in Figure.2.D.

3.6. Polylacticacid [PLA]

Polylacticacid [PLA] (Figure.2.E) is a thermoplastic “addition polymer” made from the combination of propylene monomers. It is used in a variety of applications which includes packaging for consumer products, plastic parts for various industries including the automotive industry, special devices like living hinges, and textiles. Today it is one of the most commonly produced plastics in the world. PLA is used in both household and industrial applications. Its unique properties and ability to adapt to various fabrication techniques make it stand out as an invaluable material for a wide range of uses. Another invaluable characteristic is PLA’s ability to function as both a plastic material and as a fiber. PLA’s unique ability to be manufactured through different methods and capability to be used in different applications makes it to challenge many of the old alternative materials, notably in the packaging, fiber, and injection moulding industries. Its growth has been sustained over the years and it remains a major player in the plastic industry worldwide.

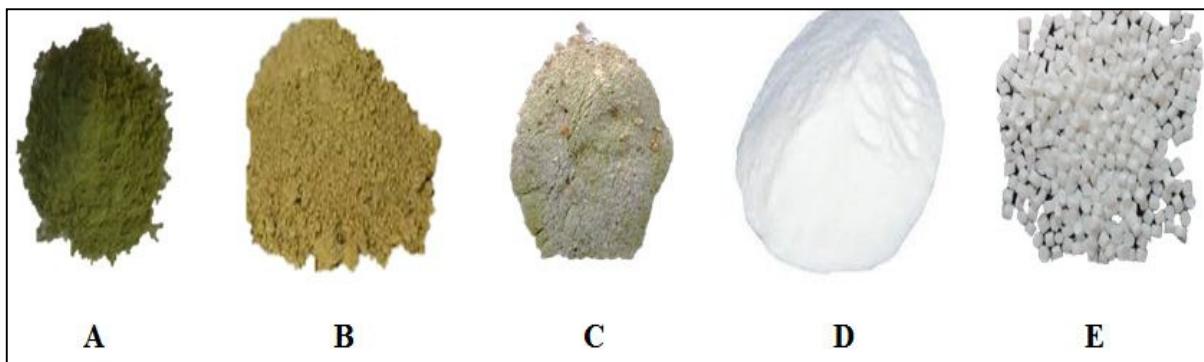


Figure.2 (a) Water hyacinth stem powder (b) Areca nut shell powder (c) Hen feather powder (d) Nano Carbon powder (e) PLA Particles

4. PREPARATION OF COMPOSITE SPECIMENS

The composite materials used for the present investigation is fabricated by using hydraulic injection moulding machine. In this investigation three samples were prepared by changing the natural fiber powders (water hyacinth stems, Hen feather shell & arecanut shell). Sample "A" contains PLA of WEIGHT % grams, 0 – 6% grams of nano Carbon powder and 0-6% grams of water hyacinth powder, sample "B" contains PLA of WEIGHT % grams, 0 – 6% grams of nano Carbon powder and 0-6% grams of arecanut shell powder and sample "C" contains PLA of WEIGHT % grams, 0 – 6% grams of nano Carbon powder and 0-6% grams of Hen feather powders respectively. The composite specimen consists of the scattered particles of nano Carbon powder and natural fiber powders as reinforcement and the PLA as matrix material. Initially well mixed sample "A" composition is taken and feed into the hydraulic injection moulding machine's (**Figure.3.a**) input cylinder and this composition is heated above the melting temperature of the PLA using the electric heater. After ten minutes the liquid state sample "A" compositions were compressed inside the input cylinder by the hydraulically operated piston. Then the liquid state sample "A" compositions are allowed to squeeze out from the input cylinder via nozzle with high pressure and temperature into the prefabricated die. Then the die is allowed for slow cooling with the atmospheric air to get the specimen output in desired dimensions. After the composite materials get cured completely, the composite material is taken out from the die and rough edges are neatly cut and removed. Then the specimen is machined as per the ASTM standard using Vertical CNC Machine (**Figure.3.b**) by as per the required dimensions. Similarly this process is repeated for remaining sample "B" and "C". The different test specimen's sizes as per ASTM standards are shown in table.1.

