# EFFECT OF IN FILL PATTERNS ON 3D PRINTED MULTI-WALL CARBON NANOTUBE BASED ACRYLONITRILE BUTADIENE STYRENE NANOCOMPOSITE ON MECHANICAL PROPERTIES

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## ABSTRACT

Addition of a very little weight percentage of micro or nanomaterials can result in enhancement of properties that will further increase the scope of use of the polymer. In this research work, multiwall carbon nanotubes (MWCNTs) were added in percentage ranging from 0.1 to 0.3% by weight in acrylonitrile butadiene styrene (ABS) and a spool in the form of material was prepared for 3D printing with the help of an extrusion machine. The samples were printed as per the ASTM D638 standard using dual extruder 3D printer by fused deposition modelling (FDM). The tensile and flexural tests were performed with and without multiwall carbon nanotubes in the ABS material. The tensile test results in an increase in strength by 21.61% while the flexural test results a decrease in strength by 15.13%. With both of the tests it indicates the increase in brittleness of the composites with increment in the percentage of nanomaterials. Further ahead in this research work, samples were prepared with variation in their printing pattern and in-fill percentage. Patterns selected were Full Honeycomb, Grid, Rectilinear and Triangular with 20, 50 and 100 % of in-fill for 0.1, 0.2 and 0.3 % of MWCNT. The Rectilinear pattern with 100% infill for nanocomposite material 0.1% of MWCNT, shows maximum tensile strength 36.31 MPa and reduction in tensile strength of 18.00 MPa is observed with 0.3% MWCNT nanocomposite material with 20% infill. Grid pattern with 50% infill for natural ABS material shows maximum tensile strength of 26.67 MPa and the reduced tensile strength of 17.79 MPa is observed by 0.3% MWCNT nanocomposite material with 50% infill. Full Honeycomb pattern with 20% infill for natural ABS, shows maximum tensile strength 26.23 MPa and reduction in the tensile strength 20.43 MPa is obtained by 0.2% MWCNT nanocomposite material with 100% infill. Triangular pattern with 50% infill for natural ABS material shows maximum tensile strength of 30.34 MPa and reduction in the tensile strength of 19.92 MPa is tailored by 0.3% MWCNT nanocomposite material with 50% infill. Thus, the infilled 3D printed ABS nanocomposites with addition of the MWCNTs have significantly improved the mechanical properties with 0.1%wt of MCNTs then adding more weight percentage of MWCNTs have reduced the tensile strength.

Keywords: FDM, Nanocomposite, Characterization, In-fill, Pattern

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# INTRODUCTION

## Additive Manufacturing

Additive manufacturing, also known as 3D printing, rapid prototyping or freeform fabrication, is 'the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies' such as machining. It became a suitable process to produce complex metal net shape parts, and not only prototypes, as before. Additive manufacturing now enables both a design and industrial revolution, in various industrial sectors such as aerospace, energy, automotive, medical, tooling and consumer goods [1].

## 3D Printing

A 3-D printing produces parts or products with addition of successive layers of material on a platform by using bottom to top approach. [2-3] A material can be a thermoset or thermosetting plastic with addition of certain additives such as CNTs (SWCNTs/MWCNTs) or graphene. For 3D printing most common and famous form is thermoplastic extrusion, known as fused deposition modelling (FDM) [3-4]. Addition of CNTs and other structured additives improve functionality of 3D printed composite parts. Polymer composites and their development as a material for 3D printing are of greatest interest among all researchers and industry specialists. Carbon nanotubes are known for their mechanical, electrical, and thermal properties, which initially makes them a suitable candidate to integrate into 3D printing polymers.
Though this technology has so many widespread uses, still it is not the primary way to produce objects in the world. Though a lot of research is being done on this technology, still many hurdles remain to make this technology more accessible and widely accepted. To make this happen additive manufacturing must have materials with wide range of properties to print with. There should be a material which is lightweight but has high strength with good electrical properties. MWCNTs were purchased from the vendor for this experimental analysis and the SEM image of the MWCNTs is shown in Figure 1.

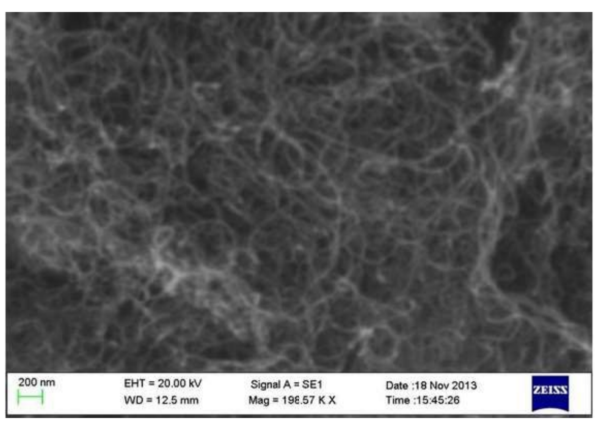



Figure 1: MWCNT an image through Scanning Electron Microscope

**Literature Review**

Till now various conductive nanoparticles have been used in 3D printing for product development, such as carbon black, Graphene oxide, reduced Graphene oxide, Graphene and multi or single carbon nanotubes. However, very limited studies have been focused and products are developed on the production of Nano composite filament feedstock for FDM.

Dudescu Cristian et.al. printed 3D components and performed standard tensile tests and to assess the influence of the technological parameters upon mechanical proprieties of printed specimens, considering different printing directions, infill rates and infill patterns. The influence of raster angles is tested through the designed specimens with different transverse plane, they are printed by placing in different angle, including 0°, 30°, 45° and 90°.Specimens with an infill rate varying from 20% to 100% and six different infill patterns has been tested [5].

