Development of Glass Fiber Composite with Secondary Inter laminar Nanofiber Optimization and Reinforcement to improve impact strength.

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***Abstract*: Fiber Reinforced Polymers (FRPs) have demonstrated their structural efficiency since their successful adoption in high-speed trains in Japan during the 1980s. Owing to their lightweight nature, high specific strength, superior corrosion resistance, and cost effectiveness, FRPs have gained extensive applications in the automobile, aerospace, high-speed transportation, and construction industries. The present research focuses on the development and characterization of lightweight, high-strength fiber-glass composite laminates suitable for construction applications. Advanced laminated composites are fabricated using the Vacuum Assisted Resin Transfer Molding (VARTM) process, incorporating electrospun interlaminar nanofibers to enhance mechanical performance. Nano-layered and conventional fiber-glass composite laminates are developed and experimentally evaluated, with particular emphasis on impact strength. A comparative assessment is carried out to understand the influence of electrospun nanofiber interlayers on energy absorption and damage resistance. The versatility of the VARTM process allows scope for extending this research to various synthetic fibers and advanced composite systems for future construction applications.**

Keywords: Fiber Reinforced Polymers, electrospun nanofiber, VARTM

I. INTRODUCTION

Fiber reinforced polymer proved their capabilities after adopting their use for high speed trains in Japan during 1980s.Since then the FRPs broadened their applications in automobile industries, high speed transportation, aerospace industries, construction etc. Due to their light weight & extra ordinary corrosion resistance, cost effective nature brought them in highest priority for construction. This research emphasizes on development and characterization of light weight, high strength composite material to get an edge in competition, cost effective advanced laminated composite materials having high specific stiffness and suitable for construction applications.This research envisages Development of Fiber-Glass Composites using Vacuum Assisted Resin Transfer Molding (VARTM) with Interlaminar Nanofibers produced by Electrospinning. Testing it with and without Nano-Layered FG composites for impact strength will be carried out. VARTM is versatile composite manufacturing process and thus for various types of Fibers of Synthetic, research can be extended over the period for possibly several potential.

A. Problem Definition

This research envisages introduction of Interlaminar nanofiber layers to improve impact strength in FG Composites produced by VARTM

B. Objectives:

1) To optimize nano fiber size to enhance impact strength of glass fiber with and without interlaminar nanofibers using Vacuum Assisted Resin Transfer Molding (VARTM).

2)To develop different laminated glass fiber composites based on weave pattern impregnated with epoxy resin with and without interlaminar nanofibers using Vacuum Assisted Resin Transfer Molding (VARTM).

3) To analyze impact strength of glass fiber composites based on weave pattern impregnated with epoxy resin with and without interlaminar nanofibers using Vacuum Assisted Resin Transfer Molding (VARTM), experimentally.

II. METHODOLOGY

A. Secondary Interlaminar Nano fiber:

Material details for obtaining Secondary Interlaminar Nanofiber

PVA Solution (by 5 wt. %), 5wt. % of PVA powder + 95 wt.% of H2O.

B. Designconditions:

TABLE I. DESIGN CONDITIONS

Glass Fiber	SecondaryNano fiber	Epoxy Resin (Matrix)	Orientation of layers	Mfg. Method	Mechanical Tests
Glass Fiber 200 gsm, Palin weave	PVA	Base – LY 556 + hardener HY 951	0^0, $0^0/90^0$	VARTM	Impact Strength
Glass Fiber 220 gsm Palin weave					
Glass Fiber 300 gsm Palin weave					
Carbon fabric 200 gsm, Twil weave					

TABLE II. COMPOSITION OF DIFFERENT COMPOSITE MATERIALS BY WEIGHT:

Epoxy Resin (wt. %)	Fiber (wt. %)	Secondary Nano fiber (wt. %)
60	40	0
60	39	1

Weight Fraction of Composite (60::40)

C. Specimen preparation without considering Secondary Nano fibers.

Considered three types of Glass-fibers for making specimen:

GlassFiber-200GSM with thickness 0.10 mm

Glass Fiber – 220 GSM with thickness 0.17 mm

Glass Fiber – 300 GSM with thickness 0.24 mm

Required thickness=10mm

a) For 200 GSM, have 0.10 mm thickness

To form 10 mm thickness, layers of fabric required = 10/0.10 = 100 layers

Considering approximately 101 layers, out of which 51 layers are of 200 GSM fabric and remaining 50 layers are (resin + hardner) with thickness approximately 0.10 mm.

