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Microstructural Finite Element Analysis for Fibre Orientation Optimization in Composite

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Abstract – *Basically In this Paper we are using Microstructural Finite Element analysis for Optimization of Fibre orientation in laminates of composite. Specific type of composite is used to evaluate, composite is made from three different material compositions. Epoxy, Nylon, Graphene are used in different structure. Ansys workbench is used for analysis, Numerical Optimization method is used to for Optimization. Ansys Workbench is used for Finite Element Analysis.*

Key Words: Microstructural FEA, Composite, Ansys, Numerical Optimization Method

1. INTRODUCTION

By inclusion of particulate composite layers in fibre composite flexibility increases as compared to other reinforced composites. Normally it contains a high modulus fiber with low modulus Particles. The high-modulus fiber provides the stiffness and load bearing qualities, whereas the low-modulus particles make the composite more damage tolerant and keeps the material cost low. It also helps to reduce weight without sacrificing strength and improves electrical and thermal characteristics of the composite material. The mechanical properties of a hybrid composite can be varied by changing volume ratio and stacking sequence of different plies. De-lamination is major problem which is observed in fibre reinforced composite is reduced by including particulate composite layers because of increasing adhesion forces between consecutive layers of the composite.

Fibre Orientation angle in Composite laminates plays an important role in for designing the Elastic properties of composite. Optimum fibre angle will help to finding directional strength, that will help to design composite for different application. Here we are using a specific type of structure of composite, Elements namely Pellet, Wire and Matrix Basically made form Graphene, Nylon and Epoxy.

1.1 Composite Structure

Basically, composite has thousands of fibre and Particles in its single layer. Here we could not simulate the Microstructural Finite Element analysis for such large extent as there will be crore of node and element. For solving we will require large work stations. Considering this issue, we are considering just small part of that composite having two layers with two fibre and Particles. Here we are describing composite structure in 3 elements as Pellet, Wire, Matrix. Their structure as follows

1. **Pellet:**

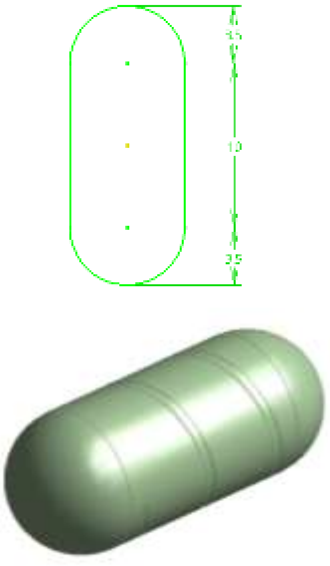


Fig.1: Pellet

It is basically a cylinder-shaped particle with hemispherical shape ends. Pellets are made up of high strength material Mostly they have high density. Here we are using Graphene as Pellet Material (E=1050 GPa μ=0.18). The volume fraction of the pellet is low as compare to the matrix (around 7-10%) basically Pellet is the reinforcement in the Matrix for increasing strength of the composite. They have a Cylindrical shape which gives Composite different strength in the different direction. Cylindrical shape with hemispherical end structure having volume 563.47 mm3. Some amount of material is removed from Pellet periphery for avoiding meshing complexity and wire can easily fit in that slot.

2. **Wire:**

Wire is also made up of high strength material but less than Pellet material and having low weight. Here we are using Nylon as wire Material (E=3GPa μ=0.39). The main purpose of wire is the connect one Pellet to Other for force Transmission. The wire has lowest volume contribution (around 2-3%). The directional alignment of wire gives different property in a different direction, the wire along with the pellet affect the properties of the composite with the angle they make relative to the force. That's how this type of Composite is considered as anisotropic material. We are making a specific pattern of pellet such that it will also contribute to directional strength. In this composite, we have arranged pellets in line and they are connected by a wire. Helix command is used for making the spiral shape of wire with 4mm pitch value and 8 mm total length of helix axis. Wire diameter is 1.6 mm. Wire solid having volume 187.26mm3