K. M. Moeed et.al. studied the variation in infill pattern as well as infill percentage and concluded its impact on the mechanical behavior of the 3D printed part. In their study FDM printed PLA specimens subjected to compressive tests in order to observe their behavior under compressive forces [6]. Christian Lubombo et.al. investigated the stiffness and strength of lightweight cellular PLA parts under uniaxial tensile loading and flexural loading both edgewise and flatwise. The cellular parts were fabricated with one and three perimeter shells by using five types of infill patterns at three different infill density levels. The results showed that the stiffness was increased by up to a factor of 2 and the strength was increased by up to 82% at the same density simply by using a different type of infill pattern for the same number of perimeter shells. Likewise, the use of a higher number of perimeter shells for the same infill pattern improved the stiffness and the strength by up to a factor of 2 and up to 84%, respectively, at the same density [7]. Mohammadreza Lalegani Dezaki et.al. studied the effects of combined infill patterns in 3D printed products. Five patterns (solid, honeycomb, wiggle, grid, and rectilinear) were combined in samples to analyze their effects on mechanical properties for tensile strength analysis. Polylactic acid (PLA) samples were printed in different build orientations through two directions: flat and on-edge. Finite element analysis (FEA) was used to determine the patterns' features and results showed honeycomb and grid have the highest strength while their weights were lighter compared to solid. Moreover, $0^0$ samples in both flat and on-edge direction had the strongest layer adhesion and the best quality. In contrast, perpendicular samples like $60^0$ and $75^0$ showed poor adhesion and were the weakest specimens in both flat and on-edge, respectively [8].

The present authors have previously reported a detailed investigation and the result shows a significant increase in mechanical and electrical properties of the composite of ABS and MWCNTs nanomaterial. With increase more weight percentage of the MWCNTS in natural ABS has further shown the decrease in tensile and flexural properties of nanocomposites of ABS. With addition of weight percentage of MWCNTs in the natural ABS have shown an increase in electrical conductivity also [9].

# EXPERIMENTATION

## 2.1 Experimental Setup

The research involved fabrication of composite material, characterization of the new material, printing the samples for testing and finally testing for the mechanical and electrical properties of this material. To achieve this, firstly the composite material was prepared at the facility provided by Solid space technology in Nashik, India [10]. Solid space filament extruder had double screw setup to ensure optimum mixing of material. A mixture of ABS and MWCNTs in various ratios was inserted into the hopper of the machine which then gave out a filament of 1.75mm diameter wound around a spool as shown in figure 2. The extrusion temperature used in this machine was 178ºC [11].

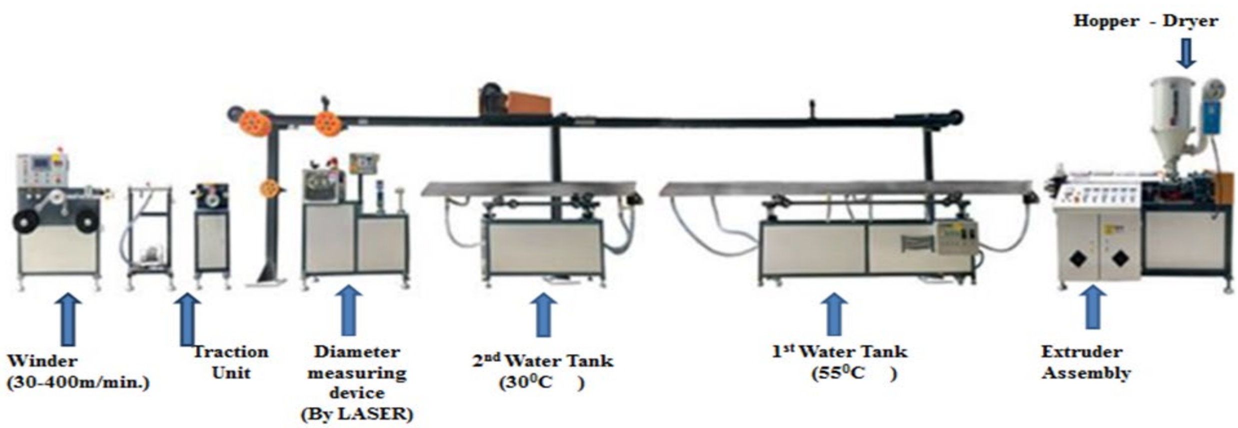



Figure 2: Solid Space extrusion machine setup Courtesy: Solidspace LPP

**Test Specimen Preparation**

After extrusion process, prepared spool was installed in a 3-D printer (ACCUCRAFT i250D) [12] available at VJTI to print the specimens from customized spool of 3D printing filament and test samples made ready for tensile test. The tensile test specimens were printed in accordance to ASTM D 638 [13] standard as shown in the figure 3 These standards were chosen as they were specifically chalked out for plastics testing.

The printed samples were then tested for tensile test in a universal testing machine (Shimadzu AGS-X 100KN) available at VJTI, Mumbai as shown in figure 4 The failed samples were then taken for Scanning Electron Microscopy (SEM) imaging at Central Institute for Research on Cotton Technology (CIRCOT), Mumbai.

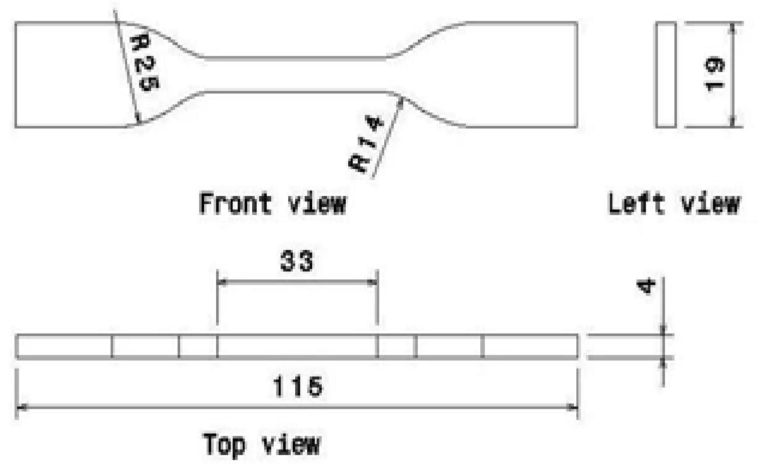


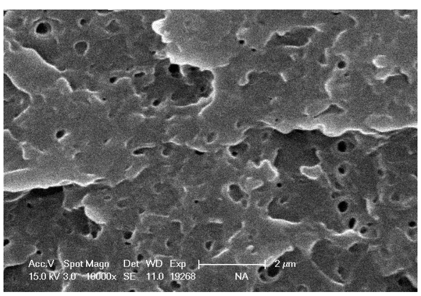

Figure 3: Test specimen for tensile test in accordance to ASTM D638. [12] (All dimensions are in millimeter)


