DOI : https://doi.org/10.56452/Jun_99

ISSN: 0974-5823 Vol. 7 (Special Issue 5, June 2022)

International Journal of Mechanical Engineering

Experimental Investigation of 3D Printing on PLA Reinforced with CF using FDM process

Kaushik M[1], V R Srinivasan[2], C P S Prakash[3]

[1]PG-Student, Department of Mechanical Engineering, Dayananda Sagar college of Engineering, Bangalore-560078, Karnataka, India.

[2]Assistant Professor, Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bangalore – 560078, Karnataka, India.

[3]Professor, Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bangalore – 560078, Karnataka, India.

Abstract

3D printing or Additive manufacturing (AM) is the technique in creating complex polymer, metallic, ceramic and composite objects using optimum printing conditions. Fused deposition modelling (FDM) being a promising widely utilised and based on material extrusion AM technique that is mostly utilised for creating thermoplastic components for applications with the goal of low cost, little waste, and ease of material conversion. Because pure thermoplastics have significantly poor mechanical qualities, there is need to enhance the mechanical property of FDM created thermoplastic components. The goal of this research is to mix carbon fiber with PLA to create carbon fibre reinforced Polylactic acid (PLA+CF) composite using 3D printing FDM process. After fabrication, the additive made specimen is subjected to tensile, flexural, wear and impact tests. The results of the FDM manufacturing method of tensile, flexural wear and impact characteristics of specimens were experimentally examined. The tensile and flexural test show 37.45% and 66.24% increase when compared to pure PLA, higher wear and impact energy was shown with the increase in carbon fiber where the least wear loss is of 2.42% and higher impact strength of 6.85 kJ/m^2. Further SEM test is done on fracture surface of tensile and impact specimens.

Keyword: Additive manufacturing; tensile test; flexural test; wear test; impact test; Carbon Fibers polymers; SEM fracture surface.

1. Introduction

3D printing is a method of producing a finished product layer by layer. Greater precision, quicker speed, and less material waste are the main advantages of this technique over conventional prototype procedures [1]. Furthermore, a 3D printer has no limitations on the sample shape and requires no further tooling. 3D printer is now available in a number of model that use various technology like Stereo lithography (SLA) and Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Digital Light Processing (DLP) and Fused Deposition Modeling (FDM). As a result the most widely used FDM technology was created for 3D printing [2]. In this investigation, 3D printing based on FDM was employed.3D printing has found an expanding range of uses from medical applications to automotive and aerospace industries, with new materials (metal-alloy or bamboo-based materials) being launched on a regular basis and 3D printer becoming lower cost by the day. A CAD file serves as the basis for an object's construction using an FDM printer. The CAD file needs to be converted into a 3D printer-compatible format before printing. To print the object, a plastic filament is unwound from a coil and fed into an extrusion nozzle [3-7].

Fused Deposition Modeling (FDM) employs a combination of various polymer for plasticizers and fillers as micro and nano materials for reinforcement [8]. FDM is a common rapid prototyping (RP) method, however the quality of the final result is dependent on a variety of process factors. FDM may create different component of complicated shape in a shorter amount of time [21]. The raw material is partly melted before being extruded from a stationary workstation's continuous deposition head. Single layers are placed on top of one another and the workbed is lowered to necessary height and accommodate the next layer [22]. Currently

DOI : https://doi.org/10.56452/Jun_99

thermoplastic filaments are the principal feedstock for FDM-based 3D printers. A polymeric material is used in the printing process as filament, such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polyimide (PA) and others, is fed at a predetermined speed by a feeder into a nozzle. ABS and PLA materials are commonly used in FDM 3D printers [23]. Melted plastic creates a sample layer upon layer by depositing laterally on just a flat plate. By regulating the relative velocity between the extrusion nozzle and the guide plate on the X-Y plane, the molten filaments deposition path is determined at each layer. Using slicer software, this route and printing parameters are derived from the 3D computer-aided design (CAD) model. STL (standard tessellation language) is the most often used format for this purpose. The filament is melted by the nozzle and extruded onto a foundation known as a build platform or table. A computer that interprets commands controls both the nozzle and the platform convert the geometry of the item into (x, y, z) coordinates [24-25].

ABS, Nylon, polycarbonate, high-density polyethylene, high impact polystyrene, PLA (polylactic acid) and other materials are already available for consumer in the market fused filament fabrication (FFF) 3-D printing [26]. PLA has grown as popular among users of consumer 3-D printers. PLA has low melting point (150°-190° C), meaning it requires less printing energy, which is advantageous for off-grid applications in underdeveloped countries [27]. Furthermore, PLA is a safer material, alternative to potentially harmful ABS composites. The materials that may become mainstream will increase the launch of several new and economical 3-D printing technology. Strengthening agents have been added to standard 3-D printable materials, and 3-D printer material have been treated to boost strength. These possible strengthening mechanisms may be applied and verified directly by the end-user with launch of recyclebot, a consumer-grade accessible plastic fiber extruder [28-29]

The inclusion of CF to the matrix feedstock significantly alters the end part's coefficient of thermal expansion (CTE) and thermal resistance. Most commercial additive systems produce components within an closed case to decrease heat gradients in the specimen during production, which causes internal stress, warping and curling [30]. Due to low-cost, desktop systems does not manage temperature changes with construction environment and their geometric precision is restricted. Demonstration by use of CF allows for buildup at ambient temperature has drastically decreased component deformation. CF technology excels in producing extremely strong, simple, lightweight structures [31]. The inclusion of CF into the matrix greatly enhances the strength and stiffness of the finished pieces, as demonstrated in this work [32]. Although the strength improves in the fiber direction, texture adhesion is still only moderate, similar to continuous CF composites. Finally, the results in this research demonstrate that PLA with CF reinforcements has the ability to significantly enhance the properties of a material [37].

A normal FDM printer with a minimally modified extrusion head was used to print the filament after it was first prepped using Pla+CF for use in FDM printers [38]. Pla+CF filaments are of high possibility of excellent first-phase impregnation when produced by skilled machines [39].

The FDM technology is particularly intriguing since it is very inexpensive, uses little material, and is simple to use. FDM-produced polymer products are weak and load-bearing qualities, the majority of 3D printed polymer goods are currently unable to be used as functional components. However, Depending on the filament used for printing, FDM technology may print polymers with reinforcement using either continuously or interrupted filaments. The inclusion of a few reinforcing materials has increased mechanical strength according to earlier experimental findings, compared to pure 3D printing, created using the FDM technique. For example Nabeel Maqsood et al. [33] studied that with addition of CCFR with SCF increases the material strength, F. Ning et al. [15] studied about ABS combined with short carbon fiber increases tensile and flexural characteristics. T. Yu et al. [16] investigated the mechanical performance and characteristics utilising CCF as reinforcement and Onyx as matrix. M. Rimasauakas et al. [17] investigation of the continuous carbon fibre impregnated with polymer filaments' tensile strength revealed that it has a high tensile strength. Nabeel Maqsood et al. [34] in this study combination of SCFR and CCFR was fabricated and studied about its mechanical properties. C. Yang et al.[18] The developed CCF reinforced ABS thermoplastic composite's flexural strength and modulus were around six times more than those of the material's conventional ABS counterparts.. M Heidari Rarani et al. [19] With the adjustment to the extruder design, produced 1000 carbon fibre roving was printed using PLA to create CCFRPC using FDM method, achieving highest tensile and bending strength. R Srinivasan et al.[35] studied tribilogical behaviour of carbon fiber mixed with PLA with varying parameters. Mishra et al. [20] studied choosing right infill density will result in a trade-off between

DOI : https://doi.org/10.56452/Jun_99

cost and strength. Araya Abera Betelie et al. [36] researched that, the tensile, flexural, and impact characteristics in sisal-epoxy composites with different proportions and fibre orientations can be evaluated.