1 layer weight of fabric=0.5075gm

Total weight of 50 layers of (resin + hardner)=25.375gm

Out of 25.375gm,60 percent is Resin and 40 percent is hardner.

60 percent of 25.375=15.225gm Resin

40 percent of 25.375 = 10.15 gm hardner

b)Glass Fiber 220 GSM, have 0.17mm thickness to form10mm thick,

l layers of fabric required=10/0.17=59 layers

Considering approximately 59 layers, out of which 30 layers are of220 GSM fabric and remaining 29 layers are of (resin+hardner) with thickness approximately of 0.17mm.

1 layer weight of fabric=0.9785gm

Total weight of 29 layers of (resin+hardner)=28.635gm

Out of 28.635 gm, 60 percent is Resin and 40 percent is hardner.

60 percent of 28.635=17.185gmResin

40 percent of 28.635 = 11.45 gm hardner

c) Glass Fiber 300 GSM,with thickness0.24mm

To form 10 mm thickness,layers of fabric required=10/0.24=41layers

Considering approximately 41 layers, out of which 21 layers are of300 GSM fabric and remaining 20 layers are of (resin+hardener) with thickness approximately of 0.24mm.

1layer weight of fabric=3gm

Total weight of 20 layers of (resin+hardner) = 60gm Out of 60gm,60 percent is Resin and 40 percent is hardner.60 percent of 60 =36gm Resin

40 percent of 60=24gmhardner

D. Specimen preparation considering Secondary Nano fibers by VARTM process.

Weight Fraction Ratio (59:01:40)

Fabric:(Resin+Hardener):Nanofiber = 59:40:1 by weight We have taken three types of Glass-fibers for making specimen:

Glass Fiber - 200 GSM with thickness 0.10 mm

Glass Fiber – 220 GSM with thickness 0.17 mm Glass Fiber – 300 GSM with thickness 0.24 mm

Required thickness = 10 mm

a) For 200 GSM, have 0.10 mm thickness

To form 10 mm thickness, layers of fabric required = 10/0.10 = 100layers

Considering approximately 101 layers, out of which 51 layers are of 200 GSM fabric and remaining 50 layers are of (resin+hardner) with thickness approximately of 0.10 mm.

1 layer weight of fabric = 0.5075 gm

Total weight of 50 layers of (resin+hardner) = 25.375 gm

Out of 25.375 gm, 59 percent is Resin and 40 percent is hardner and1 percent Nanofiber.

59 percent of 25.375 = 15.225 gm Resin

40 percent of 25.375 = 10.15 gm hardner

1 percent of 25.375 = 0.25375 gm nanofiber

b)For 220 GSM, have 0.17 mm thickness

To form 10 mm thickness,

layers of fabric required = 10/0.17 = 59 layers

Considering approximately 59 layers, out of which 30 layers are of 220 GSM fabric and remaining 29 layers are of (resin+hardner) with thickness approximately of 0.17 mm.

1 layer weight of fabric = 0.9785 gm

Total weight of 29 layers of (resin+hardner) = 28.635 gm

Out of 28.635 gm, 59 percent is Resin and 40 percent is hardner and1 perecnt Nanofiber.

59 percent of 28.635 = 17.185 gm Resin

40 percent of 28.635 = 11.45 gm hardner 1 percent of 28.635 = 0.29355gm Nanofiber

c)For 300 GSM, have 0.24 mm thickness

To form 10 mm thickness,

layers of fabric required = 10/0.24 = 41 layers

Considering approximately 41 layers, out of which 21 layers are of 300 GSM fabric and remaining 20 layers are of (resin+hardner) with thickness

approximately of 0.24 mm.