Figure 4: Shimadzu UTM at VJTI

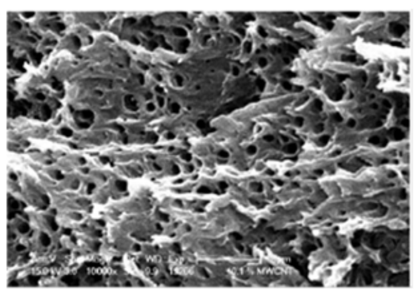
# RESULTS

## SEM Characterization

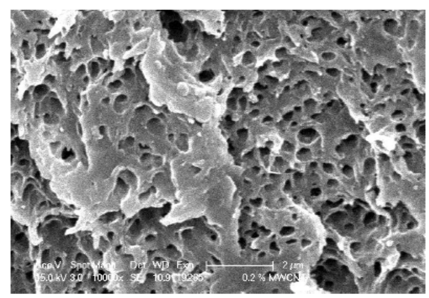
SEM characterization performed at CIRCOT, Mumbai. A nanocomposite made with addition of natural ABS in MWCNT powder shows significant difference in images taken by SEM. It can be observed by viewing following images.



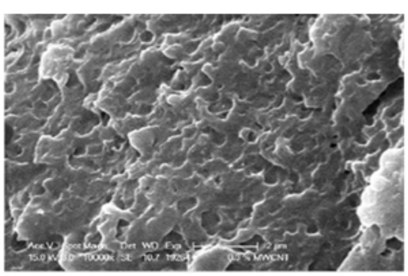
a) Natural ABS



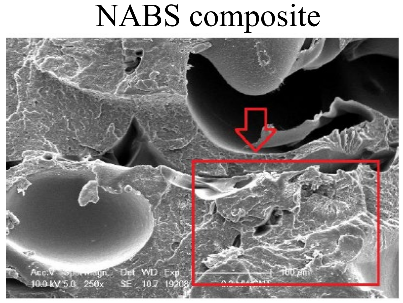
b) 0.1% by wt. MWCNTs and NABS composite



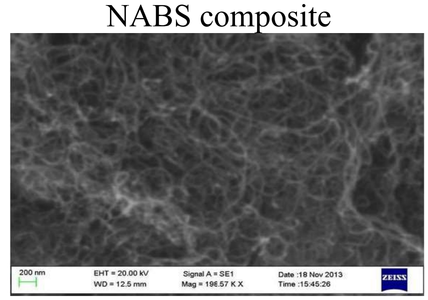
c) 0.2% by wt. MWCNTs and NABS composite



d) 0.3% by wt. MWCNTs and NABS composite



e) Presence of MWCNT



f) SEM image of MWCNTs

Figure 5: SEM images of ABS and MWCNTs with different wt. %

Courtesy: CIRCOT

Natural ABS and composites of NABS and MWCNTs are shown in Figure 5 a, b, c, d and e respectively. Additional adhesive bond will be created by MWCNTs in Natural ABS and it can be observed through rough and more fracture surface indicated in figure 5e.

### 3.2 Mechanical testing (Tensile and Flexural)

Previous research of the same researcher [9] reveals, that its tensile strength is increased maximum by 21.61% for 0.1 wt. % MWCNTs as compared to natural ABS. For 0.2 wt. % & 0.3 wt. % also, there is increase by 12.59% and 9.88% respectively in its tensile strength. Hence more wt. % addition of MWCNTs in natural ABS has shown increase in tensile strength. However adding more MWCNTs in wt% have shown decrease in the tensile strength. Also, it is observed that by adding MWCNTs in natural ABS, by certain wt. %, shows decrease in mechanical properties (Flexural Strength) of the material. Its flexural strength is decreased maximum by 15.13% for 0.1 wt. % MWCNTs as compared to natural ABS. For 0.2 wt. % & 0.3 wt. % also, there is decrease by 3.21% and 5.04% respectively in its flexural strength. Hence more wt. % addition of MWCNTs in natural ABS shows decrease in its flexural strength.

### 3.3 Electrical conductivity test

Previous research shows, due to the addition of MWCNTs to NABS, it is observed that electrical conductivity also significantly improved for the polymer composite. The addition of MWCNTs to ABS also affected the conductivity in positive manner for the polymer [9].

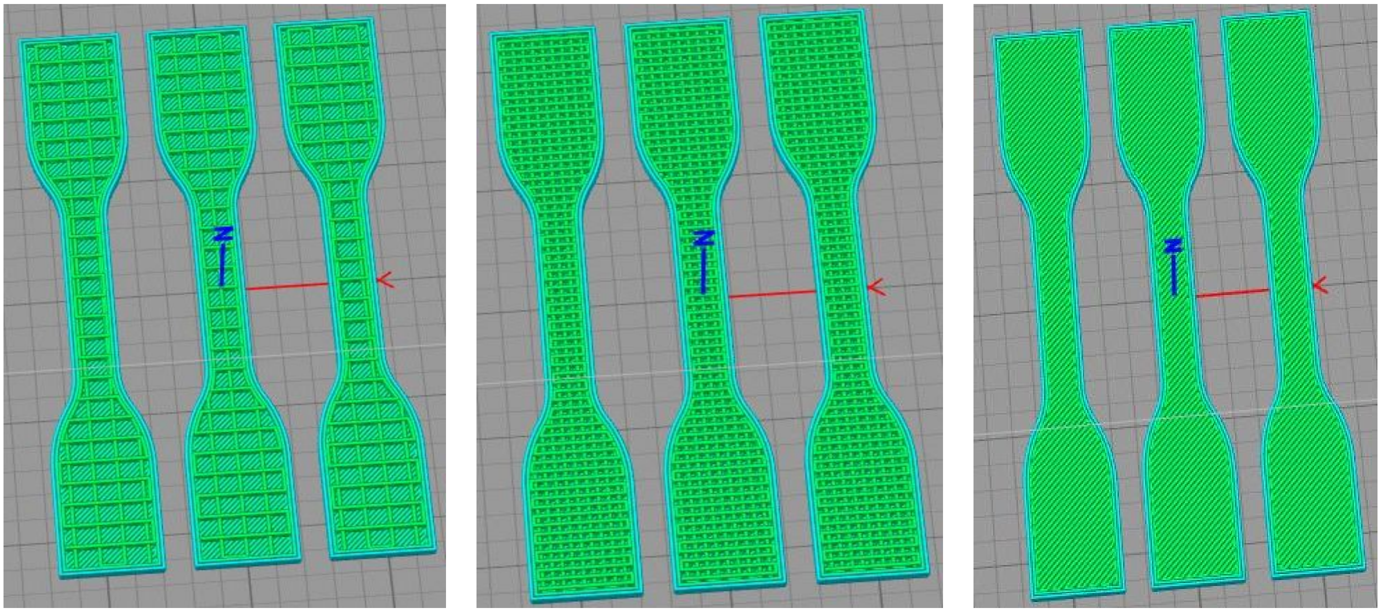
### 3.4 Tensile Testing with different In-fill percentages and Patterns

