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Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Improvement of Mechanical Properties of 2D and 3D Fiber Reinforced Polymer Composites for Automotive Structures

Master's Final Degree Project

Shriram Vaniyambadi Ravikumar

Project author

Assoc. Prof. Daiva ZELENIAKIENE

Supervisor

Kaunas, 2021

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Study programme: Vehicle Engineering (6211EX021)

Task of the Master's Final Degree Project

Given to the student: *Shriram Vaniyambadi Ravikumar*

1. Title of the Project:

Improvement of Mechanical Properties of 2D and 3D Fiber Reinforced Polymer Composites for Automotive Structures

2D ir 3D pluoštu armuotų polimerinių kompozitų mechaninių savybių tobulinimas automobilių konstrukcijose

2. Aim of the Project: To improve the mechanical properties of fibre reinforced composites for automotive structures by replacing traditional 2D glass fibres with advanced 3D ones and by matrix modification

3. Tasks of the Project:

-To optimize the epoxy matrix/fiber by embedding it with carbon-based nanofillers for the improvement of mechanical properties of composite material
-To investigate the mechanical property of modified fiber composite with the unmodified fiber composite
-To investigate and compare the impact behaviour of 2D and 3D composites
-To analyse the obtained results of 2D and 3D composite and compare the difference in mechanical properties and implementation in automotive structure.

4. Structure of the Text Part:

The structure of the text part includes introduction, literature review, methodology, manufacturing and testing, results, and the conclusion

5. Consultants of the Project:

Author of the Final Degree Project	Shriram Vaniyambadi Ravikumar	2020-02-04
	(name, surname, date)	
Supervisor of the Final Degree Project	Assoc. Prof Daiva ZELENIAKIENE	2020-02-04
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	(abbreviation of the position, name, surname, date)	

Vaniyambadi Ravikumar Shriram. Improvement of Mechanical Properties of 2D and 3D Fiber Reinforced Polymer Composites for Automotive Structures. Master's Final Degree Project / supervisor Assoc. Prof Daiva ZELENIAKIENE; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study field and area (study field group): Transport Engineering (E12), Engineering Science.

Keywords: Automotive structures, Nanofillers, Mechanical properties, 2D fibers,3D fibers

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Summary

This project aims to investigate the impact of carbon-based multi-functional nano filters on conventional 2D and 3D glass fiber woven composites in improved mechanical properties. The first half of this research paper includes a literature analysis on polymer composites used in-vehicle systems, different types of nanofillers, research on conventional 2D glass fibres and 3D glass fibres, polymer composite manufacturing processes, and mechanical properties of 2D and 3D glass fibres with the effect of nanofillers and potential application of the hybrid materials in the automotive industry.

Experimental analysis carried out to investigate the mechanical properties of 2 dimensional and 3-dimensional Glass fibres. The materials used for this project are 2D plain woven glass fiber, which is widely used in the automobile industry, and 3D orthogonal woven glass fiber, which is slowly being used in the production of modern automotive parts. The fiber orientation for 2D glass fiber was in 0 degrees, and the fiber orientations for 3D woven fibres were 0 (warp) and 90 (weft) degrees as loading direction. Hand layup was used to manufacture 2D glass fiber polymer composites, and vacuum infusion was used to manufacture 3D glass fiber composites. To compare the properties of the composites pure matrix and fibres embedded with 0.25wt % CNT were used. Considering the composite's fibres used in automotive structures four separate experimental tests were performed, Based on ISO standards. These experiments were selected to simulate the forces acting on a vehicle's structure, Tensile (ISO 527-4), Flexural (ISO 14125), Charpy impact (ISO 179), and Interlaminar shear (ISO 14130). The mechanical properties of 2D glass fiber embedded with a 0.25 wt % CNT and 3D warp pure matrix and 3D weft 0.25 wt% CNT composites show significant improvement. As compared to 2D composites, the impact and interlaminar shear properties of 3D composites were substantially increased.

2D composites with nanofillers and 3D composites with pure matrix and with nanofillers have a better strength to weight ratio, higher impact tolerance, and significant damage propagation and can be extensively used in the future for the production of automotive structures decrease on the overall fuel consumption and significantly reduce vehicle weight while making the component resilient to minor and major damage and improving crashworthiness.

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Vaniyambadi Ravikumar Shriram. 2D ir 3D pluoštu armuotų polimerinių kompozitų mechaninių savybių tobulinimas automobilių konstrukcijose. Magistro baigiamasis projektas / vadove . doc Daiva ZELENIAKIENE; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Transporto inžinerija (E12), Inžinerijos mokslai.

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Kaunas, 2021. Puslapių sk. p.52

Santrauka

Šiuo projektu siekiama ištirti anglies pagrindo daugiafunkcinių nano dalelių poveikį įprastiems 2D ir 3D stiklo pluošto audiniams, siekiant gauti geresnes mechanines savybes. Pirmoje šio darbo dalyje pateikiama literatūros analizė apie polimerinius kompozitus naudojamus transporto priemonėse, skirtingų tipų nano užpildus, įprastų 2D ir 3D stiklo pluoštų polimerinių kompozitų gamybos procesus bei mechaninių savybių tyrimus, esant nano dalelių įvedimui. Taip pat įvertinamos hibridinių kompozitų pritaikomumo galimybės automobilių pramonėje.

Eksperimentinė mechaninių savybių analizė buvo atlikta su 2D ir 3D stiklo pluoštais. Šiam projektui naudojamos medžiagos yra 2D paprasto pynimo stiklo pluoštas, kuris yra plačiai naudojamas automobilių pramonėje, ir 3D stačiakampio pynimo stiklo pluoštas, kuris pamažu pritaikomas šiuolaikinių automobilinių dalių gamybai. 2D stiklo pluošto kryptis buvo naudota 0 laipsnių, o 3D pluošto – 0 ir 90 laipsnių, kaip ir apkrovimo kryptis. 2D stiklo pluošto polimeriniams kompozitams gaminti buvo naudojamas rankinis formavimas, o 3D stiklo pluošto kompozitams - vakuuminė infuzija. Kompozitų savybėms palyginti buvo naudojama gryna matrica ir įterpta su 0.25 masės % anglies nano vamzdeliais (CNT). Atsižvelgiant į kompozito pluoštus, naudojamus automobilių konstrukcijose, buvo atlikti keturi atskiri eksperimentiniai bandymai pagal ISO standartus. Šie

eksperimentai buvo pasirinkti imituoti jėgas, veikiančias transporto priemonės konstrukciją: tempimą (ISO 527-4), lenkimą (ISO 14125), smūgines apkrovas (ISO 179) ir tarpsluoksninę šlytį (ISO 14130). 2D stiklo pluošto su 0.25% CNT priemaišomis ir 3D (0°) grynos matricos bei 3D (90°) su 0.25% CNT užpildu, mechaninės savybės parodė reikšmingą pagerėjimą. Palyginti su 2D kompozitais, 3D kompozitų smūginių apkrovų ir tarplaminarinės šlyties atsparumo savybės buvo žymiai pagerintos.