1 layer weight of fabric = 3 gm

Total weight of 20 layers of (resin+hardner) = 60 gm

Out of 60 gm, 59 percent is Resin and 40 percent is hardner and 1 percent nanofiber.

59 percent of 60 = 35.4 gm Resin

40 percent of 60 = 24 gm hardner

1 percent of 60 = 0.6 gm Nanofiber

considering above weight frcation specimens prepared using VARTM process.

III. EXPERIMENTATION

A. Production of Nano Fibers using Electro Spinning Machine

Electro spinning is a non-contact drawing process in which a solution droplet emanating from the tip of spinneret is attracted towards a grounded collector under the action of electrical potential difference applied [18–23 kV]. The electro-hydrodynamic forces cause the droplet to elongate under bending instability and whipping to produce fibers of nano-scale diameter (nanofibers) with exceptionally long lengths. Evaporation of solvents takes place as the nanofibers are deposited on a grounded collector. Fig. 1 shows the schematics of the electro spinning setup whereas Fig. 2 shows the actual laboratory electro spinning setup. This setup has four operating components involved actively during the process of electro spinning: the spinneret which is kept at positive potential; the collector plate that is grounded; the high voltage supply that maintains the potential difference between interaction of surface charge and surface tension causes the spherical droplet to stretch into a conical shape called “Taylor Cone” [13].The tip of Taylor cone has the lesser surface area but is under the influence of same voltage potential. Thus the tip of cone is elongated into a charged jet which on further increase in length and reduction of diameter experiences “bending instability” [13]. Bending instability is caused by the non-linear characteristics of electric charge and dynamics of fiber jet. Under the action of bending instability, the charged jet undergoes whipping that causes further elongation and reduction in diameter of fiber with evaporation of solvents.

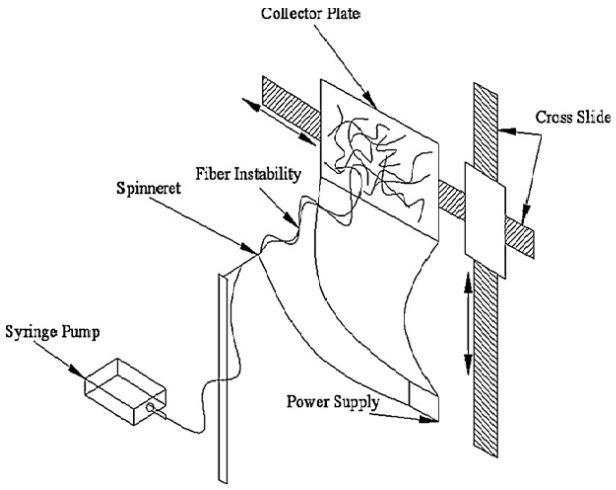

Fig. 1. Schematic of Electro Spinning setup

Fig. 2. Electro spinning Laboratory setup

Parameters for changing the Nano fiber size using Electro spinning setup

Basic input material for obtaining nano fibers: PVA Solution (by 5 wt. %) - 5wt. % of PVA powder + 95 wt.% of H2O

By varying input Voltage

By changing distance between tip of needle and flat plate collector

Specifications of electro spinning setup:

Drum speed range - 500- 4000 rpm

Flow rate - 0.1ml/hour to 199ml/hour

Syringe Size - 2 ml, 5 ml& 10ml

Flow rate setting -0.1ml /hrto1mL/hr

TABLE III. SAMPLE WITH DISTANCE BETWEEN TIP OF NEEDLE, FLAT PLATE COLLECTOR AND INPUT VOLTAGE

Sr. No.	Sample Number	Distance between tip of needle & plate collector (mm)	Input voltage(Kv)	Flow Rate of PVA solution through nozzle,	Average Nano fiber size obtained (nm)
1	Sample 1	140	17	0.5 ml/hr	101.85
2	Sample 2	140	18		97.12
3	Sample 3	140	19		93.58
4	Sample 4	110	17		84.23
5	Sample 5	110	18		82.37
6	Sample 6	110	19		86.96
7	Sample 7	80	17		237.17
8	Sample 8	80	18		266.29
9	Sample 9	80	19		276.24