The majority of the before mentioned studies were either on carbon fibre and PLA composites, where maximum strengths were attained, and very little effort was made to compare between varying percentages of CF and PLA. As a result, the research was done on the combination of CF and PLA composite in order to examine their manufacture, process ability, and mechanical performance. Therefore, it would be quite interesting to mix CF with PLA to create PLA+CF material and research the construction, process variables, and mechanical performance of this material. In this work, PLA+CF(10 wt%) and PLA+CF(20 wt%) were combined to create a composite material using the FDM method, and the difficulties encountered throughout the manufacturing process were highlighted. The goal of this study is to research the fracture interface following previously unreported mechanical testing of tensile and impact specimens using an SEM. The PLA filament reinforced with chopped carbon fibre is presented in a comprehensive tensile, flexural, wear, and impact response.

2. Experimental

2.1. Material

The PLA material used and its basic material is the polylactide resin 9051-89-02 and reinforced chopped carbon fibres 308063-67-4. 3DXTECH manufactures the PLA+CF, which is built from 9051-89-02 resin reinforced with chopped 308063-67-4 in a weight fraction of 20 wt%.

Epicenter3D which supplies the PLA+CF which is built from 9051-89-02 resin reinforced chopped carbon fibres in a weight of 10 wt%. Because basic material is same, both are equivalent in terms of the insertion of reinforcing fibres. The 3D printer filaments used have a diameter of 1.75mm. The typical value of density of PLA is considered to be 1.25 g/m^3 [42] and 10 wt% carbon fiber is considered as 1.26 g/m^3 and 1.29 g/m^3 for 20 wt % carbon fiber. the information of material on mechanical and chemical properties were provided by the suppliers.

2.2. Printing process parameters

FDM has a variety of input factors that might impact the strength of the printed item, including temperature of nozzle, layer height, printing speed and temperature of bed [41]. To optimise strength and minimise possibility of defect, the print conditions with a set of parameters are listed in the below table.

Table 1: Parameters of 3D printing

Parameters	**PLA**	**PLA+CF**
Printing speed	60mm/sec	60mm/sec
Layer height	0.2mm	0.2mm
Temperature of bed	30 °C	60 °C
Infill	100%	100%
Temperature of nozzle	170 °C	223 °C
Nozzle diameter	0.6mm	0.6mm

The studies are conducted under the idea that the test samples behaved like layered materials because layers are made of orthotropic with the printing orientation direction being the major direction of greatest stiffness [27]. At first, only rectilinear infill with a volume percentage of 100% was employed to 3D print the specimens, which limited the fused material lines to only being placed parallel to one another, generating layers that were then stacked on top of each other to produce a specimen [15].

DOI : https://doi.org/10.56452/Jun_99

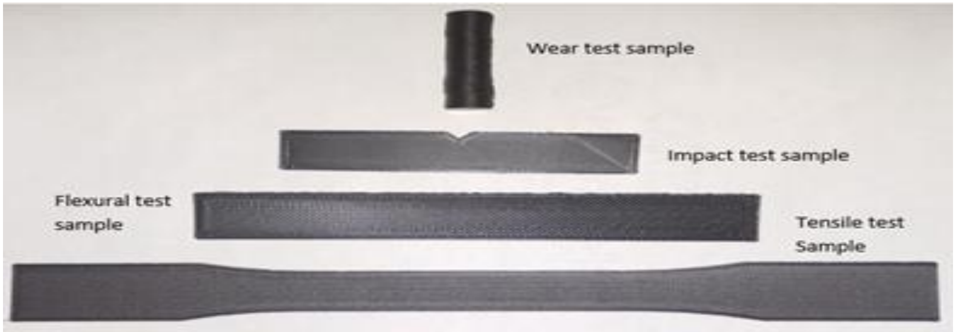

Fig 1: 3D printed specimen.

Finally in all specimens, The deposition line height and width parameters for 3D printing were kept constant. Therefore, it can be assumed that all of the experiments are conducted on a material with a same infrastructure, kept in certain orientations that follow FFF printing. [25].

2.3. Testing Measurement Procedures

Unidirectional oriented specimens printed at 45 degrees are used for this purpose, and they are tested up to failure. There is no specific standard test for printed products, adaption is based on ASTM D638, ASTM D7264, ASTM G99 and ASTM D256, fabricated specimens.

The material stiffness and strength qualities were determined using the ASTM D638 standard, which is dedicated to polymer tensile testing. The specimen form used was the I-type ("dog bone")[33]. The Tensile test was carried out at SLN testing laboratory, Bangalore, India.

The tensile strength and % Elongation are calculated using equations (1) and (2), respectively [11].

- $F_{ut} = \frac{P_{max}}{A}$ (1)

where, F_{ut} = tensile strength (MPa), Pmax = maximum load before failure (N), A = average cross-sectional area (mm^2).

- $\% \text{ Elongation} = \frac{\Delta L}{L} \times 100$ (2)

Where, ΔL = Final Length – initial length , L = Initial Length.

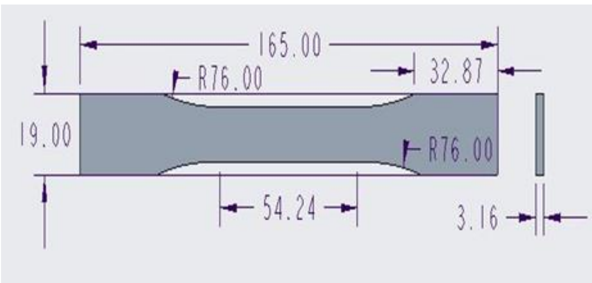

Fig 2: Tensile specimen dimension.

Fig 3: Flexural specimen dimension

Test to determine the flexibility of the material were determined using ASTM D7264, a rectangular specimen which is dedicated to polymer flexural testing [34]. The specimens are rectangular with 100x15x5 mm dimension. According to standard, flexural test is valid only if the maximum strain in the outer region of the sample breakage occurred within 5% strain limit[12]. For all the samples in this research no breakage occur more the 5% strain limit. The Flexural test was carried out at SLN testing laboratory, Bangalore, India.

The flexural stress are calculated using equations (3) respectively [12].

- $\sigma_f = \frac{3P\,L}{2bd^2}$ (3)

where, σ_f = flexural stress(MPa), P = Maximum load (N), L = effective span length (mm), b = Breath of tested sample (mm), d = distance of tested sample (mm).

DOI : https://doi.org/10.56452/Jun_99

Pin-on-Disk apparatus is used in the standard test method for wear testing, and ASTM G99 requirements are taken into consideration. The test specimen with 30xø8 mm dimensions. For a particular load, The rotating disc is pressed upon by a stationary pin. The tests run under conditions of sliding for a few sessions, and after those cycles, the wear rate and wear loss % of sample are calibrated. [12]. Wear test was carried out at Dayananda Sagar College Of Engineering, Bangalore, India.