The current research throws light on the technological parameters upon mechanical proprieties of printed specimens, considering different printing infill rates and infill patterns. Here specimens with an infill rates varying from 20% to 100% with four different infill patterns has been tested for its tensile strength.

Three specimens from each different types have been manufactured by varying the following parameters:

***Infill rate/Percentage:*** The infill rate states how much material to be melt in the printed pattern and represents the density of the pattern. For this study the values of 20%, 50%, and 100% were considered. The exact air gap between extruded filament raster cannot be specified, the parts can be created solid or hollow by adjusting the percent infill, with 100% infill component as a complete solid state and lesser the percentage being hollow component. Figure 6 represents appearance of all infill percentages. Infill percentage variation is directly related to printing parameters in 3D printing. Maximum the infill percentage, maximum will be time required for printing a specimen. Also it is related with material consumption (filament). Maximum infill will consume maximum material during 3D printing.

Mechanical Testing of 3D printed components carried out on Shimadzu 100KN UTM at VJTI. For each infill percentage and different infill pattern, each three components were printed for all different variety of materials except Natural ABS. In all we tested 27 components of Natural ABS, and 30 each components of remaining all different infill patterns. Total 107 components tested for tensile strength study as a part of this research work. It is observed that most of the tensile test specimens fail in-between their respective gauge length during testing. But for different infill percentage and pattern, we observed very much variation in their failure during tensile testing