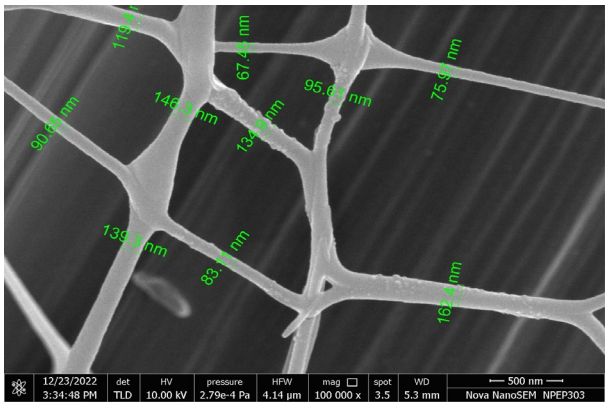

Fig. 3. Image of nono fibers for sample no.1

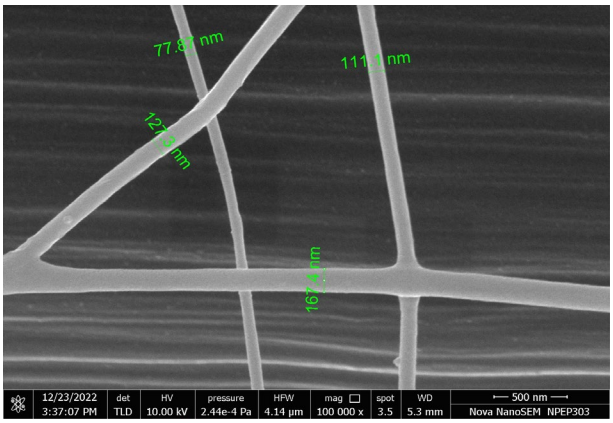

Fig. 4. Image of nono fibers for sample no.3

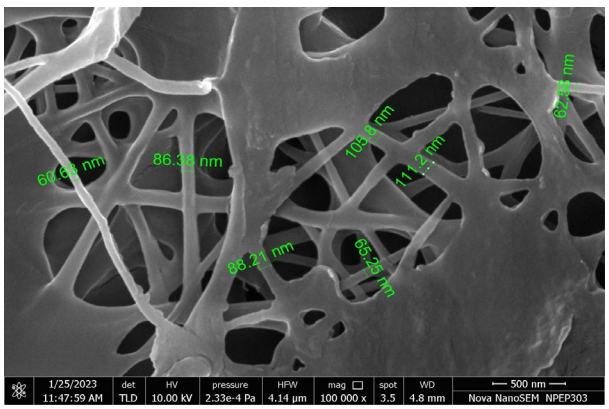

Fig. 5. Image of nono fibers for sample no.5

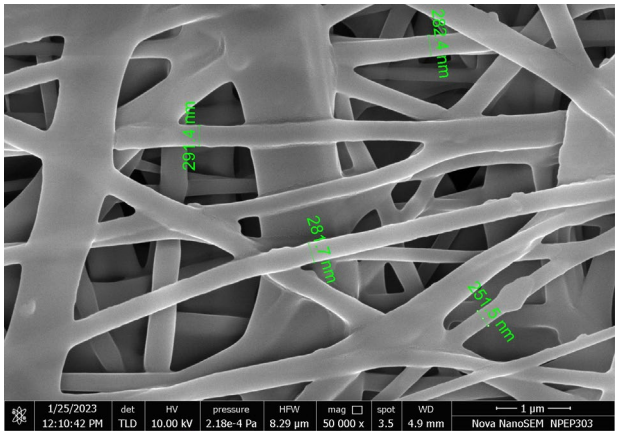

Fig. 6. Image of nono fibers for sample no.9

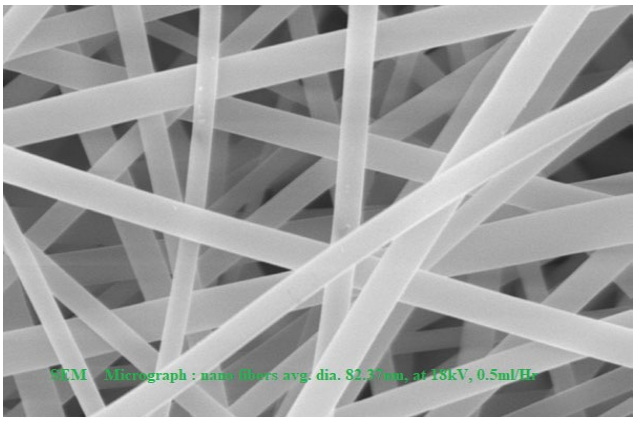

Fig. 7. Image of micrograph for minimum nanofiber size

Above fig. shows SEM micrograph of the nanofibers produced by the electrospinning process. A voltage of 18 kV and a distance of 110mm between the tip of the spinneret and the collector plate were found to produce the minimum diameter nanofibers of avg. diameter 82.42 nm.

1) To fabricate glass fiber composite with epoxy resin using VARTM process (900 Orientation)