The wear rate and wear ratio are calculated by the Eqs. (4), (5), (6), (7), respectively [13].

- Sliding Distance SD = (2 ×∏× r × N × t) / 1000, expressed in mm, (4)

Where N = speed (RPM), r = track length or radius (mm), t = time (min),

- Wear Rate = V / SD expressed in m^3/m,

Where; V = Volume of material removed, SD = sliding distance, (5)

- V = ΔW / ρ, expressed in m^3,

Where ΔW is change in weight, ρ is density of the material= 1.26×10^6 g/m^3, (6)

- ΔW = (W_i – W_j) expressed in g,

Where W_i = initial weight, W_j = final weight, (7)

- Wear Ratio = (ΔW / Wi) × 100 % .

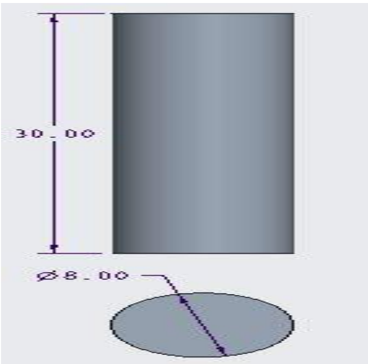

Fig 4: wear test specimen

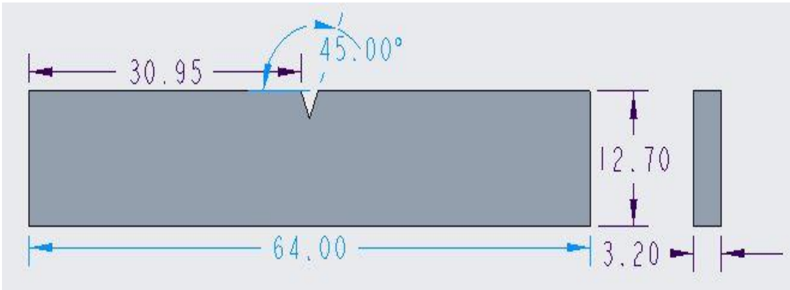

Fig 5: Impact test specimen

The printed specimens for impact test are considered using the ASTM D265 standard for polymer composite testing[36]. The sample used are rectangular with a notch at the top and were 64x12.7x3.2 mm in dimension. The angle of notch is considered to be 45° and the distance from base to notch is 10.16mm[14]. The Flexural test is carried out at SLN testing laboratory, Bangalore, India.

The impact strength in terms of J/m and kJ/m^2 is determined using Eqn. (7) and (8), respectively.

- Impact strength = $\frac{\text{Impact energy/load}}{\text{Thickness}}$, in (J/m) (7)
- Impact strength = $\frac{\text{Impact energy/load}}{\text{Distance from Notch}}$, in (kJ/m^2) (8)

2.4. Fracture Surface of Specimen.

After testing, the fracture interface of the sample is studied using optical microscope fitted with a high quality colour camera. After executing tensile and impact tests, at a five times magnification, the imaging decoding software is used to gather and analyse the data in order to look at the surface between deposited lines and also the separated and broken fibres of the sample . [33]. This study was conducted to look at the behaviour of 3D printed layers that were deposited and the process by which fibres in a composite failed after the test. To analyse the fracture interface, one specimen is chosen from among the studied sample.

3. Results and Discussion

3.1. Tensile Test

DOI : https://doi.org/10.56452/Jun_99

There are several reasons to conduct tensile testing. For engineering applications, the findings of tensile tests are used to choose materials. Tensile properties are frequently mentioned in material specifications to guarantee quality. In order to compare various materials and processes, tensile qualities are commonly investigated throughout the development of innovative materials and processes [11]. There are two approaches to evaluate the strength of interest: the stress required to cause deformation and the ultimate stress the material can withheld. These strength measurements are used cautiously in engineering design.

Table 2: Results of tensile properties measured

Material	Ultimate tensile strength MPa	Yield strength MPa	% Elongation
PLA	60.80 ± 09	59.88 ± 04	0.69 ± 0.1
PLA+CF(10 wt%)	71.89 ± 05	70.56 ± 03	0.81 ± 0.1
PLA+CF(20 wt%)	83.53 ± 04	82.36 ± 04	0.85 ± 0.1

The tensile result of each group's 3D printed specimens is displayed in table 2. According to the bar graph plot from Fig. 6, the PLA has the lowest average tensile strength and PLA+CF(20 %) group had the highest result. PLA printed with impregnated CF (20 wt%) has the maximum tensile result, roughly 1.37 times(37.38%) that of PLA and 1.18 times(18.24%) that of PLA+CF (10 %).

Fig. 7 depicts the yield strength data for each group. The pattern of findings shows same results, with the PLA+CF(20 wt%) having the greatest yield strength a 27.29% increased value of 82.36 MPa, when compared to PLA yield strength values of 59.88 MPa, respectively. The results show that increase in fibre content to matrix increases the value of yield strength

Fig.8 depicts the elongation measured from the tensile result. According to the results, PLA+CF(20 wt%) has the greatest elongation of 0.85 percent. PLA, on the other hand, had average elongation values of 0.69 percent. PLA+CF (20 wt%) demonstrated a high standard elongation value because to the inclusion of high strength carbon fibre composites in the specimens.

Thus all tensile result show the improvement in mechanical properties by the inclusion of CF to the pure PLA matrix and it can be conclude that higher the carbon fiber reinforcement there is higher tensile strength.

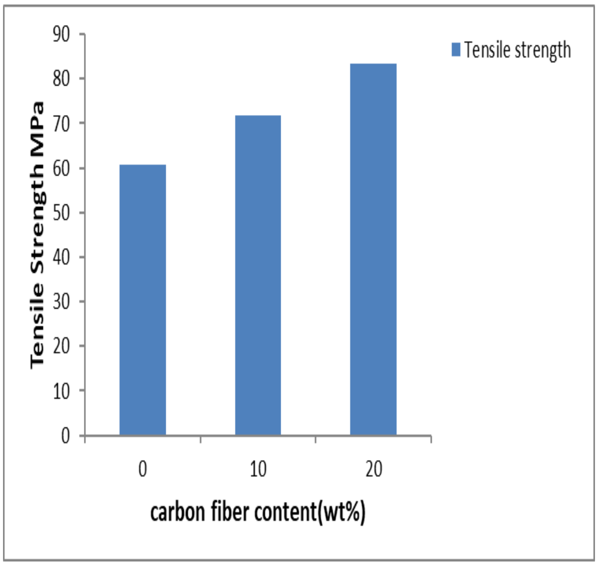

Fig. 6: Tensile strength

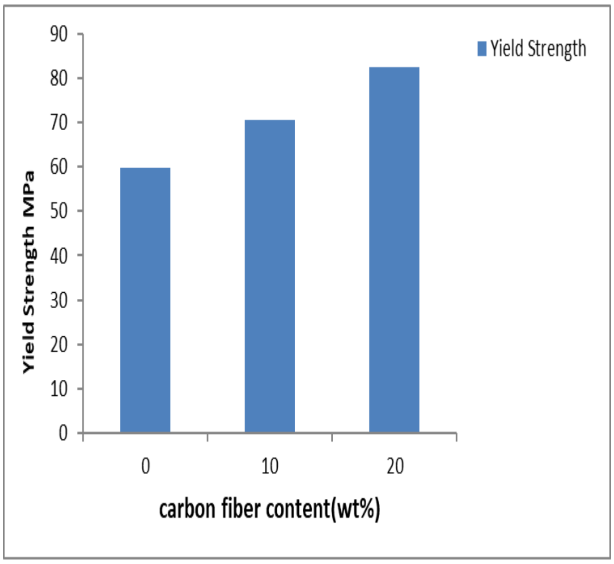

Fig. 7: Yield strength graph.