2D kompozitai su nano užpildais ir 3D kompozitai su gryna matrica bei nano užpildais pasižymi geresniu stiprumo ir svorio santykiu, didesne tolerancija smūgiams ir įtrūkimų plitimui, bei ateityje gali būti plačiai naudojami automobilių konstrukcijoms gaminti. Su šiais kompozitais galėtų būti sumažintos bendros degalų sąnaudos, sumažintas transporto priemonės svoris, suteiktas konstrukcijoms geresnis atsparumas mažiems ir dideliems pažeidimams bei pagerintas smūginis atsparumas avarijų metu.

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List of abbreviations and terms

Abbreviations:

3D- 3 dimensional

2D- 2 dimensional

GF- glass fiber

CNT- carbon nano tubes

UTM- ultimate tensile strength

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1. Introduction.

For decades, the automotive industry studied and designed composite materials as a significant replacement for metals. In the last 30 to 40 years, composites have been used in the automotive industry. Because of their strength-to-weight ratio and ability to retain and dissipate energy on contact, composites became the preferred medium for many high-performance automotive manufacturers. In the twenty-first century, the primary goal of all automobile manufacturers is to minimize their carbon footprint by mid-21st century and improve active and passive vehicle safety, favouring both passengers inside the car and pedestrians. Researchers are concentrating their efforts on developing traditional composites with carbon-based additives, and 3D composites were explored to enhance the overall crash and structural integrity of the automobile.

The novelty of this research work is the contrast of traditional 2D GF polymer composites widely utilized in mid to high performance cars with upcoming 3D GF polymer composites making their way into the automotive industry. 3D composites are actively investigated in the field of automobile to replace metals and 2D polymer composites. The data obtained from this project provide an insight on the improvement of mechanical property of 2D and 3D polymer composites and the behaviour of the composite with the infusion of CNT.

The aim of this project is to improve the mechanical properties of 2D and 3D fiber reinforced polymer composites with carbon based nanofillers for application in automotive structures. In addition, to fabricate and analyse specimens in accordance with ISO standards in order to replicate the various forces acting on an automobile structure.

The following tasks are

- To optimize the epoxy matrix/fiber by embedding it with carbon-based nanofillers for the improvement of mechanical properties of composite material
- To investigate the mechanical property of modified fiber composite with the unmodified fiber composite
- To investigate and compare the impact behaviour of 2D and 3D composites
- To analyse the obtained results of 2D and 3D composite and compare the difference in mechanical properties and implementation in automotive structure.

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2. Literature review

As shown in figure 1, cars have become the most common initiators in collisions and the victims of damage caused by accident. The majority of incidents that occur are generally frontal impacts. Where conventionally, metals like aluminium, steel, and other alloys were used to manufacture BIW (body in white) components like bumper or hood as the primary reinforcement followed by the secondary reinforcement. As a result, the automobile gains a significant amount of weight, resulting in a reduction in fuel economy. Composites are gradually being used in street-legal vehicles to stress vehicle safety and performance[1].

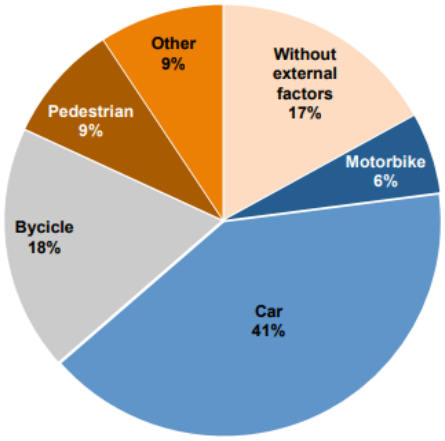

Fig. 1. Accidents involving various vehicles (in Europe)[1].

2.1.1. Frontal impact in an automotive structure

Frontal impacts are classified into two types: low-speed impacts and high-speed impacts. A low-speed collision occurs while a vehicle is parked, when manoeuvring around a slow corner due to the driver's negligence, or when there are some unintended obstructions. The low impact crash test speed ranges between 15 and 17 km/h, with the focus on structural damage. Typically, the damage is minimal, such as surface cracks or minor dents, and can be quickly repaired. High-speed crashes depend on the greater damage that occurs to the material. Typically, following a high-speed collision, the material cannot be recovered, and damaged beyond repair during or after the crash. The various specifications of a material, such as energy absorption, fracture durability, and structural deformation, are used to assess the performance of a vehicle's structure during a collision. These requirements can be achieved with the help of composite materials, including energy absorption, which has been extensively researched by scientists and automobile enthusiasts for decades.

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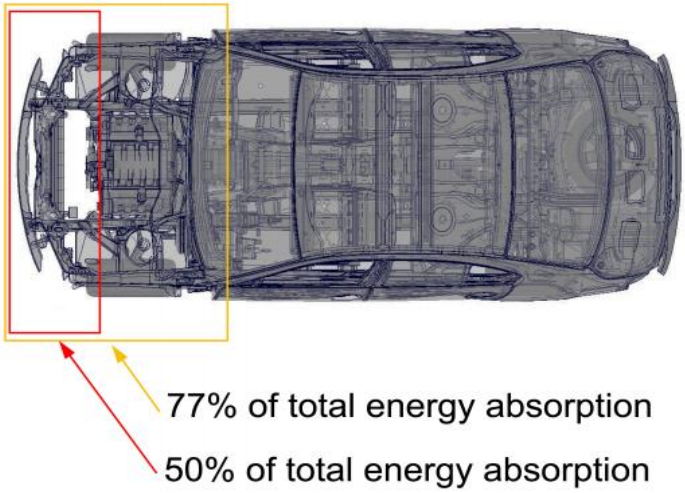

Fig. 2. BMW i3 top view, areas of absorbed energy during frontal impact

2.1.2. The behaviour of composite and metal on impact.

Composites were initially used in aircraft and high-performance cars such as Formula One, and McLaren was one of the first companies to use an epoxy carbon fiber and aluminium sandwich in their chassis in the early 1980s. Between 1985 and 2001, the frontal effect, side-impact, rear impact, and penetration tests were designed to increase vehicle safety requirements and research the energy absorption of composite materials.