Basic input materials used

a) Fiber Materials:

i)Glass Fiber 200 gsm, Palin weave

ii) Glass Fiber 220 gsm Palin weave

iii)Glass Fiber 300 gsm Palin weave

b) Epoxy resin and Hardner:

EpoxyResinLY-556

Hardener HY951

TABLE IV.

Sr. No.	Sample details	Epoxy Resin (wt. %)	Fiber (wt. %)	Nano Fiber (Wt.%)
1	Glass Fiber 200 gsm, Palin weave	60	39	1
2	Glass Fiber 220 gsm Palin weave	60	39	1
3	Glass Fiber 300 gsm Palin weave	60	39	1

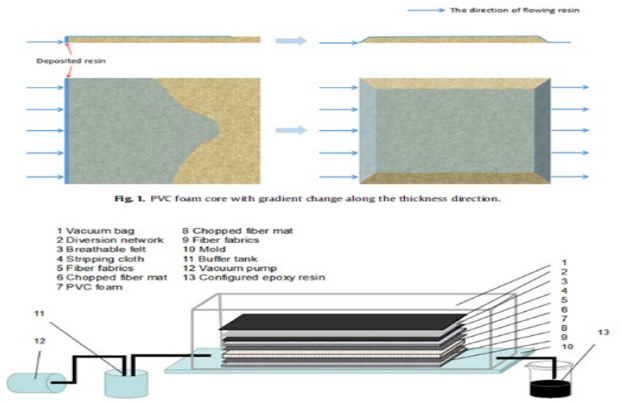

Fig. 8. Working of VARTM Setup

B. Impact Test :

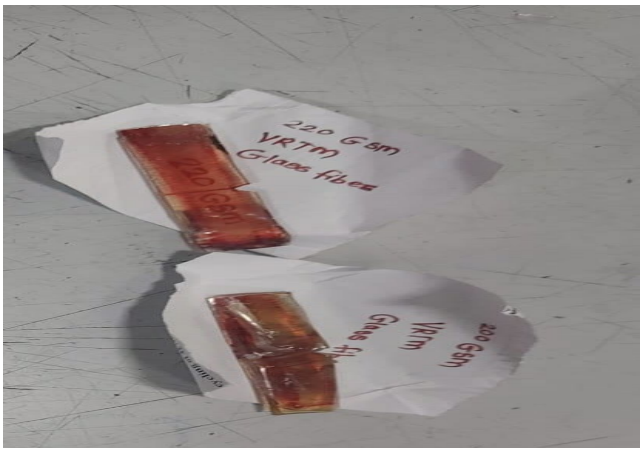

Fig. 9. Specimen made by VARTM for impact test

Fig. 10. Impact Test Setup

IV. RESULT AND DISCUSSION

TABLE V. COMPARISON OF IMPACT TEST RESULTS (IZOD)