DOI : https://doi.org/10.56452/Jun_99

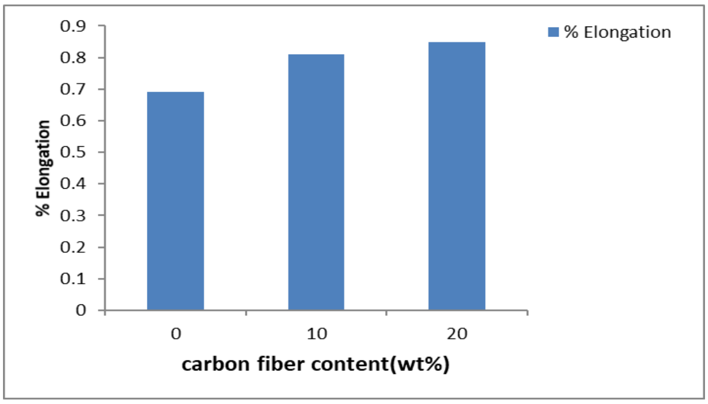

Fig. 8: % Elongation

3.2. Flexural Test

The test for flexural strength is performed using universal testing machine[34]. Flexural tests are carried out to examine the flexural strength and stress of specimens either with or without carbon fibres.

The standard states that flexural tests should be discontinued when highest strain in the outer surface of the sample reaches 5% or when break occurs prior to reaching the ultimate strain[12].

The studied show that Carbon Fiber reinforced (10 wt%, and 20 wt%) nanocomposite exhibit superior Flexural strength in comparison to unreinforced (0wt %).

Table 3: Results of flexural properties measured

Material	**Flexural Strength MPa**	**Flexural stress MPa**
PLA	14.99 ± 01	196.38 ± 1.78
PLA+CF(10 wt%)	21.34 ± 01	278.27 ± 2.14
PLA+CF(20 wt%)	24.92 ± 02	325.07 ± 1.59

Fig 9, 10 depicts the effects of carbon fibre content on the flexural strength and flexural stress of PLA and PLA+CF specimens. The flexural strength of pure resin (0 wt %) sample shows the least strength therefore the stress is also low. With the increase in the concentration of Carbon fiber, there is a significant improvement in the flexural strength of the nanocomposite material, Further the inclusion of carbon fiber of 20 wt% content, the flexural strength and stress of the composite material increases. There is 66.24% flexural strength increase than the pure sample, indicating that addition of reinforcement materials increases the flexural strength .

According to figure, there is gradual increase in the flexural strength and stress of the nanocomposite material with an increasing concentration of Carbon fiber. This confirms the observations reported in the work that the increase of Carbon Fiber facilitates the enhancement of the flexural strength and stress.

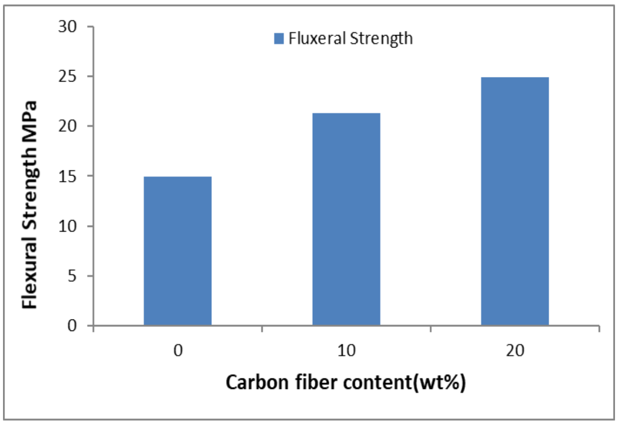

Fig. 9: Flexural strength.

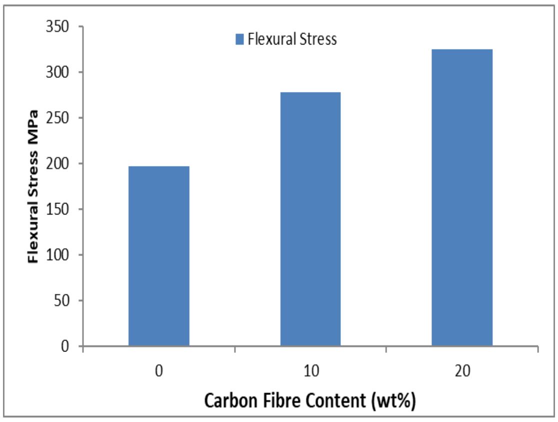

Fig. 10: Flexural stress.

DOI : https://doi.org/10.56452/Jun_99

3.3. Wear Test

The Pin on disc tribometer is used to find the tribological behaviour of the aforementioned specimens. The pin on disc experiment is a most common and quite well techniques to its ease of use and effecient representation of tribological characteristics of a material by a simplistic pin and disc movement. Due to the foreign object and specimen roughness interacting with contact between the sample surface and disc surface during the first test cycles, the wear rates are not uniform. Several cycles later, the wear track disc removes the foreign materials and roughness, which is known as the break in stage[35].