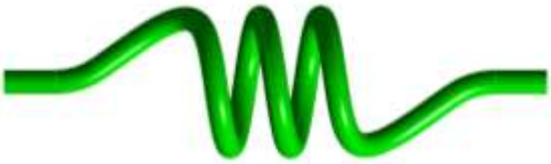


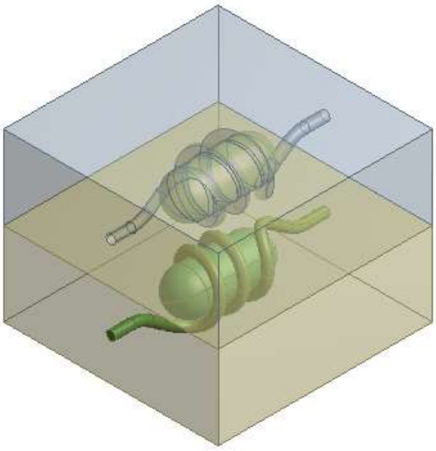
Fig.2: Wire 3D Model

3. Matrix:

Block of soft material with low density, whose strength is increased by using other reinforcement. Here we are using Epoxy as Matrix Material. (E=3.5GPa μ=0.33) The volume fraction of Matrix is highest in composite (around 90%). The other reinforcement is reinforced in Matrix as per requirements of the composite. Composite Structure different views for zero-degree angle:

(a)

(b)



(c)

Fig.3: Composite Structure Iso view

Here we are changing the angle of Fibre to longitudinal axis from 0 to 45 with interval of 5-degree total 10 structures. Structure for 10-degree angle:

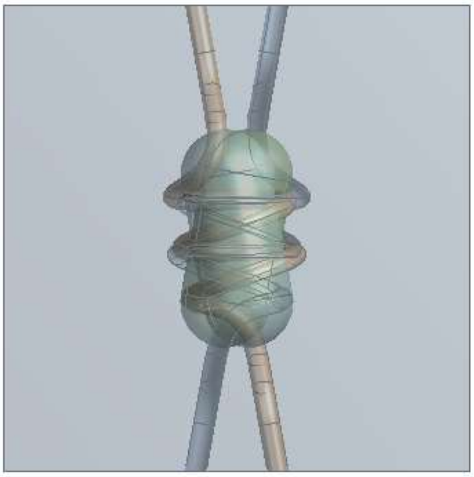


Fig.4: Fibre Orientation 10°

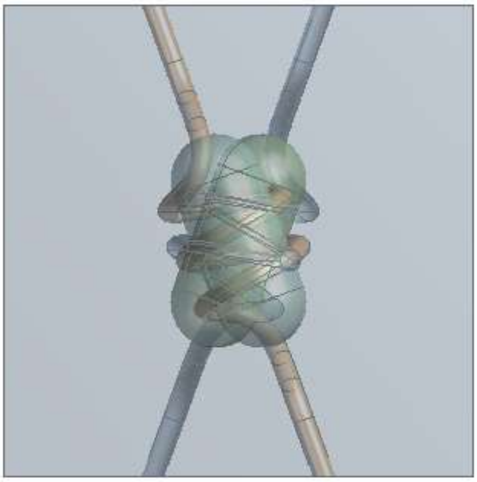


Fig.5: Fibre Orientation 20°

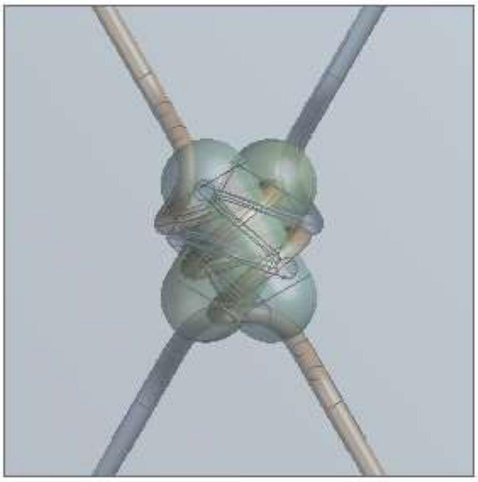


Fig.6: Fibre Orientation 30°

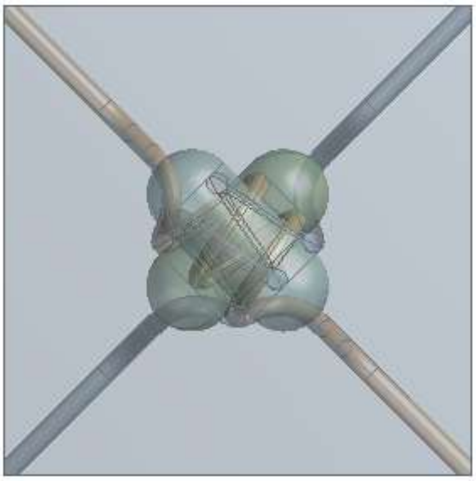


Fig.7: Fibre Orientation 45°

2. Microstructural Finite Element Analysis

Here for FEA we are using Ansys workbench. As it is difficult to model in Ansys Design Modeler we used CATIA modeling. Then step file imported to Workbench. Basically 0.5 (500µm). Hex with mid node (solid 186) is used for meshing. After mesh around 4.5 lacks element with 16 lacks were created. Solid are not glued to each other, they are having sliding contact so No Separation Contact used.

2.1 Boundary Conditions and Loading

For Finding the Normal deformation and stress we are fixing the Negative side of Block and Appling 2N force in Positive direction of the block.

For X Direction: we are fixing the Negative X side of Block and Appling 2N force in Positive X direction of the block.

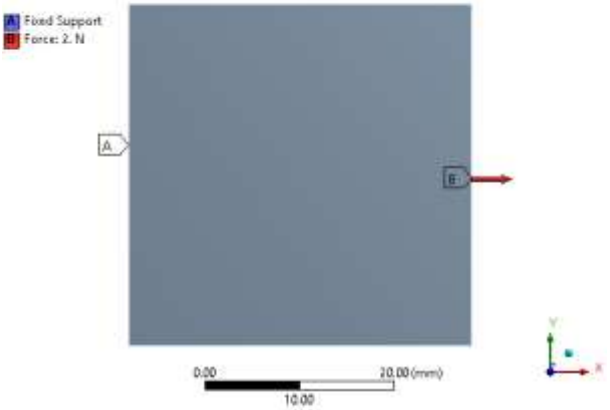


Fig.7: BCs and Loading In X- Direction

For Y Direction:

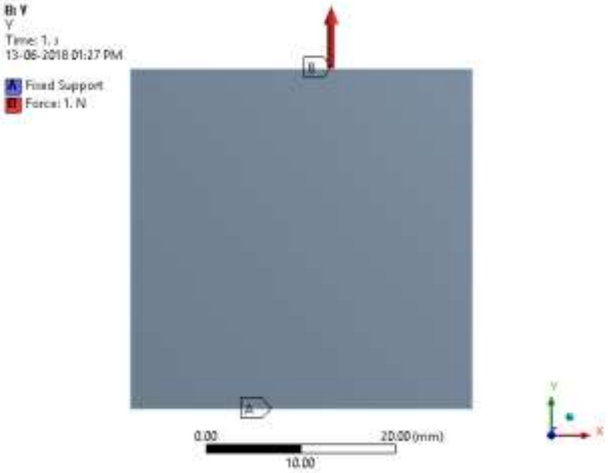


Fig.8: BCs and Loading In Y- Direction

For Z Direction:

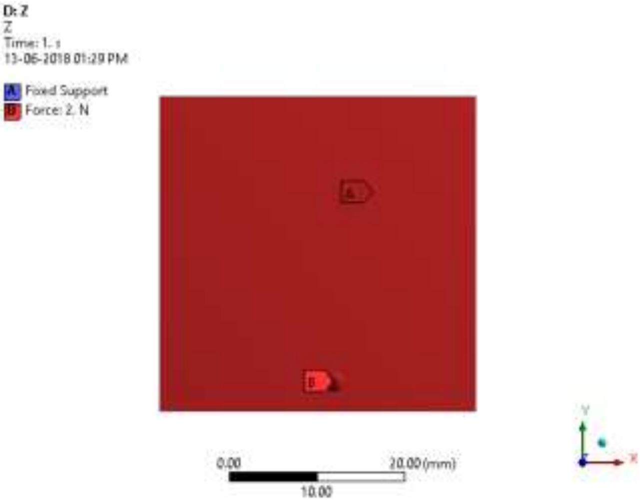


Fig.9: BCs and Loading In Z- Direction

2.2 Analysis Results for 0° Orientation

For X Direction:

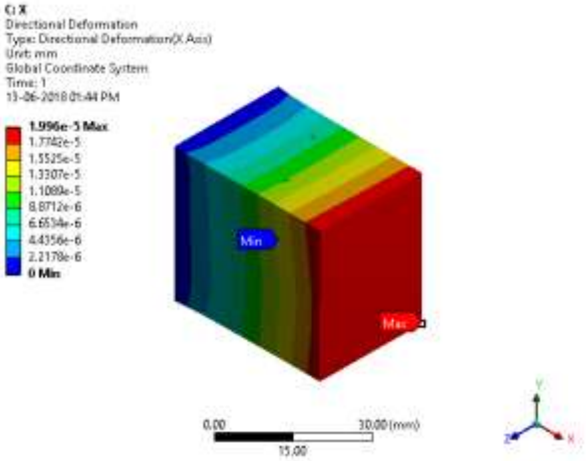


Fig.10: Directional Deformation in X - Direction

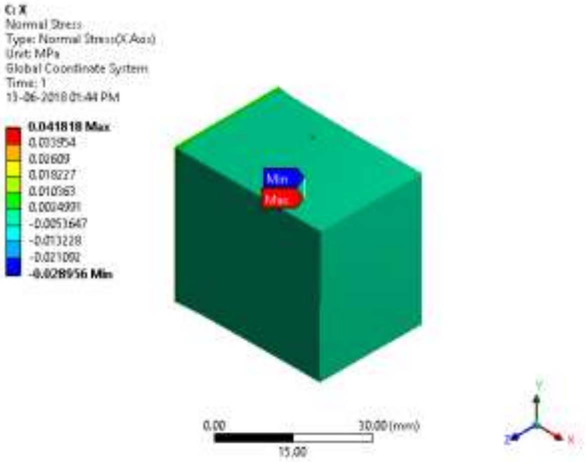


Fig.11: Normal Stress in X- Direction

For Y Direction:

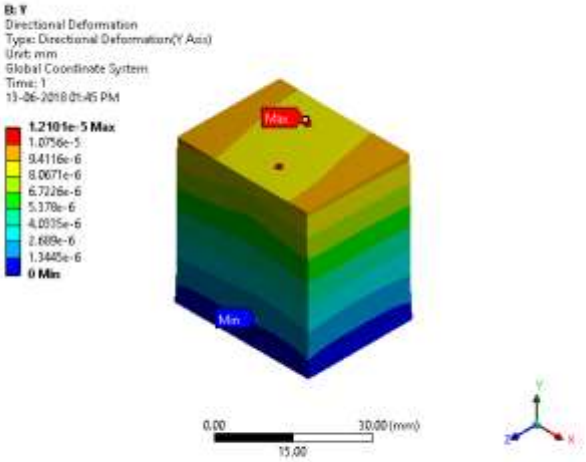


Fig.12: Directional Deformation in Y - Direction

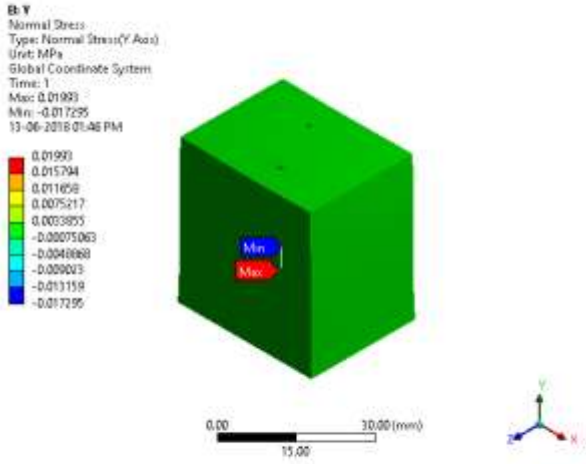


Fig.13: Normal Stress in Y- Direction

For Z Direction:

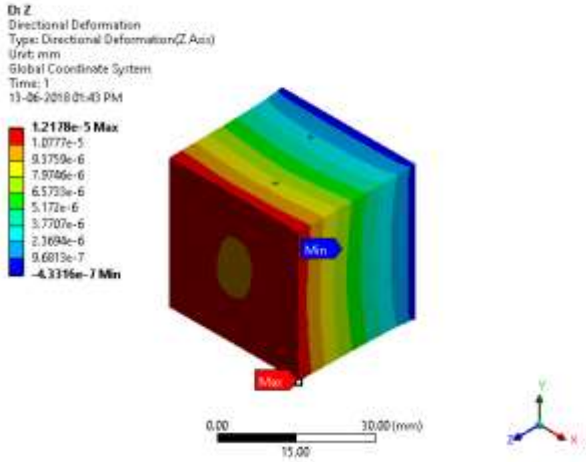


Fig.14: Directional Deformation in Z - Direction

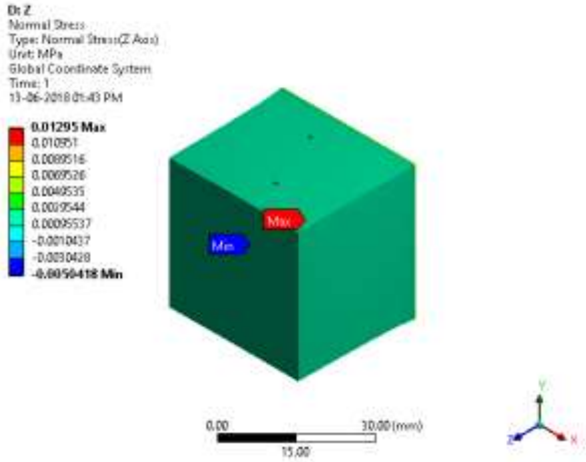


Fig.15: Normal Stress in Z- Direction

Table -1: Result Table When Loaded in X Direction

Angle	Directional Deformation (mm)	Normal Stress (MPa)
0	0.0000117175	0.032618
5	0.000012101	0.036854
10	0.00001219	0.041818
15	0.000012326	0.053318
20	0.000013993	0.057414
25	0.000012365	0.060103
30	0.000012586	0.067904
35	0.000012971	0.067509
40	0.000011319	0.068075
45	0.000012101	0.067612

Table -2: Result Table When Loaded in Y Direction

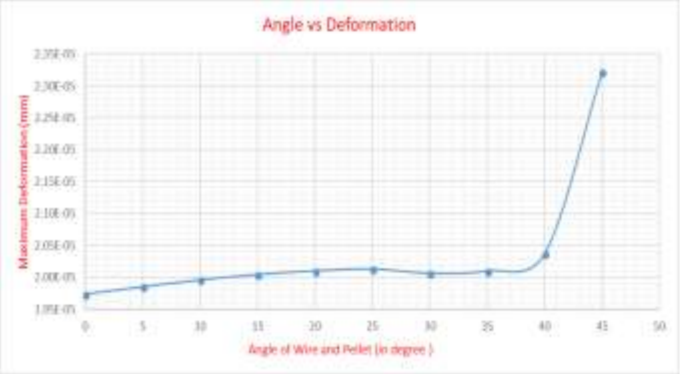
Angle	Directional Deformation (mm)	Normal Stress (MPa)
0	0.0000117175	0.0079445
5	0.000012475	0.010276
10	0.000012101	0.013799
15	0.00001219	0.015913
20	0.000012326	0.019356
25	0.000013993	0.027548
30	0.000012365	0.021605
35	0.000012586	0.030078
40	0.000012971	0.033145
45	0.000011319	0.035515

Table -3: Result Table When Loaded in Z Direction

Angle	Directional Deformation (mm)	Normal Stress (MPa)
0	0.000012156	0.012569
5	0.000012167	0.013476
10	0.000012178	0.01295
15	0.00001219	0.011116
20	0.000012202	0.013151
25	0.000012216	0.0097828
30	0.000012226	0.01115
35	0.000012235	0.012462
40	0.000012245	0.011963
45	0.000012251	0.012831

Graphs:

For X direction



Graph no 1: Angle vs Deformation (X-Direction)