a) 20% Infill b) 50% Infill c) 50% Infill

Figure 6: Appearance of Infill Percentages in 3D printing

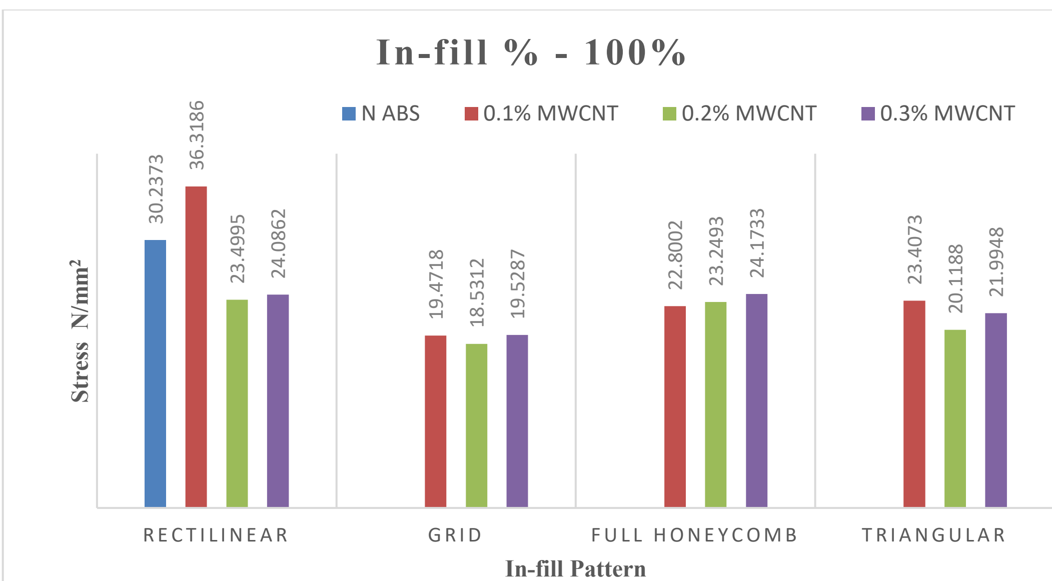



Figure 7A : Graph representing max.tensile strength for Infill 100%

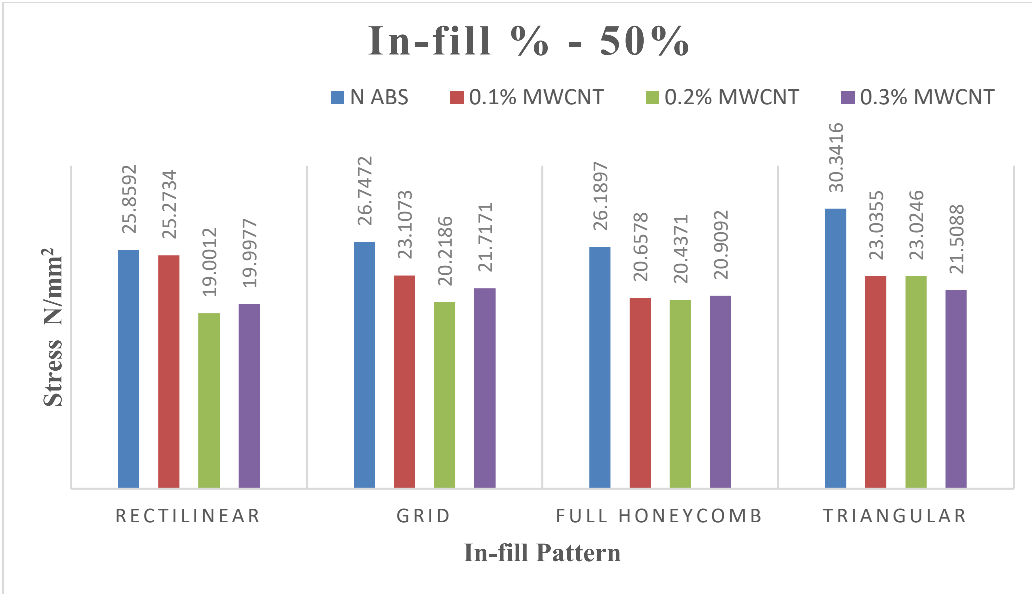



Figure 7B : Graph representing max.tensile strength for Infill 50%

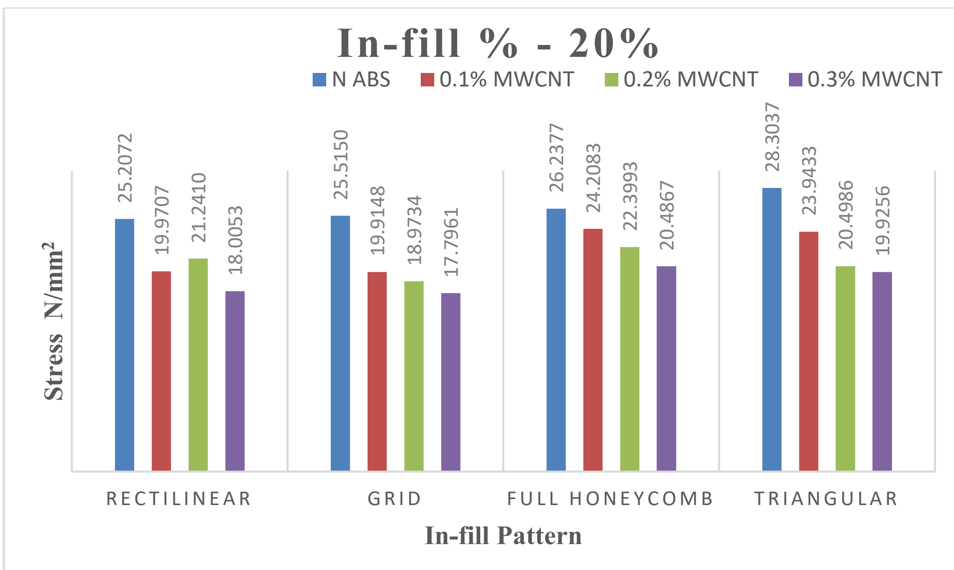



Figure 7C : Graph representing max.tensile strength for Infill 20%

For all different infill patterns (Rectilinear, Grid, Full Honeycomb and Triangular) only one component with 100% infill percentage was printed for testing purpose. Hence standard deviation for all above infill patterns for 100% infill is not mentioned in following table.
Table below represents Maximum tensile strength value in MPa and its standard deviation.

Table 1. Maximum Tensile Strength and Standard Deviation for all specimens

| In-fill Pattern | In-fill % | Max. Tensile Strength in N/mm$^2$ | Std. Deviation | Max. Tensile Strength in N/mm$^2$ | Std. Deviation | Max. Tensile Strength in N/mm$^2$ | Standard Deviation | Max. Tensile Strength in N/mm$^2$ | Std. Deviation |
|---|---|---|---|---|---|---|---|---|---|
| | | N ABS | | 0.1 % MWCNT | | 0.2 % MWCNT | | 0.3 % MWCNT | |
| Rectilinear | 100 | 30.2373 | 0.0994 | 36.3186 | 0.3695 | 23.4995 | 1.0808 | 24.0862 | 0.3268 |
| | 50 | 25.9592 | 0.5938 | 25.2734 | 1.6986 | 19.0012 | 0.5130 | 19.9977 | 0.9749 |
| | 20 | 25.2072 | 0.9363 | 19.9707 | 0.3018 | 20.9495 | 0.2715 | 18.0053 | 0.3401 |
| Grid | 100 | - | - | - | - | - | - | - | - |
| | 50 | 26.7472 | 0.5681 | 23.1073 | 0.9099 | 20.2186 | 1.2304 | 21.7171 | 0.5269 |
| | 20 | 2 5.5150 | 0.7989 | 19.9148 | 0.4681 | 18.9734 | 0.3141 | 17.7961 | 0.9515 |
| Full Honeycomb | 100 | - | - | - | - | - | - | - | - |
| | 50 | 26.1897 | 0.1107 | 20.6578 | 0.4669 | 20.4371 | 0.6834 | 20.9092 | 0.7708 |
| | 20 | 26.2377 | 0.5488 | 24.2083 | 1.4890 | 22.3993 | 1.5219 | 20.4867 | 1.4734 |
| Triangular | 100 | - | - | - | - | - | - | - | - |
| | 50 | 30.3416 | 1.0975 | 23.0355 | 0.7118 | 23.0246 | 0.8623 | 21.5058 | 0.3388 |
| | 20 | 28.3037 | 0.9979 | 23.9433 | 0.9875 | 20.4986 | 0.6525 | 19.9256 | 1.6393 |