The behaviour of composites differs significantly from that of metals used in automobile systems. Metallic structures, as seen in the figure 3, undergo plastic deformation and energy propagation through heat. On the other hand, composites undergo brittle fracturing and energy transmission by friction between laminates, compressive cracking of the material, and composite splitting, meaning that composite structures can dissipate absorbed energy considerably better than metallic structures. It can be deduced that the different natures of energy absorption of metal and composite fibres, wherein metal structures on impact the substrate folds to a certain distance providing initial absorption crashing but the material limits the dissemination of the energy, the brittleness of the composite aids in the propagation of energy inside the material, minimizing total damage to the vehicle component[2].

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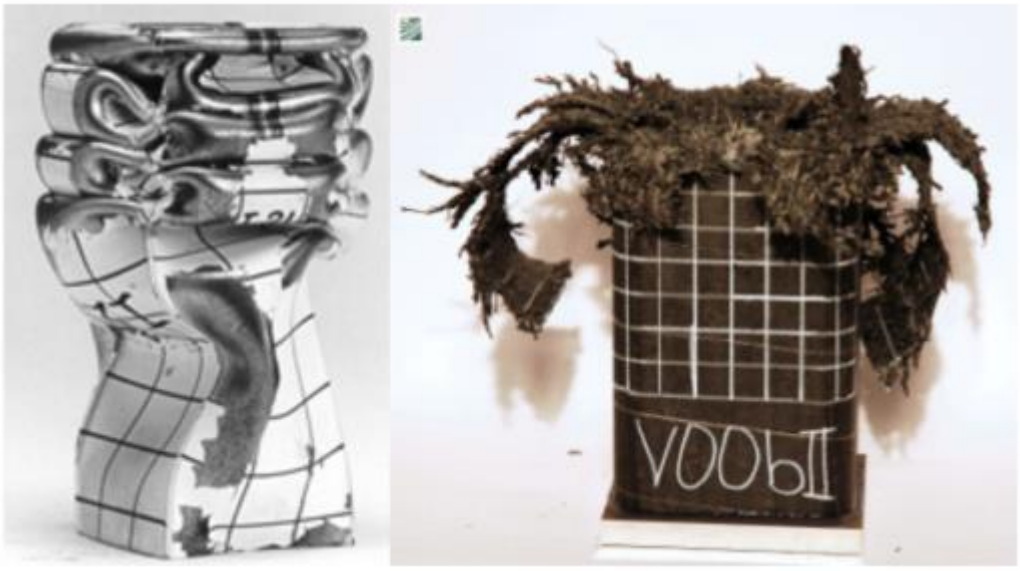

Fig. 3. Behaviour of metal and FRP under impact[2].

2.1.3. Fiber volume content.

The efficiency of composite structures is strongly dependent on the fiber volume content since it is evident that the higher the Fibercon tent, the stronger the energy absorption. For example, the SEA (specific energy absorption) value of metals such as steel and aluminium is between 15 kJ/kg and 30 kJ/kg, while the SEA of glass fiber material increases significantly with an increase in fiber volume content, which ranges from 10% to 40%. When contemplating chopped mats or chopped fibres, the increase in fiber volume fraction reduces the strength of the composite and its ability to dissipate absorbed energy[3].

2.1.4. Light weight material in automotive structures

Automobile industry has been progressing towards lightweight and high strength to ratio materials for the past few decades. the main advantage of having a lightweight vehicle is improvement of fuel economy, adaptation to sustainable environment, reduction, and emissions and better vehicle safety. Steel is the preferred material due to its durability and low cost. Composites can be engineered to increase total automotive integrity while also significantly minimizing vehicle weight. Since electric cars are the future, the need for lightweight materials has been growing exponentially[4].

2.1.5. Application of reinforced composites in Automotive sector

Attempts have been made since the 1960s to incorporate nanocomposite-based materials into automobiles. Because the Nano composite had exceptional thermal properties, it was dispersed in a polymer matrix and the resulting composite was used to construct vehicle parts arranged near the transmission. Several investigations into polymer Nano composites pursued after this. Clay Nano composites with Polybutylene terephthalate were portrayed. clay, for instance, montmorillonite could be extended to nanoparticle widths to form coated earth materials as nanoparticle material is scattered in polymers, their thermal restriction and fire-retardant properties improve. The most important aspect of clay Composite materials is how to scatter

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the Nano clay in the polymer matrix because the tensile strengths of the nanocomposites depend heavily on nanoparticle spreading. Full exfoliation or intercalation of Nano clay in a polymer matrix confirms the properties of the nanocomposite. Regardless, complete exfoliation or intercalation of nanomaterials in a polymer matrix must be practiced, to put it carefully. Resin and nanoparticles courses of action have drawbacks because they are mixed and intensified in a liquefy with a consistent blender. for instance, a twin-screw extruder, can't make sure about totally peeled or intercalated nanoparticles,[5],[6].

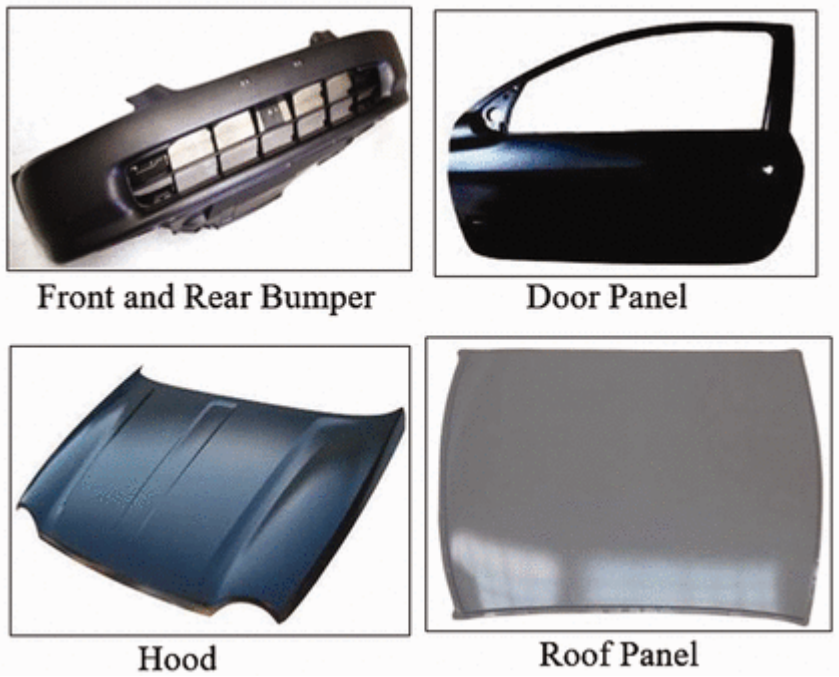

Fig. 4. Automotive components manufactured using glass fiber[7]

