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Mechanical Characterization of Kevlar Epoxy Composites derived from 3D Printing process

A. Suresh
Asst. Professor, CVR College of Engineering/Mechanical Engg. Department, Hyderabad, India.
Email: suri0341@gmail.com

Abstract: **Additively fabricated polymer based composites exhibit ascendancies over the conventional manufactured polymer products because of their tweaked delineation pliability, dwarf cadence fixture of model-to-fabrication process for shortening the waste of material and cost of investment. Emphasis on short fiber included thermo-plastic reinforced composites is increasing now-a-days and the investigation for analyzing the mechanical properties is enhancing day-to-day. On the other hand, derivation of thermo-plastic composites from 3D-printing process involves more porosity and less mechanical strength. To overcome the existing drawbacks in the present work the analysis of producing short Kevlar based reinforced epoxy composites using additive manufacturing is made. The fabrication is thus archived with the customized setup of direct-write additive manufacturing. The vibration integrated parameters involved in the fabrication process are analyzed meticulously. With this experimentation, high dense and high viscous Kevlar composite is made with a maximum of 6.1% Kevlar fibers. The produced Kevlar composite links are contrasted with the unreinforced Kevlar links with 3-point bending setup. The analysis carried out in static and dynamic aspects. At the end of the experimentation, it is observed that mechanical strength, strength to weight ratio and ductility are improved for the work pieces obtained from additive manufacturing. Hence, it is evident that the adoptability practices for the Kevlar composites using additive manufacturing are more beneficial with respect to aerospace structural applications.**

Index Terms: Kevlar composites, Additive manufacturing, 3-Point Bending.

I. INTRODUCTION

3 dimensional printing (3D) or additive manufacturing (AM) is a material deposition technique in a layer-by-layer method to produce more accurate and intricate parts. The deposition using AM of the material is a fine tuning of the expectations from the maker's point of view and strength considerations [1]. Using the 3D printing process produced outcomes are readily re-designable, easy to modify, low material waste without altering the objective function is archived. Because of the above mentioned advantages, AM is used for wide range of applications in the field of high strength wear resistant materials [2].

The chief advantage lies with AM of Kevlar composites is the weight that material has, most required property for polymers is their easy processing and specific reduction of weight. To replace the conventional materials in the field of aero space and novel structural applications additively made polymer composites are best choice [3]. The induced vibrations in the fabrication of composite material for the specific application depend on controlling the parameters. The controlling of the process parameters for obtaining the desired quality and quantity of the product is archived meticulously by the 3D printing process [4]. With respect to the mechanical performance aspects polymers of various reinforcements like carbon, glass and natural fiber are added to the composites. The choice of using the fibers depends on two options one is continuous fibers and the other is short fibers. Hence, the adoptability of fiber depends upon various factors like their elongation, shear strength and the application.

Yet, in the present work the usage of short fibers is made due to the advantage of ease in adding the fiber to the machine and also the flow-ability of the material for producing the intricate parts [5]. In addition to it, the length of the fibers to be used in AM id decided based on the previous experimentations. There is no direct verdict that length of the fiber alone can decide the strength of the material [6]. But, at the same time it is also important to use the appropriate length of the Kevlar fiber. Usually, the short fibers are made wither by milling of chopping them into smaller parts of required size [7].

The feed stocking of the Kevlar is archived by simple mixing of the Kevlar fibers with the matrix material such as thermo plastic composites. It will reduce the complexity of the fabrication to great extent and then it shows the versatile properties [8]. One more important advantage is that the thermal stability and strength most likely it happens that the usage of the Kevlar composite is made in novel structural applications and aero space applications [9]. In both the cases the material is subject to more fluid attack that leads to wear and cracks over the surface. The additively made Kevlar composite can make the components rigid and firm to face the forecasted challenges [10]. In this voyage, the credit must be given the additive manufacturing setup and also finely chopped Kevlar composite. The real time functioning and testing of the composites is made a 3-point bending experiment and also the results are compared and contrasted with the conventional outcomes [11].

II. METHODOLOGY

A. Concocting of short fibers of Kevlar using laser cutting process

The activity of generating uninterrupted, mono-directional fibers of Kevlar material with a size of about 7.5-micron radius is schlepped out by maneuvering the laser cutting process [12]. The separated fibers are then riddled to circumvent the integral segments of Kevlar folio and separate the undivided fiber fascicles.