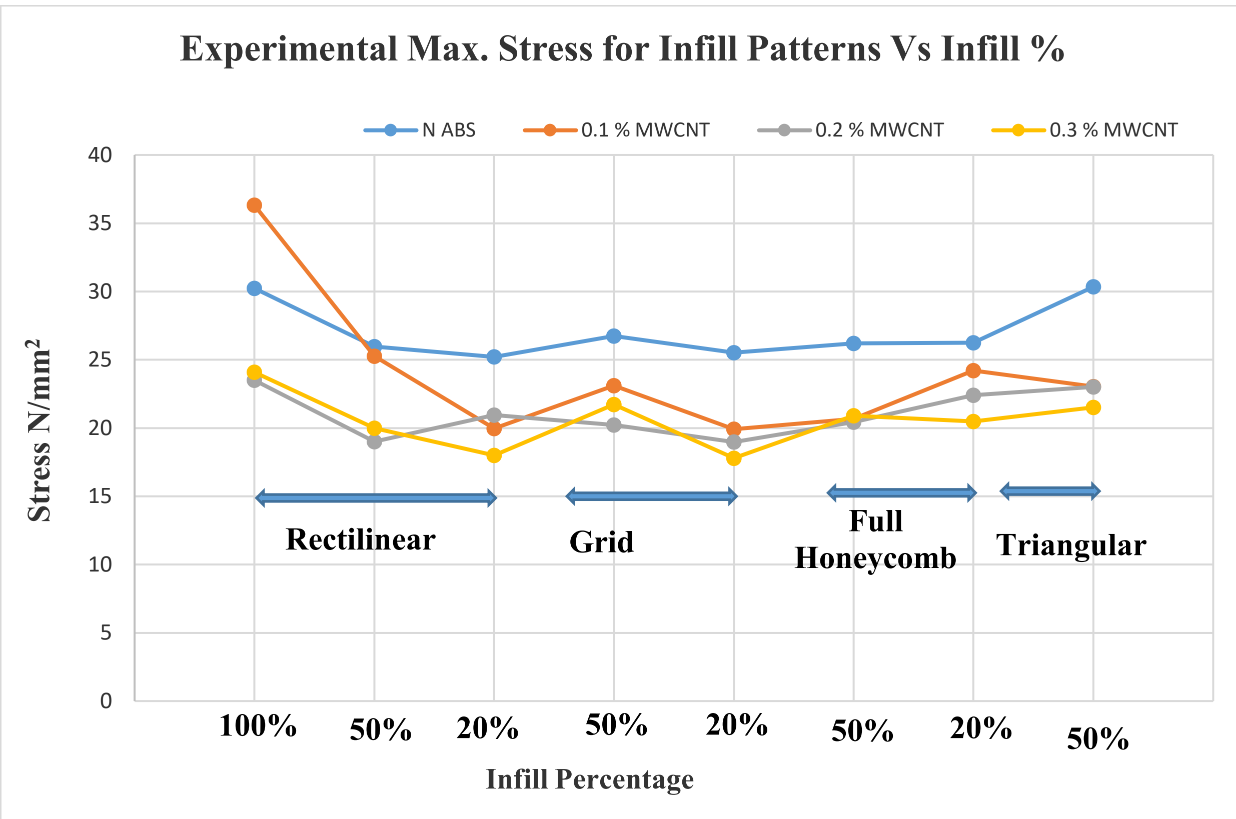
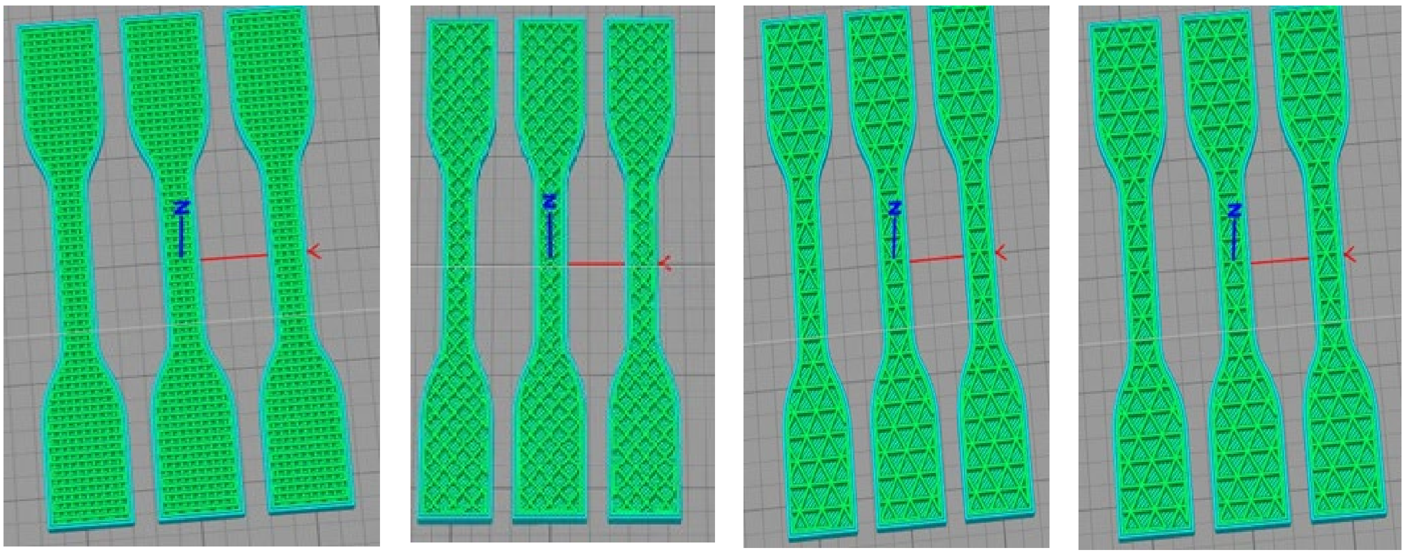



Figure 8: Graph representing maximum stress values for all Infill patterns for all Infill percentages

***Infill pattern:*** When using any infill percentage, a pattern is used to create a strong and durable structure inside the print. There are several different infill pattern options, each with advantages and tradeoffs between print time, material usage or strength of the obtained part.

3D printing software usually provides infill pattern selections for the users. We selected four infill pattern options, including Rectilinear, Grid, Full Honeycomb, and Triangular. For this current research, we printed 3 specimens each with orientation angle of $45^0$ and $-45^0$ for printing. Figure 9 represents appearance of all four infill patterns for their visual clarity.



a)Rectilinear b)Grid c)Full Honeycomb d)Triangular

Figure 9: Appearance of Infill Patterns in 3D Printing

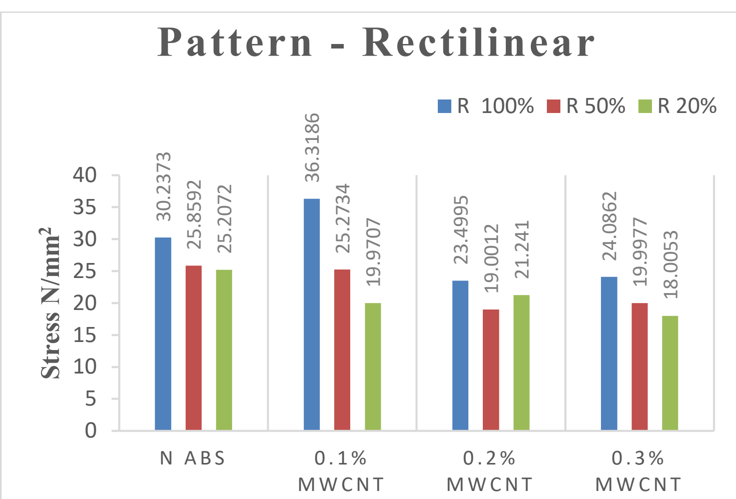



Figure 10 A : Graph representing maximum stress values for Infill Recrilinear Pattern