Test	Actual					
	200 GSMwithout Nano fibers	200 GSMwith Nano fibers	220 GSMwithout Nano fibers	220 GSM with nanofiber	300 GSM without nanofiber	300 GSM with nanofiber
Izod Impact Strength J/m	1133.33	1490.90	1194.44	1272.72	1232	1302

TABLE VI. COMPARATIVE RESULTS OF IMPACT STRENGTH VS PROCESS USED TO MANUFACTURE SPECIMEN WITH DIFFERENT GSM :

Sr. No.	Test Details	Specimen with 200 GSM Glass Fiber	Specimen with 220 GSM Glass Fiber	Specimen with 300 GSM Glass Fiber
1	Impact strength of specimen prepared by Hand Layup process without considering Secondary Nano fibers (Joules/m)	1133.33	1194.44	1232
2	Impact strength of specimen prepared by VARTM processes without considering Secondary Nano fibers (Joules/m)	1490.90	1272.69	1302
3	Impact strength of specimen prepared by VARTM processes with considering Secondary Nano fibers (Joules/m)	1532.46	1316.84	1305.02

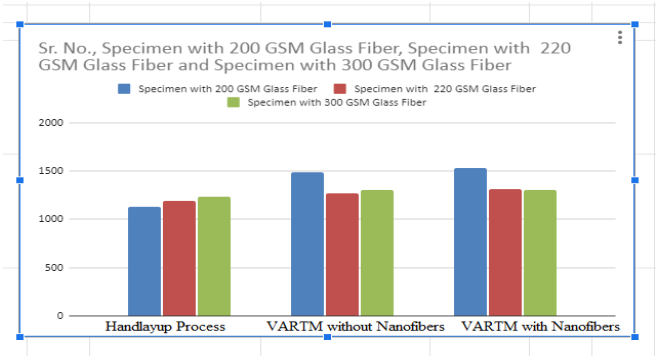

Fig. 11. Impact strength Vs Process used to mfg. specimen with different GSM

TABLE VII. COMPARATIVE RESULTS OF IMPACT STRENGTH OF 200 GSM GLASS FIBER WITH DIFFERENT MFG. TECHNIQUES

Mfg. Tech. Used / Test Details	Hand layup Processes	VARTM processes without nano fibers	VARTM processes with nano fibers	% increase in Strength
Impact strength of specimen for 200 GSM (Joules/m)	1133.33	1490.90	1532.46	2.78% to 35.25%

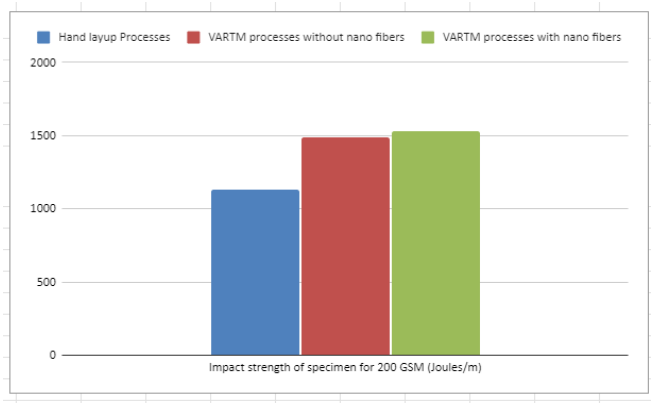

Fig. 12. Impact strength Vs Process used to mfg. specimen with 200 GSM

V. CONCLUSION:

From the above test results, it is found that the specimen prepared with considering secondary nano fibers with Glass Fiber has more strength compared to specimen prepared without nano fiber by VARTM process.

Also Glass Fiber of 200 GSM has more strength than Glass fibers of 220 GSM and 300 GSM with secondary nano fibers by 2 to 3 %.

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