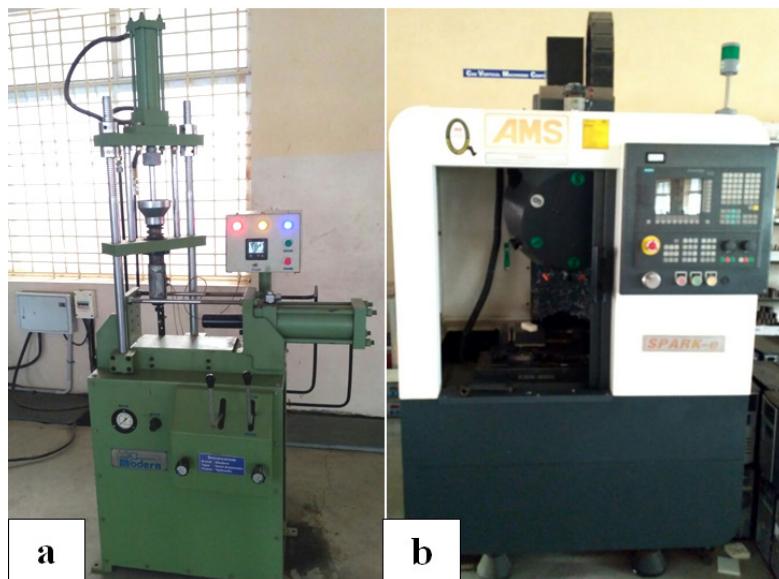


Figure 3 (a) Hydraulic Injection Moulding Machine (b) Vertical CNC Machine

Table.1. Different test specimens sizes as per ASTM standards

S1.No.	Name of the test	Specimen standards	Specimen size (Length , width & thickness (mm))
1.	Hardness test	ASTM D785	(10 x 10 x 6)
2.	Impact test	ASTM D256	(63.5 x 12.7 x 12.7)

4.1. Hardness Test

The execution of hardness properties was examined with the variety of PLA with loading of Nano Carbon Fibers as appeared in Fig.4. Besides the principal system-1 (WH+ NC+ PLA) values were organized. Hardness for unadulterated mix was 89.04 HRB, where when stacked with fiber execution of the Nano composites, there was gradual increments for different diverse fiber loadings viz. 0 to 6 wt. %. Hardness was 105.47 HRB at 5 wt. %, it is roughly expanded to 18.45% when contrasted and 0 wt. % PLA Nano filler loading. In any case, after 5 wt. % PLA Nano filler varieties, execution of the hardness was diminished abruptly from 105.47 HRB to 100.97 HRB. The image 'Bar Graph' in the figure shows variety of information by then.

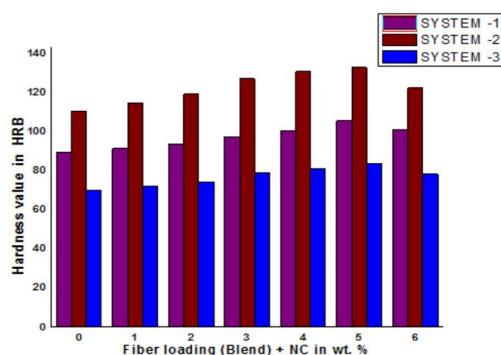


Figure 4. Hardness value (HRB) vs Fiber loading (Blend) + NC in (wt. %)