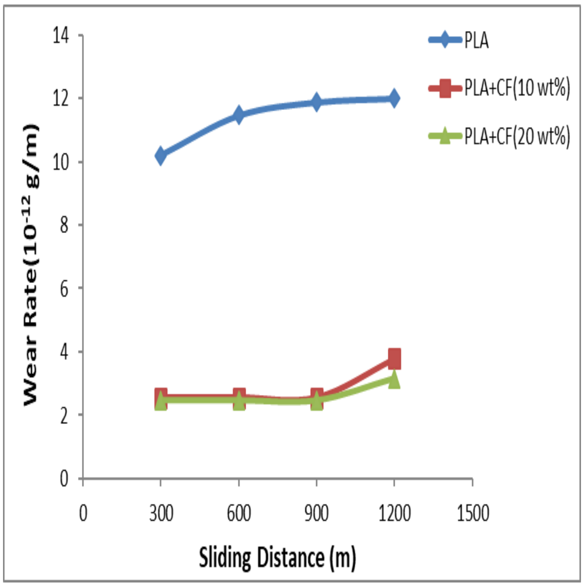

Fig. 11: Wear rate for 20N load

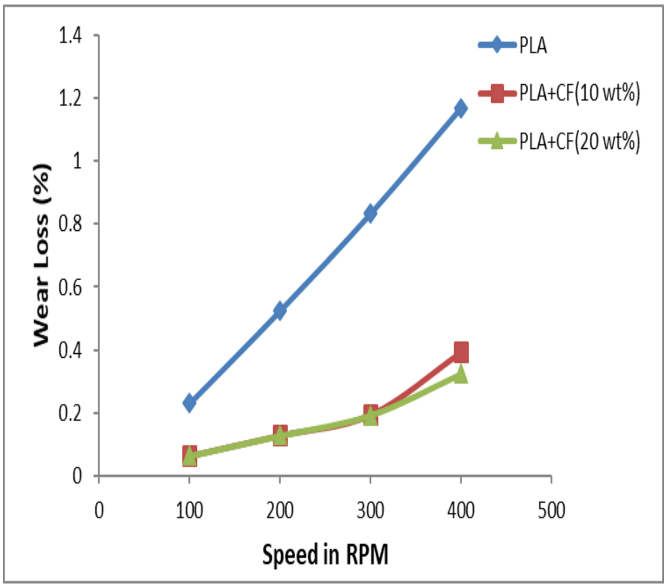

Fig. 12: Percentage of wear loss for 20N load

For first readings the PLA and PLA+CF variable specimen are tested for 20N load with 10 min time intervals and wear rate and wear loss % is determined. From Fig. 11, 12 it is considered that PLA has the highest wear loss and wear rate followed by CF 10 wt% and 20 wt%. From result there is limited wear rate seen in CF 10 wt% and 20 wt% but has a steady wear loss%.

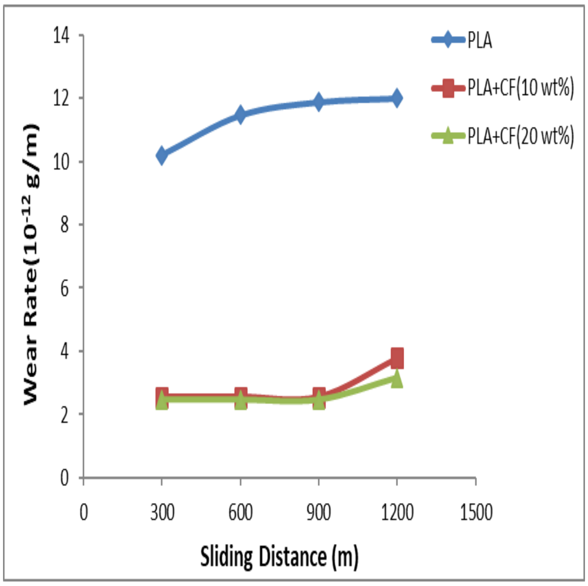

Fig. 13: Wear rate for 40N load

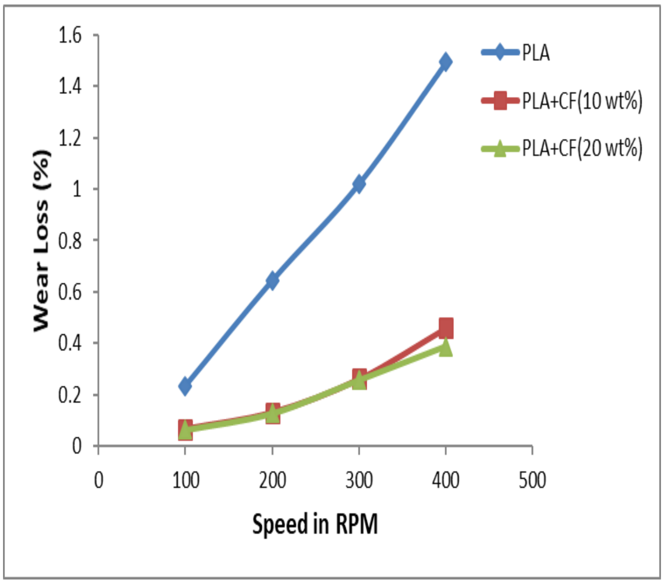

Fig. 14: Percentage of wear loss for 40N load

The second readings also show PLA and PLA+CF variable specimens for 40N load with 10 min time intervals for wear rate and wear loss%. The result remains same, where PLA exhibiting lowest wear rate and loss%. As shown in Fig. 13, 14 it is considered that with increase in load the wear rate and loss increases. From the result carbon fiber reinforcement specimen show greater resistance to wear by gradually increasing unlike PLA which has a high increase in wear rate and a steady wear loss%.

DOI : https://doi.org/10.56452/Jun_99

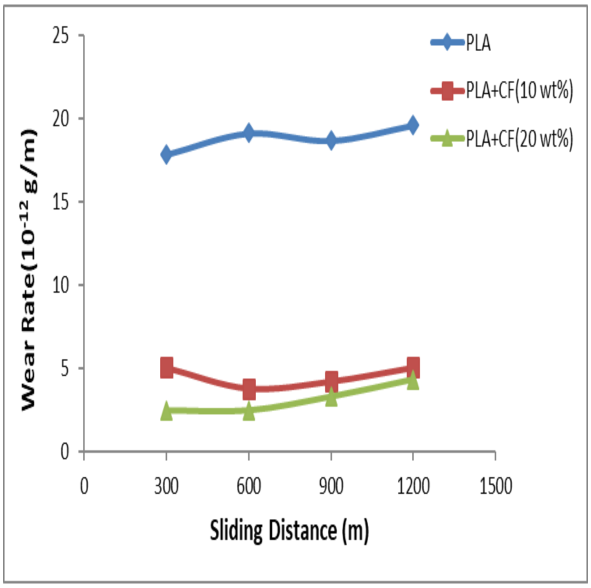

Fig 15: Wear rate for 60N load

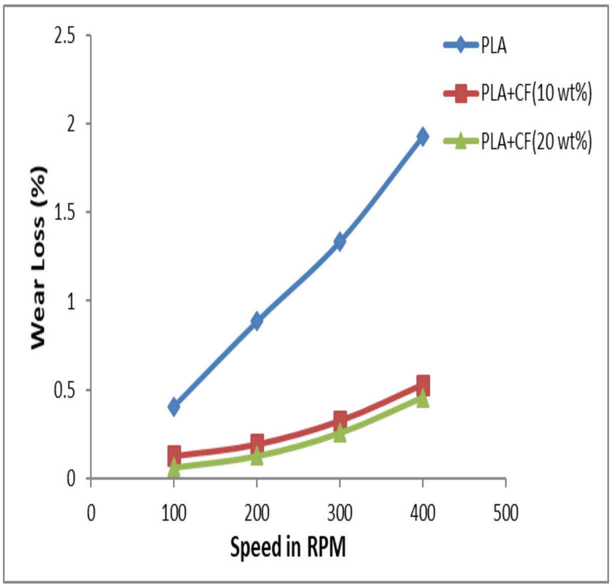

Fig 16: Percentage of wear loss for 60N load

The final results show that PLA and PLA+CF variable specimens readings for 60N load at 10 min interval of wear rate and wear loss%. The results indicate a very unsteady and a increasing loss of wear rate but the wear loss% having constant loss. PLA+CF(10 wt%) show a high wear rate initially and reduces wear rate and again has a steady increase, similar results are seen in PLA where a steady increase is gone through and a decrease in wear rate and again a steady increase.

Line graphs are used to visually compare the PLA and PLA+CF wear rates and wear loss % of the test results. The graphs show how the specimens' wear rate and wear loss % have changed over time in response to their different reinforcements. The results show that adding CF to PLA results in the least amount of wear, the overall loss is found to be in PLA being the highest (10.10%) and PLA+CF(20 wt%)being the lowest (2.42%).