3D glass fibres are entering the automotive markets with wide applications in floor panels, crash beams, fairings, spoilers etc. the incorporation of 3D fibres in automobile are at development stages as further investigation is conducted by research and development department in the automotive sector

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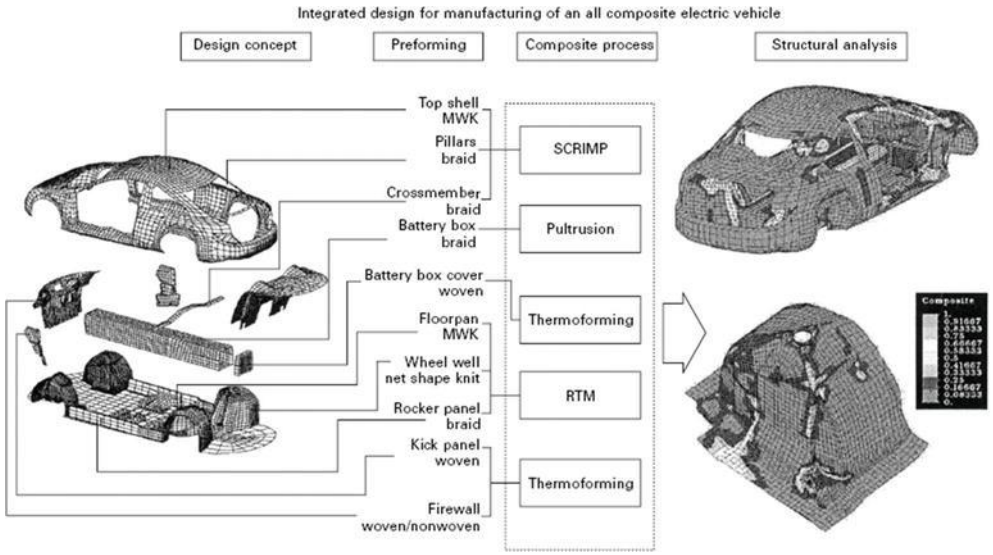

Fig. 5. Manufacturing of Car components using 3D fabric and composite manufacturing method[5]

The fabrication process for products made of fiber reinforced polymer composites is changing. In regular mixture shaping, short glass strands (typically 3 mm) reinforced polymer composites are used. Broad glass strands (typically 3-25 mm) reinforced polymer composites have been used in ejection pressure and layer removal structures for a long time. Polymer composites with unwavering fiber and weaving surface are used in pultrusion, thermo stepping, or pressure framing. A weight shaping technique is used to collect leaves behind thermoset-grid composites that start with sheet molding composites (SMC) is a thin layer of glass strands in a thermosetting resin, the majority of which are about 25 mm long. When para-aramid fibres (such as Kevlar) or carbon fibres are used as reinforcement strands in SMCs, these composites may replace metal. These composites are also being used in racing cars. Polyester, vinyl ester, epoxy, phenolic, and bismaleimide are the most well-known thermoset surface structures.[8][9]

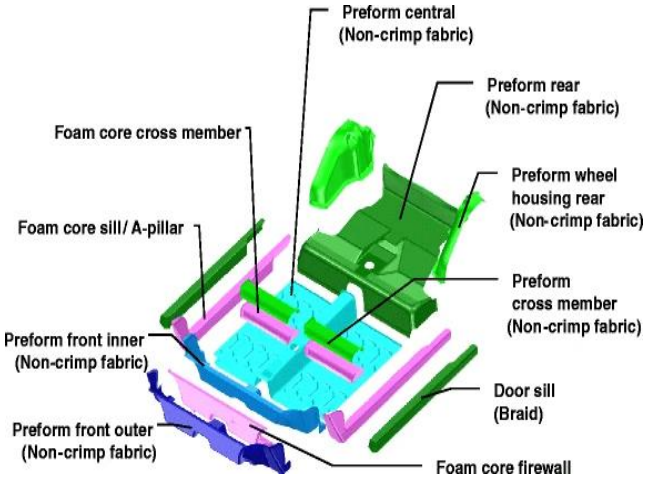

Fig. 6. Secondary vehicle structures employing composites material [10]

In recent decades, thermosetting has been used to produce vehicle parts, mostly for Formula One vehicles, to minimize the impact of an accident. Also, street-legal cars from automakers such as Mercedes-Benz and Porsche use composites to build the chassis. the use of composites Nowadays, in new street legal cars minimize weight by 50% and the amount of components used in a composite car by 70%[10].

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2.2. Composites

Before a material is labelled as a composite, three conditions must be fulfilled. as mentioned below.

- •The composite's properties need not be identical to those of the constituent.
- •The constituents could be quantifiable in quantity.
- •An interface can be used to link the various materials in different stages

Composite materials can be defined in various ways. A composite material, in a wider context, is created by combining two or more materials to produce a wide range of properties. Composite materials are often materials made by combining two substances with distinct frameworks, textures, and properties separated by an interface/ another compelling meaning is that the term composite material refers to any solid material made from several substances in distinct phases. The final description is broad and covers a diverse variety of materials, including fiber-reinforced plastics, conventional solids, steel-stimulated concrete, particle-stimulated polymers, and so on. Regardless The subject of this book is carbon nanotube-enhanced polymer lattice composites. As a result, where the terms "composite" or "composite material" are used, the following meaning is intended: Composites are structures made of a sturdy base that keeps the fortification stage in place.

Two phases are involved in the development of composite materials.: a persistent and generally less resolute called grid stage and the spasmodic, and generally progressively rigid indicated fortifying stage. The idea of "Composite" is found in nature and is not a man-made one. There is a notably good number of models available. For instance, wood may be a composite made up of lignin and cellulose fibres. Composites include the shells of invertebrates including snails and shellfish. Bone and teeth are excellent representations of composites in the human body[11][12].

2.2.1. Polymers

Polymers are considerable particles produced from repetitive structures ordinarily generally strengthened by covalent bonds. Considering their low thickness diverged from various materials, basic processability, and erosion obstruction, polymers have ended up being standout among the most notable designing materials that are extensively associated in the automobile and aviation industries. Polymers can be classified into Elastomers, Thermosets, and Thermoplastics. Some basic Polymers include Polystyrene, Polypropylene, Poly-ethylene, Poly-ethylene Terephthalate, Poly-urethane, and Epoxy resin. Below represents the choice of polymer and their concoction structures. Despite the wide range of benefits that polymeric materials have, their use is compelled by their thermal efficiency., which is consistently below 150 °C Furthermore, certain mixed polymers, such as Poly-amides and Poly-azols, have both thermal and mechanical properties[13].