The results and the pattern behavior standard are keeping pace with those got by various analysis. As the fiber increments from particular characteristics to an obliged justified, despite all the trouble will streamline its enormity of the execution. Since as the fiber goes on builds its consistency moreover expands due to that flow-ability of the modified solution will decrease. Along these lines, solutions won't go all the spots as a result of this voids will frame. In addition, another credited reason was normal extend consistency agglomeration will appear in view of uncalled for mixing of fiber with the lattice as an outcome of that air bubbles exudes. In the second system (AC + NC + PLA) fiber and Nano carbon with the fiber (PLA) was blended though 0 to 6 wt. % PLA was blended with the mix in all variety. Fiber was loaded as made reference up above. For neat blended NCFRPCs, hardness was discovered expanded as 110.22 HRB. About 20.26% of execution was expanded when contrasted and pure NCFRPCs of (AC + NC+PLA). As the PLA filler builds the hardness was enhanced further from 1 to 5 wt. % however diminished after. It was seen that hardness is 132.56 HRB at 5 wt. %, it is around expanded to 15.73% when contrasted and 1 wt. % fiber loading. Comparative procedure to be go to in the third system (HF + NC + PLA) fiber was blended though 0 to 6 wt. % PLA was blended with the mix in all variety. Fiber was loaded as made reference up above. For pure hybrid mixed NCFRPCs, hardness was discovered expanded as 69.741 HRB. Almost 19.45% of execution was expanded when contrasted and pure NCFRPCs of (mix + NC). As the PLA filler expands the outfit was enhanced further from 1 to 5 wt.% however diminished after. It was seen that hardness is 83.31 HRB at 5 wt. %, it is around expanded to 15.75% when contrasted and 1 wt. % fiber loading. The decreased adaptability of these precedents can be attributed to the WH/AC/HF fibers, which may get broke and have sharp corners that make the composite slanted to restricted break begin and proliferation. There may in like manner be an embrittlement impact in light of the closeness of the hard Nano carbon with the fibers, achieving extended neighborhood stretch center goals. Likewise, the fortifying fibers restrict the segment of the separations, either by making pressure fields in the matrix or by incorporating substantial contrasts in the adaptable lead between the PLA Polymer and the WH/AC/HF fiber scattered. This conduct is apparently a direct result of void nucleation in the midst of the plastic stressing of the reinforcement, either by help interface or by the attachment of the matrix reinforcement interface.

4.2. Impact Strength Test

The impact strength of three different systems (NC+ PLA+ WH /AC /HF) as a function of fiber detailed in the related graph is shown in the Fig. 5. Impact strength for pure blended composite was 152.04 J/m and it was slowly amplified from 1 wt. % fiber to 5 wt. % fiber loading and the impact strength was optimized at 5 wt. % PLA Nanocarbon ratio, on the contrary, it start decreasing after 5 wt. % PLA Nanocarbon ratio. The percentage of performance was increased to 30.26 % at 5 wt. % when related with 1 wt. % of PLA loading. Without fiber substance First system (WH + PLA + NC), miscible mixes showed to some degree second rate mechanical properties as contrasted and PLA filled PLA Polymer blends, demonstrative of reduced interfacial bond among duel stages.

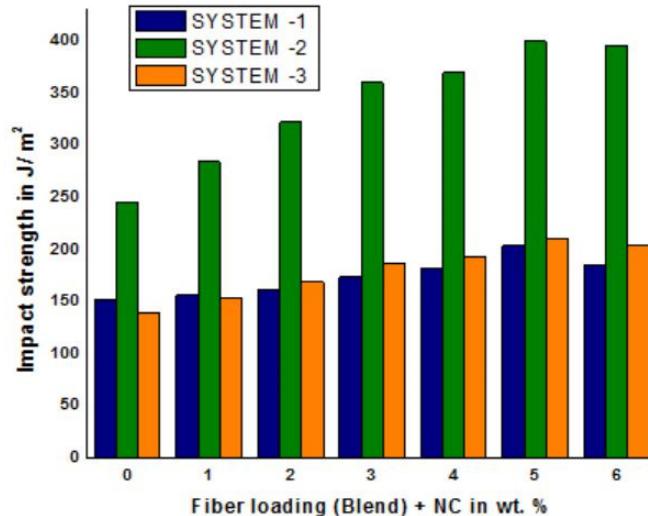


Figure 5. Impact strength test vs Fiber loading (Blend) + NC in (wt. %)

At the point when related with perfect PLA Polymer-PLA Polymer blends and twofold blends with the expansion of fiber demonstrated striking change in the mechanical characteristics. Past examinations shown that including little proportions of PLA Nano-carbon into PLA Polymers may potentially enhance the characteristics like impact quality, durability, hardness of the NCFRPCs with a PLA Nano carbon ratio less than 5 wt. %. This substantiates the nearness of a perfect cut-off since the physical properties of these Nano-structural substances and PLA Polymers are unmistakable. In the second game plan of (AC + PLA + NC) for pure mixed NCFRPCs showed impressive execution when looked at and system degrees of impact strength.