3.4. Impact Test

Specimens are prepared for the Izod impact test according to [14] ASTM D256, ISO 180, with a pendulum capacity of 2.74 J. The composite impact characteristics are investigated by applying a load normal to specimens longitudinal axis. The notch on a notched specimen is facing the oncoming pendulum. When the height of the pendulum swing is adjusted for impact, the pendulum smashes the specimen [36]. Fig. 17 shows bar graph of impact strength specimens.

It is anticipated that the 3D-printed samples would demonstrate some good impact energy in comparison to conventional materials like ABS (Acrylonitrile, Butadiene, and Styrene) and PLA because CF is one of the most durable and rigid materials.

Table 4: Result of impact test measured

Material	Impact strength in J/m	Impact strength in kJ/m2
PLA	15.62	4.84
PLA+CF(10 wt%)	18.69	5.85
PLA+CF(20 wt%)	21.87	6.85

Table 4 discusses the impact results. In the table, the PLA+CF(20 wt%) revealed the greatest impact energy, but PLA show the weakest impact energy. As a result the CF (20 wt%) reinforced with PLA shows high impact strength of 6.85 kJ/m^2 and 21.87 J/m resulting higher strength in material. CF(10 wt%) reinforced with PLA show the second highest impact strength and PLA shows the least impact strength.

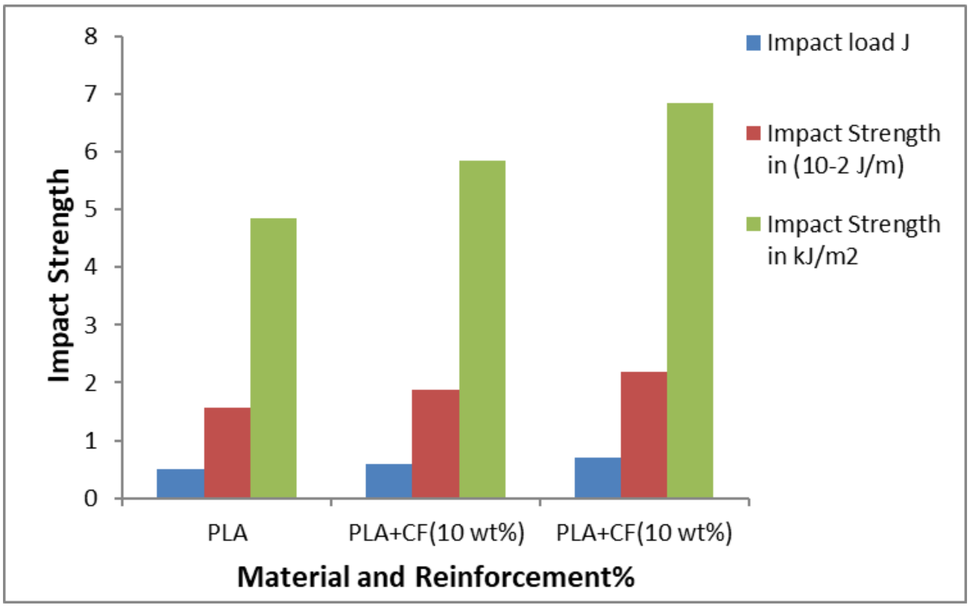

Fig.17: Impact Strength vs. reinforce material %.

3.5. Fracture Interface Observation after Mechanical Testing.

SEM test are used to examine the fracture surface. The fracture surface SEM images are displayed in Fig. 18, 19. When comparing composites samples to pure samples, it is observed that the ductile dimples are less common in the composites samples [43]. This suggests the carbon fiber improves the brittleness of the composites by decreasing its ductility.

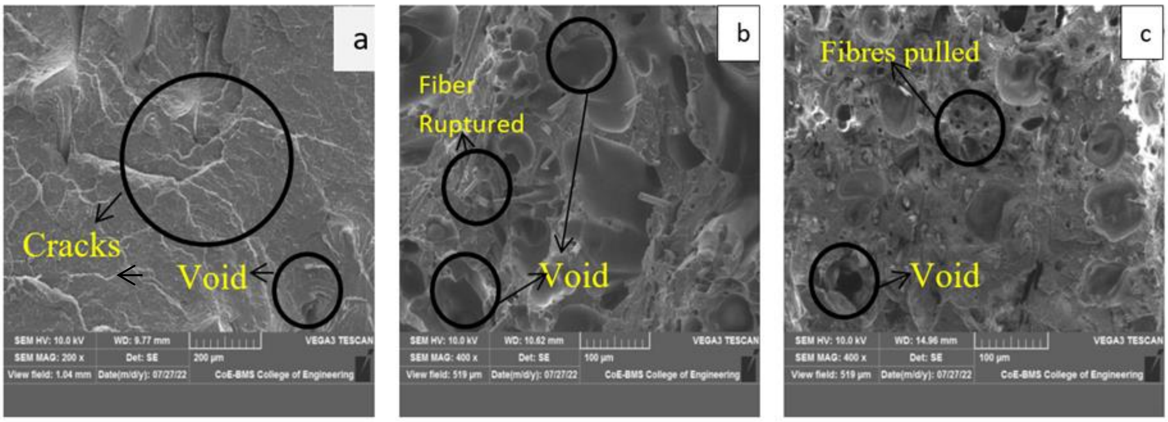

Fig. 18: SEM tensile fracture test images (a) PLA, (b) PLA+CF(10 wt%), (c) PLA+CF(20 wt%).

Figure 10 shows The pure PLA specimen ruptured at the point of contact, showing that there is no adhesion and that each layer is independent of the others. A similar result is observed in the PLA+CF, which has a rough surface from the presence of fibres and a clear rupture when each printed layer is separated after testing. Although chopped fibre filament improves stiffness, the product strength is still restricted since fibre is pulled out in PLA+CF might happen before fibre breakdown. The load was easily transmitted from the matrix to fiber reinforcement for enhanced properties, as seen by the burst fibers at the fracture interface. Higher tensile strength measurements also support this.

DOI : https://doi.org/10.56452/Jun_99

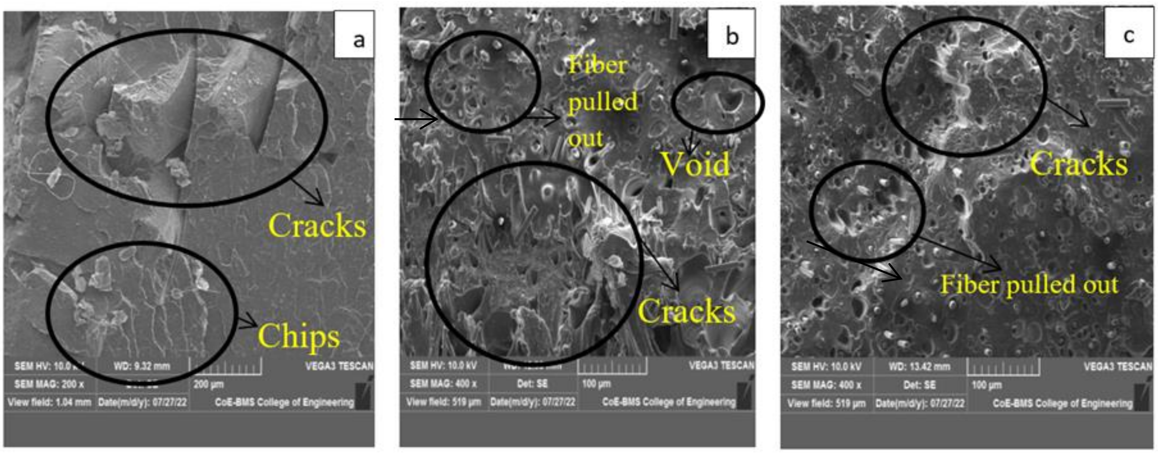

Fig. 19: SEM impact fracture test images (a) PLA, (b) PLA+CF(10 wt%), (c) PLA+CF(20 wt%).