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2.3. Properties of polymers and composites

2.3.1. Mechanical stability:

There are several varied definitions of composite materials. However, the most prominent one is that any material produced on a fusion of two substances is a composite, but this definition is too wide to even think about consider being helpful. Specifically, the part of the description, as well as the composition and organization of constituents, must all be considered. Composites are currently being used for a significant number of components; a noteworthy description is as follows:

A polymer is often a multi-stage substance that is formed by combining materials with different structures on a large scale to produce specific properties and performance. The constituents maintain their personalities & properties with the end goal of displaying an interface between them and working in concert to create better synergistic properties that would be impossible to achieve if either of the parts acted individually.

Three aspects limit the properties and performance of composites.: constituents' inherent characteristics, the constituents' composition, and supporting mechanism, as well as their convergence. The normal order or scope of the products of composites is determined by constituent properties. Composites' adaptability is due to their form (size and shape), auxiliary system, amalgamation, and dispersion with constituents, which all contribute to the overall execution[14].

2.4. Detailed insight in manufacturing of composites

2.4.1. Fibres used in automotive industry

2.4.1.1. Carbon Fibre

Carbon fiber is a popular commodity in the automotive industry for high-performance automobiles due to its high mechanical strength and superior thermal conductivity. Carbon fibres are processed using two methods: PAN-based (polyacrylonitrile) and pitch-based. Because of its high strength-to-weight ratio, the PAN-based approach is commonly used in commercial aspects. Furthermore, the pitch-based carbon fiber allows for greater thermal transfer[15].

2.4.1.2. Glass Fiber

Glass fiber is created by combining silica, aluminium oxides, calcium oxides, and magnesium oxides in varying amounts to create three varieties of glass fibres: E-glass, S-glass, and S2-glass. E-glass is created by adding boron oxides, while S-glass is created by increasing silica oxides, which improves mechanical properties. Glass fibres have considerably greater tensile strength, are resistant to contaminants, and can withstand high temperatures. And they are very affordable and widely available, making them the chosen option for low-cost cars.

Other notable features include aramid fibbers' high temperature resistance and resistance to high pressure. High temperature resistance. Ultrahigh molecular weight polyethylene fibres

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have a fast susceptibility to wear and tear as well as fatigue. And ceramic fibres, which improved temperature tolerance[15].

Table 1. Properties of fibres[15]

	Young's modulus (GPa)	Tensile strength (GPa)	Density (g/cm^3)	Specific modulus (Mm)	Specific strength (Km)	Failure strain (%)	Fiber diameter (μm)
E-glass	71	1.5-3.0	2.55	2.8-4.8	58-117	1.8-3.2	10-20
S-glass	87	3-5	2.5	3.5	140	4.0	12
S_2-glass	86	4.0	2.49	3.5	161	5.4	10
carbon	220-230	2.3-3.7	1.8-2.0	12-18	130-190	0.7-1.7	7
Aramid	60-180	2.6-3.4	1.4-1.47	4.0-12.2	180-235	4-1.9	12

2.4.2. Matrices

2.4.2.1. Thermosetting matrix

the most of polymers used as a matrix Composite fabric are used in textiles. Thermosetting polymers versus thermoplastics Thermosetting is a common technique. The application of the liquid on the composite material is the first step in creating the setting matrix. The second step is curing the material at a moderate temperature to strengthen the molecular bond between the resins. The resin begins to harden as pressure and temperature are applied, which can vary from 70 to 200 degrees Celsius. Thermosets, unlike thermoplastics, cannot be recycled, which is a major disadvantage. Thermosetting resins have the following. Polyester and epoxy. Vinyl ester and phenolics the primary benefit. There are thermosetting resins. Low-temperature processing High temperature resistance. High-strength, low viscosity. In terms of fibres, it has strong wettability[16].

2.4.2.2. Thermoplastic

Thermoplastics are created by heating and cooling the material. Unlike thermosetting, when heated, the material begins to melt, and when cooled, the material begins to harden, making it a suitable material to recycle when broken or fixed. This is a reversible method. Some thermoplastics include polypropylene and polyethylene, as well as polyester and polyether ketone resins, which are used as insulation in composites. The benefits of thermoplastics over thermosets Material waste is kept to a minimum. Low production cost, recyclable several times, eco safe, easy to handle, ductile, and impact resistant[16].

2.4.3. Composite Manufacturing Techniques

The manufacture of composites is largely dependent on the form of matrix used and considers other considerations such as the shape of the component. The matrix substance, as well as the type of reinforcement, The region's size as well as the fiber volume fraction. By using the thermosetting form, the matrix is. Usually in the form of a jelly. with increased viscosity. But.

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In Thermoplastic method. The material is usually melted and then applied to the reinforcement. There are different methods to manufacture composites using thermosetting. Example. Resin transfer moulding. Hand layup, compressive moulding. Winding of filament. Infusion of resin. Autoclave moulding. And pultrusion. Injection moulding and thermoforming are the most widely used methods for Thermoplastics based composite. [17]

2.4.3.1. Hand layup

The hand layup is one of the most common and. The simplest way to make a composite. It necessitates no experience. And all of the components are available at a discounted rate. Moulding materials include wood, plastic, and metal. The releasing agent is applied as the first step in the hand layup operation. and Gel coating is used. To improve the finish of the composite, once it has been removed, the fibre is put on top of the coating end mix of resin, and a hardener is added to the fibre. The resin is then applied using a roller, and the process is repeated with several layers of fiber and resin until the desired thickness and form are obtained; after completion, the composite is laid to cure, with the curing period ranging from 12 to 24 hours. This method is time-consuming and labour-intensive, and the composites generated are of low quality.

2.4.3.2. Resin transfer molding

Resin transfer molding is regarded as one of the best technologies for producing high-quality parts. It is made up of two parts: male and female. The fabrics are inserted within the cavity of the female part and replaced with the male element; the hole is filled with a mixture of hardener and resin hey before the fabric is fully wetted. The composite is now allowed to heal. Resin transfer molding is highly effective and timesaving; vacuum-assisted resin transfer molding is the next stage of resin transfer molding. A vacuum is used to remove the air bubbles within the wetted cloth.