After completion of laser cutting of fibers the investigation of the boundaries of cut fibers below a

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microscope (optical) then investigated the laser cutting procedure [13]. During the investigation just about hundred microns cavernous blazed suburbs from fiber verge at every side. Hence, the chosen stretch of fibers, four crimps eight hundred microns that is greater than complete flicker span to prune the smoldering reverberation of laser next to incise suburbs.

After the cutting of the Kevlar fibers using laser cutting process, Scanning electron microscope (SEM) is employed to discern the arrangement of short Kevlar fibers [14]. To proceed with the SEM imaging for minimizing charging of Kevlar fiber a layer of about 1-1.5nm of thickness is used for coating on the surface. The fibers are maintained under the pressure of 50 milli-torr (vacuum) for about 28 seconds with super scribing coating instrument [15].

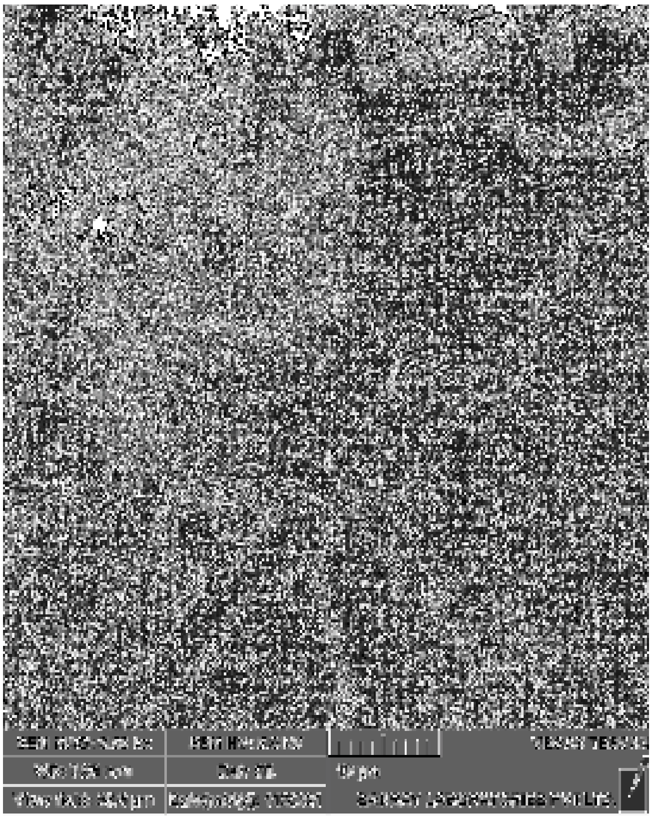

Figure 1. SEM image showing the single and bunch of fibers

In the above figure 1 of SEM analysis observation is made a magnification level of 3530x and the image showing the fibers are at a scale of 10 microns. In the figure it can be clearly seen that the single fibers and bunch of fibers are present.

Fibers are rationally separated to a required length maneuver the detailed technique as shown in Figure 1. In this figure, detached, unique fibers along with the bundles of fiber in this the fibers aren't fully detached are also descried.

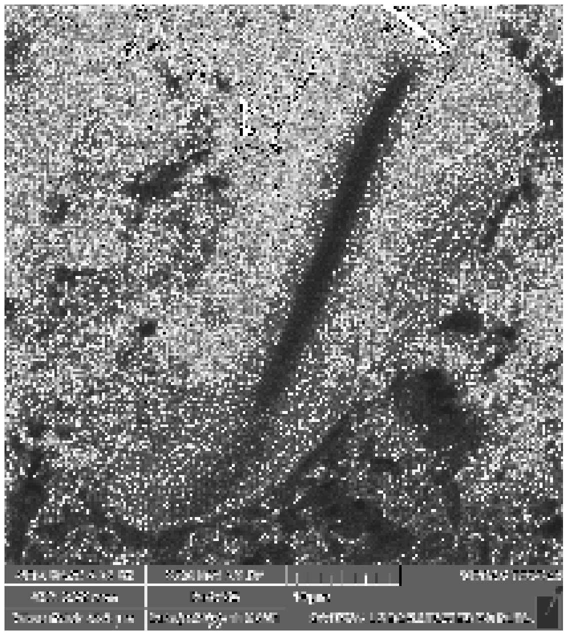

Figure 2. SEM image showing single fibers

In the above figure 2 of SEM analysis observation is made a magnification level of 4230x and the image showing the single fibers are at a scale of 10 microns.

B. Printing Ink concocting approach

Hexion an epoxy is chosen as thermo-set resin during the current work. The making of composite ink is initiated with addition of nano-clay material, a form of additive to make the epoxy resin by revamping the physiochemical combination of the ink [16].