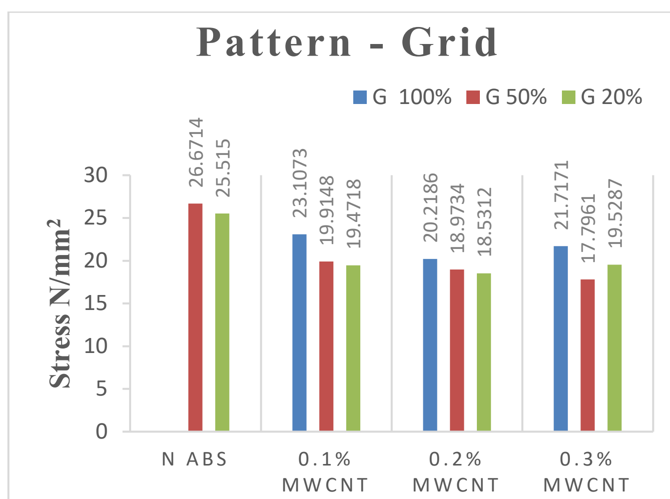



Figure 10 B : Graph representing maximum stress values for Infill Grid Pattern

From above figure 10 A, it can be clearly seen that Rectilinear pattern with 100% infill for nanocomposite material 0.1% MWCNT, shows maximum tensile strength 36.31 MPa and minimum tensile strength 18.00 MPa is obtained by 0.3% MWCNT nanocomposite material with 20% infill.

From above figure 10 B, it can be clearly seen that Grid pattern with 50% infill for natural ABS material shows maximum tensile strength of 26.67 MPa and minimum tensile strength of 17.79 MPa is obtained by 0.3% MWCNT nanocomposite material with 50% infill.

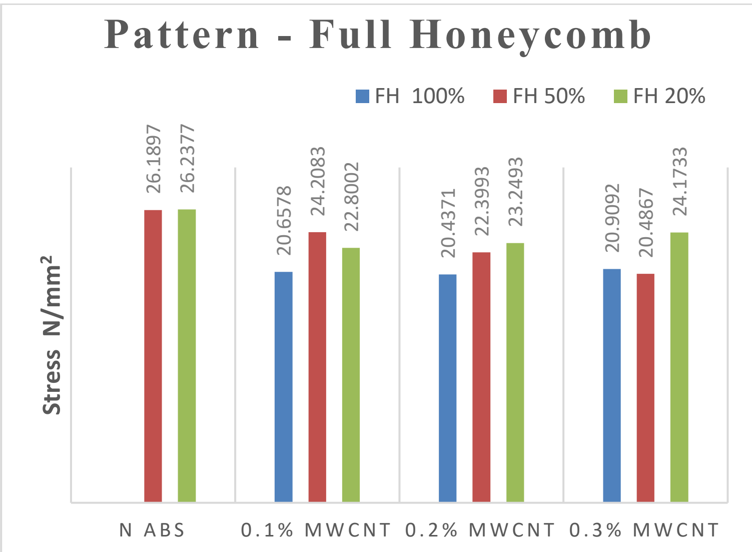



Figure 10 C : Graph representing maximum stress values for Infill Full Honeycomb Pattern

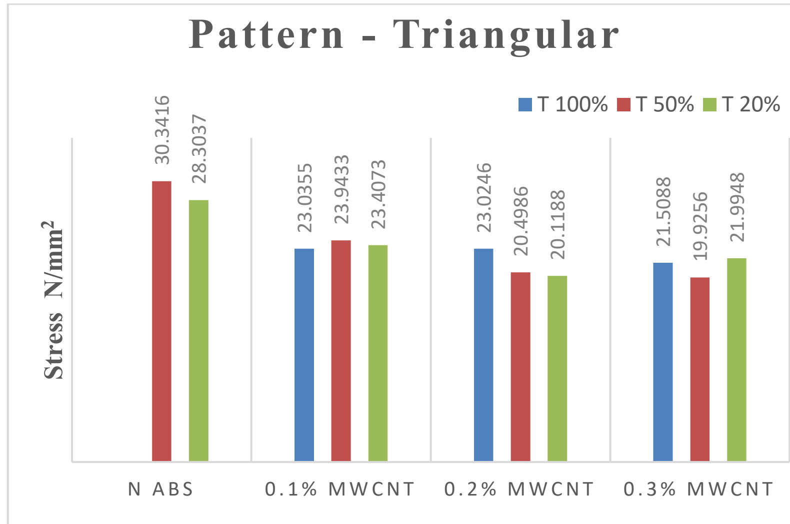



Figure 10 D : Graph representing maximum stress values for Infill Triangular Pattern

From above figure 10 C, it can be clearly seen that Full Honeycomb pattern with 20% infill for natural ABS, shows maximum tensile strength 26.23 MPa and minimum tensile strength 20.43 MPa is obtained by 0.2% MWCNT nanocomposite material with 100% infill.

Figure 10 D shows it can be clearly seen that Triangular pattern with 50% infill for natural ABS material shows maximum tensile strength of 30.34 MPa and minimum tensile strength of 19.92 MPa is obtained by 0.3% MWCNT nanocomposite material with 50% infill.

The specimens failed in between gauge length and cross section of failed area can be observed with rough surface as shown in figure 10. Test speed of 2 mm/min was kept constant for all testing specimens with gauge length of 50mm. Also extensometer was attached with test component to observe the elongation of test specimen. Extensometer has applied a pause of 0.3 mm. during tensile testing.