The fracture test results of PLA demonstrate that cracks and chips occur in impact tests with voids, and similarly, 10 wt% reinforcement of CF shows more fractures and indicates increased impact damage to the material. There is less vacancy in 20% CF, however there remains a gap owing to fibres being pulled out of the material. Thus, impact damage is connected with matrix fracture development and broken fibres.

4. Conclusion

In this current study, carbon based polymer nanocomposite are fabricated using Fused Deposition Modeling (FDM) based additive manufacturing. Main conclusions are listed as follows,

Composites specimens with 0, 10 and 20 wt % are successfully printed by Fused Deposition Modeling technique.

The PLA has the lowest average tensile results in considering to carbon finer reinforced specimens. Thus from the study the tensile results conclude with the addition of CF the tensile values ie, Yield strength, ultimate tensile strength and % elongation increases roughly 37.38% compared to PLA.

Compared to sample with unreinforced PLA, the printed carbon fiber-incorporated composites had increased flexural characteristics. After inclusion of carbon fiber, the flexural strength was improved up to 66.24%, while the maximum flexural results was obtained as by 20 wt% carbon fiber reinforced specimen.

The test to both wear rate as well as wear loss% show a greater loss in PLA due to weak mechanical characteristics thus by addition of carbon fiber the wear losses are reduced drastically.

The impact result show that a maximum resistant is achieved by addition of carbon fiber where, where PLA+CF(20 wt%) show a high impact energy of 6.85 kJ/m^2 and a least impact energy in unreinforced PLA with a impact strength of 4.84 kJ/m^2.

Further the SEM images show fracture results of tensile and impact tested samples, where the breakage of the specimens are determined. The PLA samples have less amount of voids but a lot of cracks in tensile and impact test. In carbon reinforced specimens as a result of rupture the fibres are been pulled out causing a lot of voids in tensile test as a result , and cracks are found in impact.

In summary, adding 10-20 percent carbon fiber by reinforcing to PLA, significantly boosts the strength of composites produced by FDM for manufacturing various carbon based products.

5. Reference

[1] M. Ajay Kumar, M. S. Khan and S. B. Mishra, Effect of fused deposition machine parameters on tensile strength of printed carbon fiber reinforced PLA thermoplastics, Materials Today: https://doi.org/10.1016/j.matpr.2020.03.033

[2] Gholamhossein Sodeifian, Saghar Ghaseminejad , Ali Akbar Yousef, Preparation of polypropylene/short glass fiber composite as Fused Deposition Modeling (FDM) filament, (2018), doi: https://doi.org/10.1016/j.rinp.2018.11.065.

[3] Vinayak C. Gavali, Pravin R. Kubade, Hrushikesh B. Kulkarni, Property Enhancement of Carbon Fiber Reinforced Polymer Composites Prepared by Fused Deposition Modeling, 2019 Elsevier Ltd

[4] Wenli Ye, Guoqiang Lin, Wenzheng Wu , Peng Geng, Xue Hu, Zhiwei Gao, Ji Zhao, Separated 3D printing of continuous carbon fiber reinforced thermoplastic polyimide. 2019 Elsevier Ltd., https://doi.org/10.1016/j.compositesa.2019.04.002.

[5] Qingxi Hu, Yongchao Duan, Haiguang Zhang, Dali Liu, Biao Yan , and Fujun Peng, Manufacturing and 3D printing of continuous carbon fiber prepreg filament. National Nature Science Foundation of China (NSFC) 2017. DOI 10.1007/s10853-017-1624-2

[6] A. F. Calles, D. Carou, R. T. Luiz Ferreira, Experimental Investigation on the Effect of Carbon Fiber Reinforcements in the Mechanical Resistance of 3D Printed Specimens. Applied Composite Materials (2022) 29:937–952, https://doi.org/10.1007/s10443-021-09996-7

[7] Wittbrodt B, Pearce JM, The Effects of PLA Color on Material Properties of 3-D Printed Components, Addit Manuf (2015), http://dx.doi.org/10.1016/j.addma.2015.09.006

[8] Demei Lee and Guan-Yu Wu, Parameters Affecting the Mechanical Properties of Three-Dimensional (3D) Printed CarbonFiber-Reinforced Polylactide Composites. Polymers 2020, doi:10.3390/polym12112456

[9] Hao Dou , Yunyong Cheng , Wenguang Ye , Dinghua Zhang , Junjie Li , Zhoujun Miao and Stephan Rudykh, Effect of Process Parameters on Tensile Mechanical Properties of 3D Printing Continuous Carbon Fiber-Reinforced PLA Composites. Materials 2020, 13, 3850; doi:10.3390/ma13173850

[10] Huiyan Luo, Yuegang Tan, Fan Zhang , Jun Zhang, Yiwen Tu and Kunteng Cui, Selectively Enhanced 3D Printing Process and Performance Analysis of Continuous Carbon Fiber Composite Material. Materials 2019, 12, 3529; doi:10.3390/ma12213529

[11] ASTM Standard D638 (2014) Standard test method for tensile properties of plastics. ASTM International, West Conshohocken, PA

[12] ASTM Standard D7264 (2007) Standard test method for flexural properties of polymer matrix composite materials. ASTM International, West Conshohocken, PA.

[13] ASTM Standard G99 (2000) Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus. ASTM International, West Conshohocken, PA.

[14] ASTM Standard D256 (2002) Standard test methods for determining the izod pendulum impact resistance of plastics. ASTM International, West Conshohocken, PA

[15] F Ning, W Cong, J Qiu, J Wei, S. Wang, Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling, Compos. Part B Eng. 80 (2015) 369–378, doi:10.1016/j.compositesb.2015.06.013

[16] T Yu, Z Zhang, S Song, Y Bai, D. Wu, Tensile and flexural behaviors of additively manufactured continuous carbon fiber-reinforced polymer composites, Compos. Struct. 225 (2019) 111147, doi:10.1016/j.compstruct.2019.111147.

[17] M Rimašauskas, T Kuncius, R. Rimašauskienė, Processing of carbon fiber for 3D printed continuous composite structures, Mater. Manuf. Process. 34 (2019) 1528– 1536, doi:10.1080/10426914.2019.1655152.

[18] C Yang, X Tian, T Liu, Y Cao, D. Li, 3D printing for continuous fiber reinforced thermoplastic composites: mechanism and performance, Rapid Prototype J. 23 (2017) 209–215, doi:10.1108/RPJ-08-2015-0098

[19]] M Heidari-Rarani, M Rafiee-Afarani, AM. Zahedi, Mechanical characterization of FDM 3D printing of continuous carbon fiber reinforced PLA composites, Compos. Part B Eng. 175 (2019) 107147, doi:10.1016/j.compositesb.2019.107147.