For pure NCFRPCs impact strength was 246.35J/m² and as the expansion fiber further expands impact strength was expanded up to 5 wt. % and the impact strength was 400.36J/m², anyway after 5 wt. % fiber execution diminished. It was seen that (WH/AC/HF) fiber to matrix interface was the huge reason and holding strength was likewise expanded. In this way, strength could increment up to 62.51% for 5 wt. % fiber loaded composite when related by 0 wt. % PLA Nano carbon is loading. Identified with third course of action of (HF+PLA+NC) for pure mixed NCFRPCs demonstrated impressively execution when thought about and structure degrees of impact strength. For pure NCFRPCs impact strength was 139.437 J/m² and as the expansion fiber further expands impact strength was expanded up to 5 wt.% and the impact strength was 211.54J/m², anyway after 5wt.% fiber execution diminished. It was seen that WH/AC/HF fiber to matrix interface was the noteworthy reason and the holding strength was likewise expanded. In this manner, strength could increment up to 51.71% for 5 wt.% fiber loaded composite when related by 0 wt.% PLA Nano carbon loading.

5. CONCLUSION

Hardness value is linearly enhancing from the 0 wt. % fiber to 5 wt. % of PLA nanofiller. In system -2 at 5 wt. % nano carbon and fiber loading with PLA, the hardness value was detected as 132 HRB and hardness value was enhanced up to 20.26 % for 5 wt. % when related with 0 wt. % PLA nanofiller ratio. Where System-2 is better compared to system 1 and 3.

Impact strength is linearly enhancing from the 0 wt. % fiber to 5 wt. % of PLA nanofiller. In system -2 at 5 wt. % nano carbon and fiber loading with PLA, the impact strength was detected as 400.36 Mpa and impact strength was enhanced up to 62.51 % for 5 wt. % when related with 0 wt. % PLA nanofiller ratio. Where System-2 is better compared to system 1 and 3.

1. Nomenclature
2. TS - Tensile strength
3. TM - Tensile modules
4. CM- Compression Modules
5. CS - Compression strength
6. FS - Flexural Strength
7. FM - Flexural modulus
8. PLA – Polylactic acid

REFERENCES

- [1] Sutivisedsak, N., et al., Evaluation of cotton byproducts as fillers for poly (lactic acid) and low density polyethylene. *Industrial crops and products*, 2012. 36(1): p. 127-134.
- [2] Agunsoye, J. and V. Aigbodion, Bagasse filled recycled polyethylene bio-composites: Morphological and mechanical properties study. *Results in Physics*, 2013. 3: p. 187-194.
- [3] Ojha, S., G. Raghavendra, and S. Acharya, A comparative investigation of bio waste filler (wood apple-coconut) reinforced polymer composites. *Polymer Composites*, 2014. 35(1): p. 180-185.
- [4] Ribeiro, M., et al., Re-use assessment of thermoset composite wastes as aggregate and filler replacement for concrete-polymer composite materials: A case study regarding GFRP pultrusion wastes. *Resources, Conservation and Recycling*, 2015. 104: p. 417-426.
- [5] Mohan, T. and K. Kanny, Water barrier properties of nanoclay filled sisal fibre reinforced epoxy composites. *Composites Part A: Applied Science and Manufacturing*, 2011. 42(4): p. 385-393.
- [6] Ludueña, L., A. Vázquez, and V. Alvarez, Effect of lignocellulosic filler type and content on the behavior of polycaprolactone based eco-composites for packaging applications. *Carbohydrate polymers*, 2012. 87(1): p. 411-421.
- [7] Ghalia, M.A., A. Hassan, and A. Yussuf, Mechanical and thermal properties of calcium carbonate-filled PP/LLDPE composite. *Journal of Applied Polymer Science*, 2011. 121(4): p. 2413-2421.
- [8] Stassi, S. and G. Canavese, Spiky nanostructured metal particles as filler of polymeric composites showing tunable electrical conductivity. *Journal of Polymer Science Part B: Polymer Physics*, 2012. 50(14): p. 984-992.
- [9] Liu, W., et al., Ionic conductivity enhancement of polymer electrolytes with ceramic nanowire fillers. *Nano letters*, 2015. 15(4): p. 2740-2745.
- [10] Shim, J., et al., Polymer Composite Electrolytes Having Core–Shell Silica Fillers with Anion-Trapping Boron Moiety in the Shell Layer for All-Solid-State Lithium-Ion Batteries. *ACS applied materials & interfaces*, 2015. 7(14): p. 7690-7701.
- [11] Tanimoto, M., et al., Anisotropic thermal diffusivity of hexagonal boron nitride-filled polyimide films: effects of filler particle size, aggregation, orientation, and polymer chain rigidity. *ACS applied materials & interfaces*, 2013. 5(10): p. 4374-4382.