2.4.3.3. Vacuum infusion

This technique is widely used to produce thermoset composites; the fibres are mounted within a large mold made of wood or plastics; the sides are covered with vacuum bags, and sealant tapes are used to prevent air leakage. The air inside the sealed molds is fully extracted using vacuum pumps that generate pressure inside the mold. In the other side, the resin is infused into the fiber with the aid of a vacuum before the resin completely wets the fiber; this process is used to fabricate basic molded fabrics that are cured at room temperature.

2.4.4. Types of 2D fibres

2D can be manufactured in 4 different ways, namely woven fabrics, braided fabrics related fabrics, and non-woven fabrics

2.4.4.1. woven Fabric 2D

As see in figure 1, Woven fabrics have manufactured the combination of yarns in the X&Y axis. The most commonly used 2D woven composite is biaxial fabric, where the yarns are interlaced at 90 degrees to each other. There are four steps in manufacturing 2D woven

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composite 1) shedding, 2) insertion of feeding, 3) beat up, and 4) fabric and warp control. The fabric is manufactured using jacquard looms. Biaxial fabrics have stabilized mechanical properties and dimensional stability. The fabric can be produced at low cost and are easy to handle the significant disadvantages are that they limited in-plane shear since the fabric has yarns in the X&Y axis, the thickness is compromised, and decrease in tensile properties are affected due to crimping of the fabric[18][19].

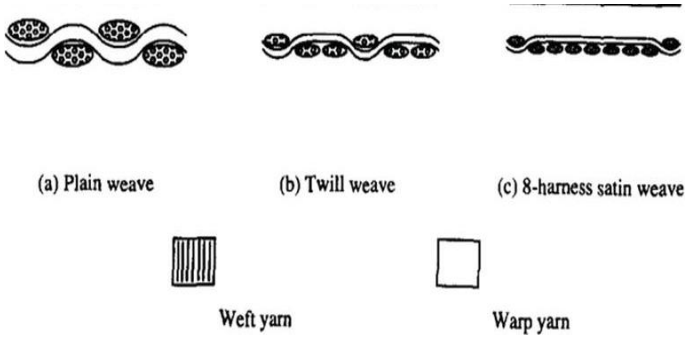

Fig. 7. Type of weave, a) plain, b) twill, and c) satin[19]

2.4.5. Types of 3D fibres

3-dimensional fabric is the most recent advancement in hybrid materials. 3D composites can be made in a variety of diverse architectures. One of the primary properties of 3D composites is their thickness along the Z-axis, which increases their resistance to damage and interlaminar shear.

2.4.5.1. Woven Fabric 3D

3D woven fabrics are classified into three groups depending on their manufacturing:1) orthogonal, 2) angle interlocked, and completely interlaced weaves. There are two kinds of angle interlocked: layer to layer angle interlocked and angle interlocked across the thickness. The main disadvantage of 3D woven fabrics is that they take longer to manufacture and have little in-plane reinforcing in the bias direction[20].

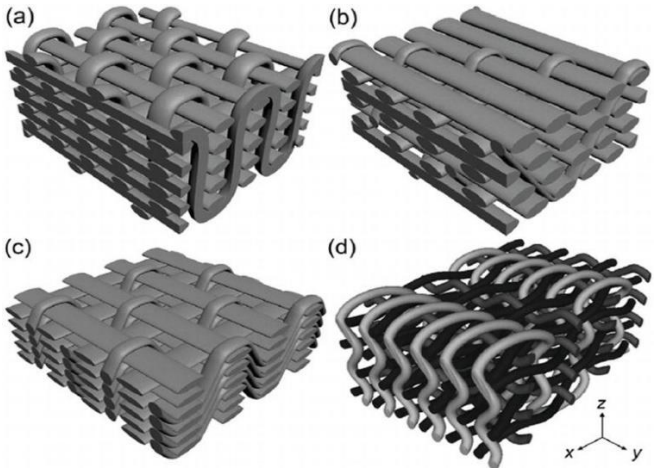

Fig. 8. 3D woven fabric, a) orthogonal, b) angle interlocked (through the thickness), c) angle interlocked (layer to layer) and d) interlaced[20]

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2.4.5.2. Braided Fabric 3D

The technique used to create 3D braided fabric is identical to that used to create 2D braided fabric. Other devices that can be used to make 3D braids include horngear and cartesian. The main differences are that braiding times in horngear are much shorter, and complicated patterns can be produced using cartesian due to their small scale. 3D braid fabric is made in three ways: strong braiding, two-step braiding, and four-step braiding.

2.4.6. Nanofillers in Hybrid and Hierarchical Polymers

In the upcoming segment, addictive plastics could also be the most essential for upgrading a compound's physical properties. External components are added to the polyolefin matrix, such as fillers and fabrics produced using inorganic and natural materials. The external components added, "foreign contaminants," usually are artificially dormant except for how they respond when coupled with the Resins—coupled by probable cost funds and more significant mass to strength proportions, making the mechanical characteristic basic for newly built polyolefin applications.

While discussing fillers and fibres, there is some inconsistency observed. An increase in the value of the properties can be found when fibres and numerous fillers are made use of, even though the most popular modest nano-fillers, for instance, calcium-carbonate, are used to reduce the price surge as an extender for removing the polymer that is essential for an item (for broadening the volume of an item). The occurrence of drastic increment in the price has led to increased utilization of fillers as extenders [21]

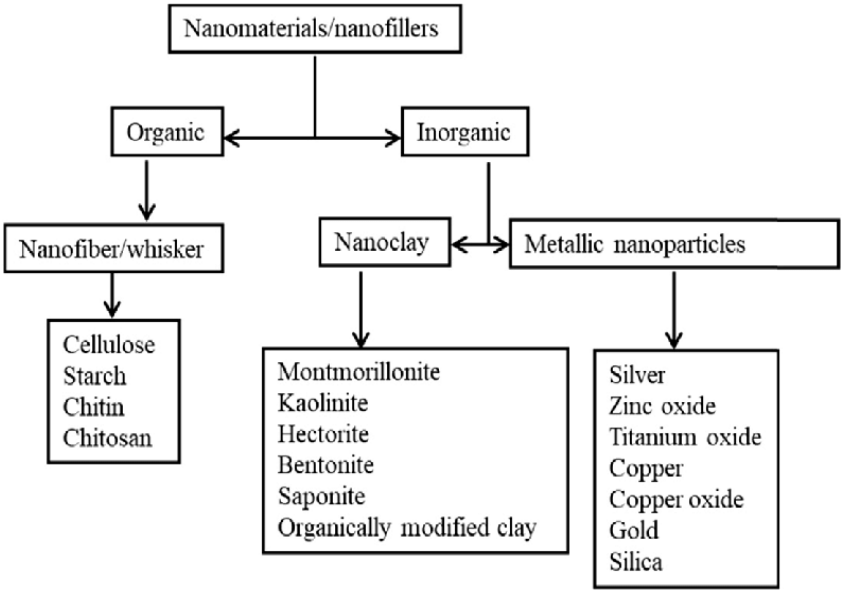

Fig. 9. Classification of nanofillers[21]