[20] S.B. Mishra, R. Pattnaik, S.S. Mahapatra, Int. J. Prod. Qual. Manage. 21 (3) (2017) 375–391.

[21] Bochnia, J.; Blasiak, M.; Kozior, T. A Comparative Study of the Mechanical Properties of FDM 3D Prints Made of PLA and Carbon Fiber-Reinforced PLA for ThinWalled Applications. Materials 2021, 14, 7062. https://doi.org/10.3390/ ma14227062

[22] Kovan V., Tezel T., Camurlu H.E., Topal E.S, EFFECT OF PRINTING PARAMETERS ON MECHANICAL PROPERTIES OF 3D PRINTED PLA/CARBON FIBRE COMPOSITES. YEAR IV, ISSUE 4, P.P. 126-128 (2018).

[23] Lonnie J. Love, Vlastamil Kunc, Orlando Rios, Chad E. Duty, Amelia M. Elliott, Brian K. Post, Rachel J. Smith, Craig A. Blue, The importance of carbon fiber to polymer additive manufacturing. Materials Research Society 2014, DOI: 10.1557/jmr.2014.212.

[24] M Vinyas, SJ Athul, D Harursampath and T Nguyen Thoi, Experimental evaluation of the mechanical and thermal properties of 3D printed PLA and its composites. Mater. Res. Express 6 (2019) 115301, https://doi.org/10.1088/2053-1591/ab43ab

[25] M. Kamaal, M. Anas, H. Rastogi, N. Bhardwaj, A. Rahaman, Efect of FDM process parameters on mechanical properties of 3D printed carbon fbre–PLA composite. Springer Nature Switzerland AG 2020, https://doi.org/10.1007/s40964-020-00145-3.

[26] Marcus Ivey, Garrett W. Melenka, Jason. P. Carey & Cagri Ayranci (2017): Characterizing short-fiber-reinforced composites produced using additive manufacturing, Advanced Manufacturing: Polymer & Composites Science, DOI: 10.1080/20550340.2017.1341125

[27] Luiz Ferreira RT, Amatte IC, Dutra TA, Bürger D, Experimental characterization and micrography of 3D printed PLA and PLA reinforced with short carbon fibers, Composites Part B (2017), doi: 10.1016/j.compositesb.2017.05.013.

[28] Li, Nanya, Li, Yingguang, Liu, Shuting, Rapid Prototyping of Continuous Carbon Fiber Reinforced Polylactic Acid Composites by 3D Printing.Journal of Materials Processing Technology http://dx.doi.org/10.1016/j.jmatprotec.2016.07.025

[29] Sudhir Kumar , Rupinder Singh, Mohit Singh, TP Singh and Ajay Batish, Multi material 3D printing of PLA-PA6/TiO2 polymeric matrix: Flexural, wear and morphological properties.The Author(s) 2020 Article reuse guidelines: sagepub.com/journals-permissions DOI: 10.1177/0892705720953193.

[30] Tian, X., et al., Recycling and remanufacturing of 3D printed continuous carbon fiber reinforced PLA composites, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.11.139

[31] DA Türk, F Brenni, M Zogg, M. Meboldt, Mechanical characterization of 3D printed polymers for fiber reinforced polymers processing, Mater. Des. 118 (2017) 256–265, doi:10.1016/j.matdes.2017.01.050.

[32] Wenfeng Hao , Ye Liu, Hao Zhou, Haosen Chen, Daining Fang, Preparation and characterization of 3D printed continuous carbon fiber reinforced thermosetting composites. Polymer Testing 65 (2018) 29-34, https://doi.org/10.1016/j.polymertesting.2017.11.004.

[33] Nabeel Maqsood , Marius Rimaˇsauskas, Delamination observation occurred during the flexural bending in additively manufactured PLA-short carbon fiber filament reinforced with continuous carbon fiber composite. 2021 The Authors. Published by Elsevier B.V, https://doi.org/10.1016/j.rineng.2021.100246.

[34] Nabeel Maqsood , Marius Rimašauskas, Characterization of carbon fiber reinforced PLA composites manufactured by fused deposition modelling. 2021 The Author(s). Published by Elsevier B.V, https://doi.org/10.1016/j.jcomc.2021.100112.

[35] R. Srinivasan, B. Suresh Babu, V. Udhaya Rani et al., Comparision of tribological behaviour for parts fabricated through fused deposition modelling (FDM) process on abs and 20% carbon fibre PLA, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.03.689

[36] Araya Abera Betelie, Anthony Nicholas Sinclair, Mark Kortschot, Yanxi Li and Daniel Tilahun Redda, " Mechanical properties of sisal-epoxy composites as functions of fiber-to-epoxy ratio". AIMS Materials Science, Volume 6, Issue 6, 985–996(2019). DOI:10.3934/matersci.2019.6.985.

[37] X. Wang, M. Jiang, Z. Zhou, J. Gou, D. Hui, 3D printing of polymer matrix composites: a review and prospective, Compos. B Eng. 110 (2017) 442–458, https://doi.org/10.1016/j.compositesb.2016.11.034.

[38] P. Parandoush, D. Lin, A review on additive manufacturing of polymer-fiber composites, Compos. Struct. 182 (2017) 36–53, https://doi.org/10.1016/j. compstruct.2017.08.088.

[39] A.N. Dickson, J.N. Barry, K.A. McDonnell, D.P. Dowling, Fabrication of continuous carbon, glass and Kevlar fibre reinforced polymer composites using additive manufacturing, Addit. Manuf. 16 (2017) 146–152, https://doi.org/10.1016/j. addma.2017.06.004.

[40] T Yu, Z Zhang, S Song, Y Bai, D. Wu, Tensile and flexural behaviors of additively manufactured continuous carbon fiber-reinforced polymer composites, Compos. Struct. 225 (2019) 111147, doi:10.1016/j.compstruct.2019.111147

[41] Diana Popescu, Aurelian Zapciua, Catalin Amza, Florin Baciu, Rodica Marinescu, "FDM process parameters influence over the mechanical properties of polymer specimens: A review", Polymer Testing Volume 69, August 2018. https://doi.org/10.1016/j.polymertesting.2018.05.020.

[42] https://en.wikipedia.org/wiki/Polylactic_acid

[43] Ecker, J.V., Haider, A., Burzic, I., Huber, A., Eder, G. and Hild, S. (2019), "Mechanical properties and water absorption behaviour of PLA and PLA/wood composites prepared by 3D printing and injection moulding", Rapid Prototyping Journal, Vol. 25 No. 4, pp. 672-678. https://doi.org/10.1108/RPJ-06-2018-0149.

[44] Fernandes J, Deus AM, Reis L, Vaz MF, Leite M (2018) Study of the infuence of 3D printing parameters on the mechanical properties of PLA. 3rd International Conference on Progress in Additive Manufacturing (Pro-AM 2018) 14–17 May 2018, Singapore. https ://doi.org/10.25341/D4988C

[45] https://www.3dxtech.com/products/carbon-fiber-filaments/

[46] https://en.wikipedia.org/wiki/Carbon_filament