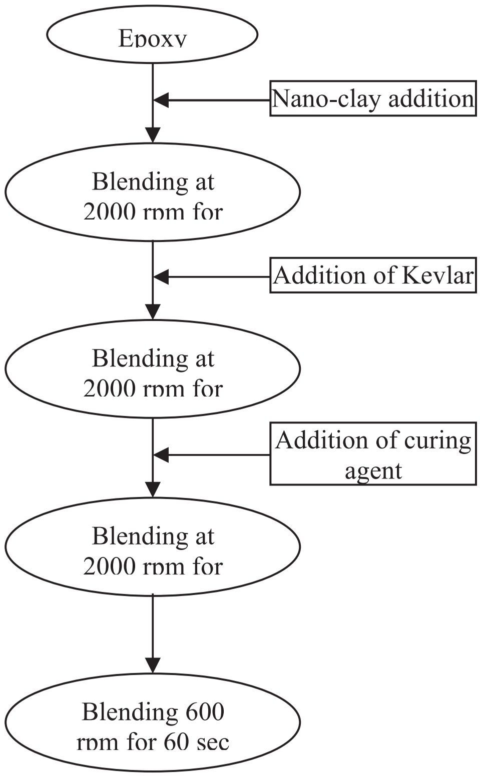

Figure 3. Preparation of ink for 3D printing

In the next step, separated Kevlar fibers are pretended into a mixture made up of nanoclay-epoxy comprehensively prior to outstretch to a paramount quantity of Kevlar fibers. Its quality is improved in terms of nano-clay reduction and densification of ink mixture [17]. The mixture obtained has a viscosity that is proportional to the conventional paint or ink. To obtain the desired dense mixture of paint the quantification of nano-clay addition is achieved with trial and error method with the quantities of 0, 3.7 and 6.1%. The below figure 3 depicts the 3D printing procedure.

Fiber content in the fabricated ink was found out by making the calculation with densities of constituents and also the mass fractions. The density of the ink is calculated by taking the density of the epoxy as 1.15 $\frac{g}{cm^3}$, nano-clay as 1.97 $\frac{g}{cm^3}$, Kevlar as 1.45 $\frac{g}{cm^3}$ and curing agent as 1.05$\frac{g}{cm^3}$.

C. Flow characterization of ink

The flow characteristics of the prepared ink for all the specimens are pervaded maneuvering the using the Rheometer. Appraising topology is institute on a eight mm plumb plate accompanied by a cranny apogee of 500 mm. Preceding to everyone scrutiny, specimens are put through a 60 seconds constraining juncture at a unceasing rate of shear of about 0.1 sec^{-1} accompanied by a two minute repose stretch for reconversion of structure of structure kindred to erstwhile swatting [18]. Specimen's viscosity is sedated as concomitant of rate of shear with panoramic by way of superintended with rate of shear 0.004^{-19} s^{-1} and depositary & mislaying modulus of elasticity are determined as the concern of shear stress in a kindred vogue.

D. Additive manufacturing of Kevlar ink maneuvering direct write method

Figure 4 details the outline of direct write additive manufacturing approach required in present work for juxtaposition with prosaic fused filament manufacturing procedure. The defects in the fused filament manufacturing can be seen in the below figures as compared to direct write AM.

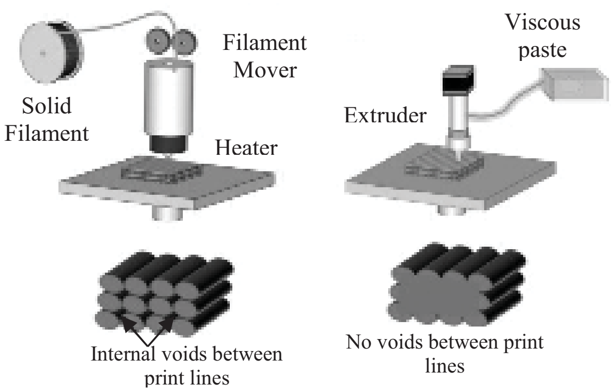

Figure 4 Difference between Fused filament manufacturing and Direct write additive manufacturing

In the above figure 4 the difference in between the two processes are shown in detail. There are some voids present in between the produced bars as seen in printed lines with the fused filament process whereas in the direct write AM the probability of getting the voids is less and hence in the present work it is considered.