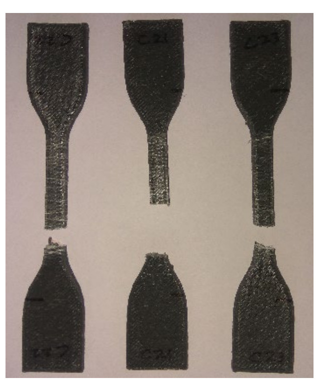


Figure 10: Failed Tensile test specimens (NABS+MWCNTs)

**3.5 Discussion**

SEM imaging shows that MWCNTs were successfully assimilated in ABS material. Tensile test analysis shows significant increase in strength by almost 22 % with 0.1 % wt. of MWCNTs. Also it must be noted that pure ABS sample failed with large amount of plastic deformation while with increase in wt. percentage of MWCNTs the brittleness of the composite also increased which in most situations can be considered as a downside.

MWCNT's strength is about 90GPa along its layer. But clearly this strength was not achieved in the tests. Many reasons can be attributed to this result. All these reasons will be discussed below.

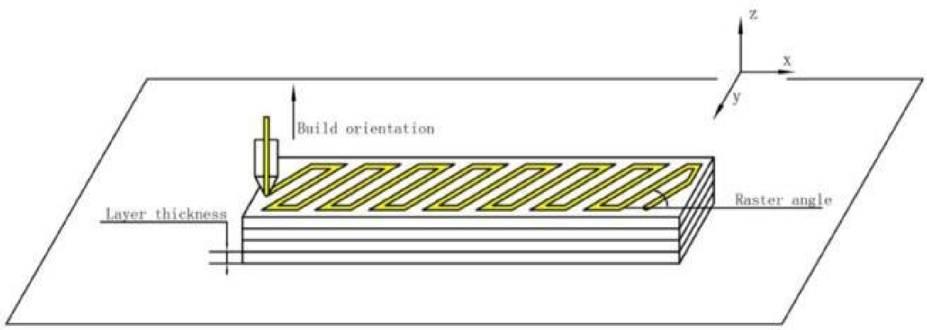



Figure 11: Direction of deposition of material in a 3D printer [3]

While observing the failed specimen it was noted that many samples failed along a 45$^{o}$ angle to specimen's longitudinal axis. It must be noted that sample is printed at 45$^{o}$ angle as it is the standard way of printing according to the infill pattern of G-codes of a 3-D printer. It hints that sample may not have failed because of breaking of layers but by breaking the bond between two layers. Another reason for a premature failure can be that the MWCNT's super strength is along its layer. When it is added in a polymer its 2-D strength is unable to give high strength in a 3-D polymer.

The electrical conductivity test on the composite material shows an increase in electrical conductivity. This is quite improvement in the properties of the nanocomposites. But again if it is compared with the conductivity of MWCNTs, the increment in composite is miniscule.

## CONCLUSIONS

Previous research work shows a significant increase in mechanical and electrical properties of the composite of ABS and MWCNTs nanomaterial. The tensile test showed an increase in strength by 22% .As we increase more weight percentage of the MWCNTS in natural ABS, it is observed decrease in tensile properties of nanocomposites of ABS. Test confirmed the increase in brittleness of the nanocomposites with increment in the percentage of MWCNTs. Also there is increase in electrical conductivity with addition of weight percentage of MWCNTs in the natural ABS.

The tensile properties of 3D-printed nanocomposite parts with four different infill patterns and three different infill percentages were investigated. The effect of structure on its tensile strength was analyzed through mechanical testing. It is observed that, infill 100% for 0.1% MWCNT nanocomposite shows maximum tensile strength among all other variants. As we lower the infill percentage, it shows decrease in tensile strength in all specimens of all different infill patterns, expect some rise in tensile strength is observed in 50% and 20% infill of Triangular pattern specimens.

It can be clearly seen that Rectilinear pattern with 100% infill for nanocomposite material 0.1% MWCNT, shows maximum tensile strength 36.31 MPa and minimum tensile strength 18.00 MPa is obtained by 0.3% MWCNT nanocomposite material with 20% infill , Grid pattern with 50% infill for natural ABS material shows maximum tensile strength of 26.67 MPa and minimum tensile strength of 17.79 MPa is obtained by 0.3% MWCNT nanocomposite material with 50% infill, Full Honeycomb pattern with 20% infill for natural ABS, shows maximum tensile strength 26.23 MPa and minimum tensile strength 20.43 MPa is obtained by 0.2% MWCNT nanocomposite material with 100% infill, Triangular pattern with 50% infill for natural ABS material shows maximum tensile strength of 30.34 MPa and minimum tensile strength of 19.92 MPa is obtained by 0.3% MWCNT nanocomposite material with 50% infill.

A trend seen from experimentation, that tensile strength decreases as infill percentage decreases irrespective of infill pattern. Some unexpected values are also observed and noted from above graphs such as 20% infill of NABS for Full Honeycomb pattern gave maximum value for tensile strength. Our past research matches with this experimentation, as 0.1% MWCNT nanocomposite gives maximum value and further 0.2% & 0,3% MWCNT nanocomposite shows minimum value for tensile strength. When comparing the infill patterns, overall Rectilinear infill pattern shows satisfactory test results for tensile test as compared with other infill parts. 0.1% MWCNT specimens with Rectilinear infill pattern gave the best result in terms of tensile strength. 0.2% and 0.3% specimens with different infill patterns shows decrease in tensile strength and can be correlated with our past research work.

Overall, all the infill patterns and percentages combinations showed similar behavior with exception solid (100%) infill pattern. This study also reveals that infill Vs printing time, it is observed that the maximum printing time occurred for 100% infill percentage for all selected infill patterns. For more than 50% infill, complex infill pattern specimens can take more time for 3D printing due to complex movement that printer has to make in order to print the patterns inside the specimen. The material consumption in 3D printing of different infill pattern and percentage components.

Future research work can be carried out with flexural testing of same set of components to study effect of infill patterns and percentage on its flexural properties. Also strain gauges can be set on tensile test specimen to verify and study its Poison’s ratio as a material property.

## ACKNOWLEDGEMENT

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