2.4.6.1. Carbon-based nanofillers

Carbon-nanotubes (CNT) are thin cylindrical particles of carbon. The size is in the nanometre-estimate diameter and micrometre in length. Since then, they have been used in a variety of applications. [22]. CNTs are made up of enlisted graphite sheets and a planar-hexagonal plan to treat the molecule of carbon articulated in a honey-comb structure. [22][23]. There are two

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types of nanotube structures: multiwall (MWCNT) and single-wall (SWCNT), and the selection depends on the preparation technique [24]. SWCNT is made up of graphene sheets that have been folded into a Barrel[25][26]. Minimum of a couple of round and hollow shells of graphene sheets are positioned around an open focal centre in multiwall CNT consist of exceptional properties with a variable modulus on demand of 1 TPa, and most extreme elasticity achieved 3000 MPa (without any damage) along with excellent conductivity [23][27]. Mentioned properties are known to have a solid covalent bond within the carbons and its game plan round and hollow nanostructures[28].

2.4.6.2. Graphene

Graphene was discovered in 2004. Its outstanding electric, Mechanical properties helped to shift the technological boundaries of nanoelectronics and compact material science. Graphene has started gigantic. Micrographs were acquired by transmission electron microscopy of nanocomposites with polyetherimide (PEI) and MWCNT[29].

Graphite comprises a single nuclear sheet of covalently sp2-reinforced carbon particles in hexagon shape[30]. The simple shape of graphene is made with a couple of unequal atoms, A and B, and this two sub-lattice are deciphered from one another by a carbon-carbon remove distance ac- c = 1.44 Å. Graphene can be made from graphite in a variety of ways, for example., Chemically intercalated graphite with thermal expansion, graphite micromechanical shedding, concoction vapour deposition, and graphene oxide chemical reduction technique [31]. Young's modulus of graphene is one tera pascal, crack resistance (1250 Mpa), thermal efficiency (500 W/m.K), and conductivity (6000 S/cm) are all characteristics of graphene. [32]. These characteristics, along with graphene's extremely high surface area (Maximum 2630 m2/g) and flow properties, demonstrate graphene's enormous great potential to improve the mechanical, thermal, and properties of polymer nanocomposites [33].

2.4.6.3. Mxene

The development of graphene and its exceptional properties, two-dimensional (2D), has led to a breakthrough in material science. Other 2D materials, such as metal carbides, nitrides, and carbonitrides, also known as MXene, have undergone growth.[34][35]

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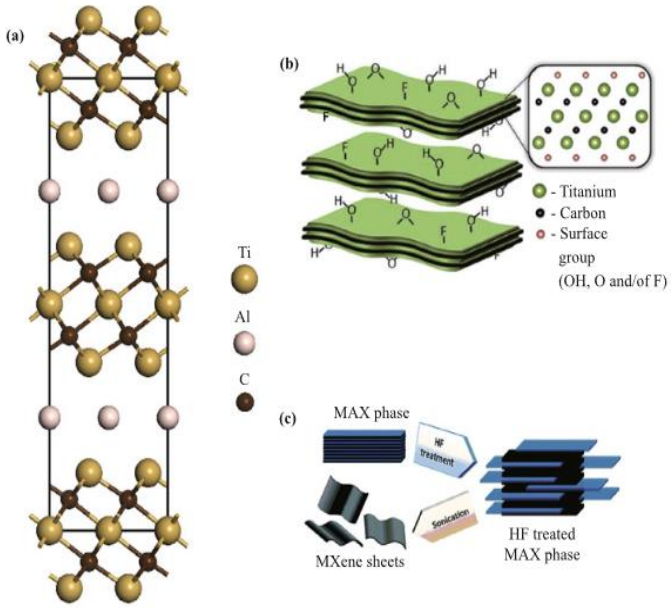

Fig. 10. Chemical structure of Mxene in MAX phase. [36]

Till date, in excess of 70 MAX phases have been reported[37], however the founded Mxene family just includes Ti_3C_2,Ti_2C, $(Ti_{0.5}$,$Nb_{0.5})2C$, $(V_{0.5},Cr_{0.5})3C_2$,Ti_3CN, Ta_4C_3[36], Nb_2C, V_2C[38], and Nb_4C_3[39].For exfoliation from a quantitative group of MAX stage are dependent on MXene materials. During the etching process, the exfoliated surfaces' exterior surfaces are often terminated with F, OH, and O groups. These terminated MXene groups will now be referred to as Mn+1XnTx, where T refers to top layer accumulation (F, OH, and O) and "x" refers to the number of cancellations.

Mxene was reported to have exceptional properties since its discovery. Mxene, for example, has conductivity comparable to multi-layered graphene. [36]. MXene is strong, according to density functional theory (DFT) calculations, with inter-planar plastic constants exceeding 5000 MPa. [40][41]

3.Influence of nanofillers in polymers and matrix in 2D and 3D fibre composites and development in Mechanical properties

The accelerated thermal ageing of epoxy resin 3-dimensional carbon fibre at various temperature settings from 90 degree Celsius to 180 degree Celsius, and compression testing is done find out matrix degradation in fibres and resin. The composites were isothermally aged at different temperatures for different intervals of 1,2,4,8, and 16 days. The compression test is done at room temperature, composites aged beyond 180-degree Celsius head prominent cracks between the fibre and the matrix interface, which provided a way for gaseous diffusion and further degrading f the composite. Mechanical properties composites are enhanced by Accelerated curing[42] The multiple mechanical properties, mainly tensile test, compressive test, bending, impact, knife penetration, and dynamic mechanical analysis on different polymer structures, E.g., unidirectional, polymers, 2-dimensional polymers, 3D polymers (Orthogonal, Angle Interlocked, and Warp Interlocked) with weaving, resin and hardener percentage and also curing pressure optimization .box and Ben can method is used to obtain the best results

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for impact test. The test conducted using ASTM standards, and the unidirectional composites have more significant delamination at the point of force impact than 3D. The impact resistance is effective in 3-dimensional polymers. [43]