The printing of the Kevlar composite is made at a temperature of 100ºC for about 15 hours. The additively manufactured made Kevlar composite material specimens are made by extrusion process with a nozzle of 2mm diameter and the jet processes the printing with a velocity of 40mm/sec. During the process of direct injection, the vibration of the nozzle becomes a significant criterion. It happens due to the problem of solidification of the injecting fluid. Because of mismatch in temperature inside the nozzle and outside the solidification may take place. This problem is popularly known as nozzle clogging. During the experimentation, the nozzle clogging problem is taken into consideration. The issue of nozzle clogging happens mainly due the high loading of the fibers. The increase in loading of fibers inside the nozzle leads in "nozzle clogging". The problem of nozzle clogging is resolved by introducing the vibration motors along with the direct write AM [19]. The vibration motors make the injecting nozzle position in dynamic position that in turn makes the nozzle function without jam. The surface plate is coated with the Teflon to avoid the sticking of the Kevlar composite.

The following figure 5 shows the images of specimens before and after curing process of base ink. Figure 6 shows the images of specimens before and after curing process of Kevlar composites.

Figure 5. Additively manufactured specimen of base ink

Figure 6. Additively manufactured specimen of Kevlar composite

III. Results and Discussions

The testing of the Kevlar composite specimens is made using a three point bending experiment. In the three points bending experiment a total of 4 samples are tested. The major constituents of the Kevlar fiber are about 3.5% and 6.3% of Kevlar fiber and about 7% of the nano-clay. The

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experimentation is carried out in a static and cyclic loading condition.

The fatigue calculation is made by the repeated experimentation with the increment in loads. The loads increased are tested for about standard number of cycles in the present case it is considered as 2 million cycles. Soon after the initiation of the experimentation of the Kevlar composite the failure point is observed by taking the reading at the first crack generated in the specimen.

Right from the lower loads to the continuous incremental loads experiment is performed. From the experimentation it is found that the highly loaded Kevlar composite has shown high strength and yielded more modulus. And in the specimens that has less Kevlar composition the modulus is found as low. The highest strength against failure is found to be 300kPa and shear strength of 1000Pa observed for 6.3% of kevlar. In the case of Kevlar composite with 3.5% composition the values are found as 160 Pa and 630Pa.

The below figure 7 shows the comparison of the results for various Kevlar composite specimens.

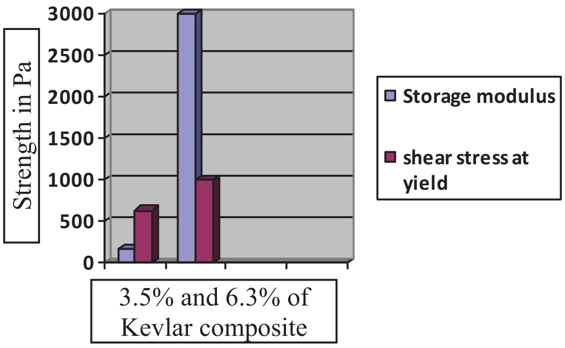

Figure 7. Comparison of Kevlar composites specimen 3.5% and 6.3%.

Similarly the flexural strength, flexural strain and flexural modulus of the Kevlar composites are compared after the experimentation. The comparison in between the base ink, Kevlar composite of 3.5% and Kevlar composite of 6.3% is made with the following graphs.

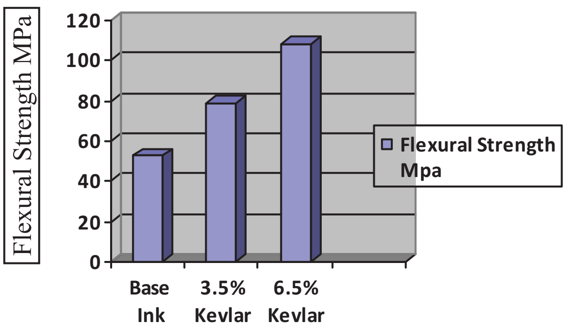

Figure 8. Comparison of Kevlar composites specimen 0%, 3.5% and 6.5% for Flexural Strength.

From the above figure 8 the flexural strength of the direct injected additively manufactured Kevlar composite specimens of 0%, 3.5% and 6.5% is compared. The specimen comprise 0% Kevlar that is base ink is having a flexural strength of 52.63 MPa. The specimen having 3.5% Kevlar has shown a flexural strength of 78.30 MPa. The specimen having 6.5% Kevlar has shown a flexural strength of 108 MPa.