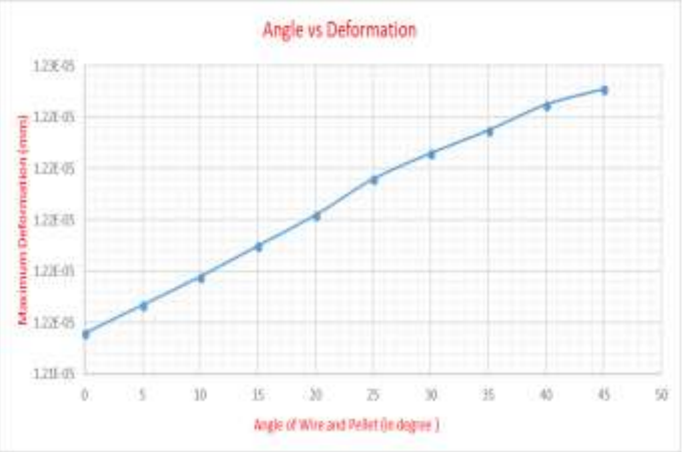
Graph no 2: Angle vs Normal Stress (X-Direction)

For Y Direction:

Graph no 3: Angle vs Deformation (Y-Direction)

Graph no 4: Angle vs Normal Stress (Y-Direction)

For Z Direction:



Graph no 5: Angle vs Deformation (z-Direction)

Graph no 6: Angle vs Normal Stress (Y-Direction)

From above Result table and Graphs what we are getting is that the behavior of composite is not similar in all three directions. So, we could not conclude the best angle by considering a single result table or Single graph. We needed the result that is optimized by using all three directions. For that we are using Numerical Optimization Technic.

3. Numerical Optimization

For X Directional Result We are dividing the same column with column Maximum for both Deformation and Normal Stress.

Maximum Deformation: 0.000023215 mm

Maximum Normal stress: 0.068075 MPa

After dividing by these two values to their respective column we are having Relative Deformation and Relative Normal Stress. Shown in next column:

Angle	Relative Deformation	Relative Stress
0	0.850226147	0.479147999
5	0.855222916	0.541373485
10	0.85978893	0.614293059
15	0.863493431	0.783224385
20	0.865905664	0.843393316
25	0.867197932	0.882893867
30	0.864311867	0.997488065
35	0.865905664	0.991685641
40	0.877536076	1
45	1	0.993198678

While l Designing the composite material, we give more importance for deformation rather than stress value. So, we are adding importance factor here as:

Importance Factor:

Deformation: 0.7

Normal Stress :0.3

Then we will multiply both column with respective importance factor. Then we are having another two columns Deformation (Importance) and Stress (Importance), and in the last column we have taken Sum of these two for calculating Net value in X- Direction.

Angle	Deformation (Importance)	Stress (Importance)	Net Value
0	0.5951583	0.143744	0.738903
5	0.59865604	0.162412	0.761068
10	0.60185225	0.184288	0.78614

15	0.6044454	0.234967	0.839413
20	0.60613397	0.253018	0.859152
25	0.60703855	0.264868	0.871907
30	0.60501831	0.299246	0.904265
35	0.60613397	0.297506	0.90364
40	0.61427525	0.3	0.914275
45	0.7	0.29796	0.99796

Then we will calculate the same Net value for Y and Z Direction, and at last column in next table we will have NET sum.

Angle	Net X	Net Y	Net Z	Net Sum
0	0.7389027	0.6532763	0.6532763	2.0454553
5	0.76106809	0.7108647	0.7108647	2.1827976
10	0.78614017	0.7219146	0.7219146	2.2299695
15	0.83941272	0.7442241	0.7442241	2.3278610
20	0.85915196	0.7801110	0.7801110	2.4193740
25	0.87190671	0.9327016	0.9327016	2.7373100
30	0.90426473	0.8010596	0.8010596	2.5063839
35	0.90363966	0.8836877	0.8836877	2.6710151
40	0.91427525	0.9288547	0.9288547	2.7719847
45	0.9979596	0.8662331	0.8662331	2.7304258

While designing composite we design for minimum value of deformation and stress. So here will consider the minimum value of Net Sum which is 2.0454553 and the respective angle 0° is the Optimum angle considering all three directions.

4. CONCLUSIONS

By this paper its conclude the use of Finite Element analysis of composite laminate for finding out optimum angular orientation of fibre in particulate included composites is very useful. Here for this Specific Microstructure Zero Degree fibre Orientation is optimum. The combination Microstructural FEA and Numerical Optimization suit bests for this type of analysis. Microstructural FEA should be preferred for composite analysis.

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