From the below figure 9 the flexural modulus of the direct injected additively manufactured Kevlar composite specimens of 0%, 3.5% and 6.5% is compared. The specimen comprise 0% Kevlar that is base ink is having a flexural modulus of 3.24 GPa. The specimen having 3.5% Kevlar has shown a flexural modulus of 3.84 GPa. The specimen having 6.5% Kevlar has shown a flexural modulus of 4.23 GPa.

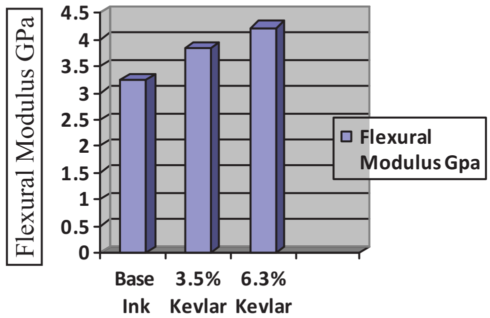

Figure 9. Comparison of Kevlar composites specimen 0%, 6.3% and 3.5%.for flexural strength

From the below figure 10 the flexural strain of the direct injected additively manufactured Kevlar composite specimens of 0%, 3.5% and 6.5% is compared. The specimen comprise 0% Kevlar that is base ink is having a flexural strain of 1.6%. The specimen having 3.5% Kevlar has shown a flexural strain of 2.2%. The specimen having 6.5% Kevlar has shown a flexural strain of 3.15%.

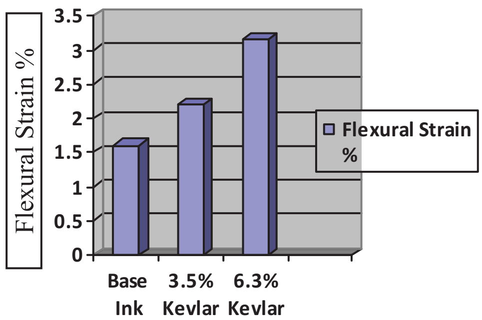

Figure 10. Comparison of Kevlar composites specimen 0%, 6.3% and 3.5%.for flexural strain.

From the below figure 11 the flexural fatigue strength of the direct injected additively manufactured Kevlar composite specimens of 0%, 3.5% and 6.5% is compared.

The specimen comprise 0% Kevlar that is base ink is having a flexural fatigue strength of 3.24 MPa. The specimen having 3.5% Kevlar has shown flexural fatigue strength of 3.84 MPa. The specimen having 6.5% Kevlar has shown flexural fatigue strength of 4.23 MPa.

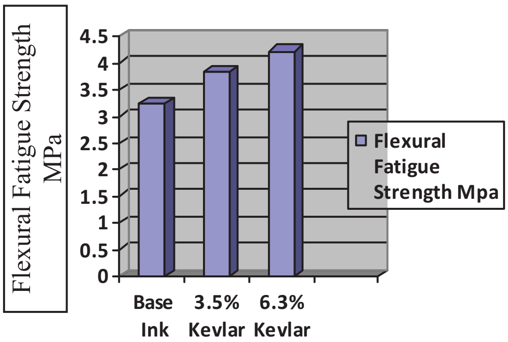

Figure 11. Comparison of Kevlar composites specimen 0%, 6.3% and 3.5%.for flexural fatigue strength

IV. Conclusions

In the present work, investigation and analysis of Kevlar composite material made from direct write additive manufacturing is made. The short Kevlar and nano-clay composite material static and flexural strengths are made and results are analyzed and the following conclusions are made.

- The void free Kevlar fiber composite is made by direct write additive manufacturing as compared to other manufacturing procedures.
- There is a significant improvement in the storage modulus and shear stress at yield with improvement of Kevlar composite from 3.5% to 6.5%.
- There is a significant improvement in the flexural strength with improvement of Kevlar composite from 3.5% to 6.5%. The flexural strength improved from 52.63 MPa to 78.30 MPa.
- There is a significant improvement in the flexural modulus with improvement of Kevlar composite from 3.5% to 6.5%. The flexural modulus improved from 3.84 GPa to 4.23 GPa.
- There is a significant improvement in the flexural strain with improvement of Kevlar composite from 3.5% to 6.5%. The flexural strain improved from 2.2% to 3.15%, for the base ink it is found to be 1.6%.
- There is a significant improvement in the flexural fatigue strength with improvement of Kevlar composite from 3.5% to 6.5%. The flexural fatigue strength improved from 3.84 MPa to 4.23 MPa, for the base ink it is found to be 3.24 MPa.

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