The four different types of 3D woven composites (orthogonal, layer by layer binding, Angle interlocked, and modified Angle interlocked, four different samples are created, namely S1, S2, S3, S4 using resin transfer moulding. The fibre volume fraction of S1 is 61.3%, S2 is 61.9%, S3 is 55.4%, and for S4 is 54.3%, it is evident that the fibre volume fraction of S1 and S2 are different from S3 and S4. The size of the tensile specimen is 250mm × 25mm. The tensile strength of S2 and S4 are at an average of 7KN, whereas it's 6.27 KN for S1 and the lowest for S3 at 5.43 KN. Proving that orthogonal structure with layer-by-layer binding has greater tensile strength and elongation.[44] the crack propagation in carbon and glass fibre 3D woven composites yarn in the transversal reinforcement are oriented from average to the midplane. To develop a crack propagation, A comb loading device is used. The results obtained were that the translaminar did not prolong the crack propagation and the initiation of the damage. The resistance increased ten folds at a 0.2mm opening and reached a maximum of 0.5 mm.[45]

the significant performance difference between a 2D and a 3D polymer composite. The impact load used in the fiber was 9kg. on experimentation. the straining and fracturing of 3d woven fabric, especially on the z-axis and more excellent absorption of energy, the spread of radial damage, was more significant in 3 Dimensional due to the straight fibres. They were proofs that 2D fibres have more significant strength transverse deflection. The 3-dimensional fabric handled multiple impact strikes, and the reactions occurred only on the z Axis.[46] the mechanical properties and behaviour of a 3-dimensional composite panel of carbon fiber. With an overall fiber volume fraction of 43 %. Obtain the young's modulus and Poisson's ratio, stress, and strain rate tensile testing is done. The testing is done at room temperature, and the test speed is 1mm/min. The modulus of filler yarn is greater than the stuffer yarn direction. It is similar in the failure strength. And vice versa with failure strain. The waves present in the fibres contributes to the more excellent input factor.[47]

3.1. 2D & 3D Infused with Carbon Nanotubes study of static and dynamic mechanical properties

The multiwalled carbon nanotubes are doped into woven carbon fiber, and their characteristics are studied using a low-velocity impact test. The doping ranges from 0.5% to 1.5%, and the load parameter from 15-120J is set. The carbon fiber used is plain weave with a thickness of 0.25mm and the tensile strength of 4.5Gpa and modulus of 231GPa the. And the sample is cured for 24 hours at room temperature. The multiwall carbon nanotubes are manufactured using "catalytic chemical vapor deposition." The composite was prepared using hand layup and later vacuuming it. The test does in a free-fall impact test, The impact energy absorption was more excellent by 50% when 1/5% of multiwalled carbon nanotubes were used, and overall it is proven that the addition of nanotubes provides significant improvement.[48]

The carbon nanotubes infused in the woven fiber using both experimental and theoretical approaches—the theoretical methods are Mori Tanaka scheme, Chamis, Hahn, and Halpin-Tsai approaches. Change in temperature does affect the viscosity of the doped epoxy providing

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greater values of young's modulus.[49] in-grown carbon nanotubes in 3D woven carbon fiber and understanding how it enhances the property of the 3D composite. The materials used are T-300 6K carbon fiber manufactured by Cytec. The CNTs were imparted into the fiber using the thermal evaporation method by placing the woven in-between 2 metal plates were grown using EasyTube 1000 CVD reactor. The epoxy used are MGSL285 and MGS H285 hardener. Fracture test is done with ASTM D 5528 and the results obtained were a significant increase in the fracture toughness and zero loss in Bending rigidity. The application of CNT also provides epoxy composite integrity.[50]

Carbon nanotubes are embedded into the fiber directly using vapor deposition. There is a significant amount of development with interlaminar fracture toughness. The Modelling of CNT bridging while shear testing is successfully implemented. Providing facts that the strands of CNT's can withstand the shear strength and hold the bond, providing better stability [51]. the flexural properties of unstitched and non-doped 3D woven composites and its counter opposites stitched, and CNT doped 3D woven fabric are studied. Various kinds of woven carbon fibres are used twill (2/2) and satin (1/4); both are made of 12K carbon fibres. The addition of carbon nanotubes and stitching significantly improves the failure properties of the composites due to limiting the delamination of the matrix. Flexural strength is decreased in the stitched satin fiber due to stitching irregularities and improper spreading of CNT in the fibres and matrix.[52]

the mechanical properties and behaviour of 3D woven composites with differing weave in Angle interlocked composite. Three different angles interlocked 3D woven composites with several stacking sequences are employed. Weaved carbon is the composite used.

- weave 1 orientations are [90/0/45/-45/0/90/0/-45/45/0/90]
- weave 2 orientations are [90/45/0/0/-45/90/-45/0/0/45/90]
- weave 3 orientations are [90/0/63.4/-63.4/0/90/0/-63.4/63.4/0/90]

Weave 3 is a little different in that the use of resin transfer molding forms the composites. The composite with a traditional stacking series had significantly higher tensile strength and stiffness. As the Angle of the z yarn was changed, the tensile strength decreased in the warp direction and improved in the weft direction. There was no discernible change in the strain value. When the fractures were examined, it was discovered that the fibres had fractured in the warp direction, with only a minor alteration in the z-direction[53].

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4. Materials and Experimental methodology

4.1. Materials

Epocyl 128-02 CNT NC 7000 (multi-walled CNT with an average diameter of 10 nm), Biresin CR-122 Bisphenol F epoxy resin with hardener. 2D glass fabric (GF) (plain weavings, having GSM value of 80 g/m^2), 3D woven glass fabric (orthogonal, having a GSM value of 3270 g/m^2) were used as reinforcement to manufacture composite specimens.

For each set specimens, the CNT master batch was diluted in the resin and placed in a vacuum chamber for 10 mins to remove macro and micro bubbles.

4.2. Manufacturing of composites

4.2.1. Manufacturing of 2D composite using hand-layup

As seen in Figure 10, Composite specimens were manufactured using the hand layup technique. They were infused with epoxy and hardened at room temperature for 12 to 24 hours an additional post thermal curing was done at 80 °C for 5 hours. The sample was prepared on a flat plane metal surface to provide a smooth surface finish and the epoxy is applied using a roller to the composites and vacuumed at 101.3 kPa for 2 hours and cured in the oven. Similar method is used to manufacture the specimens with the infusion of CNT, the CNT was mixed into the epoxy using magnetic stirring and vacuumed inside a vacuum chamber to remove macro/micro air bubbles present in the mixture and embedded into fiber 6 hours prior to hand layup.

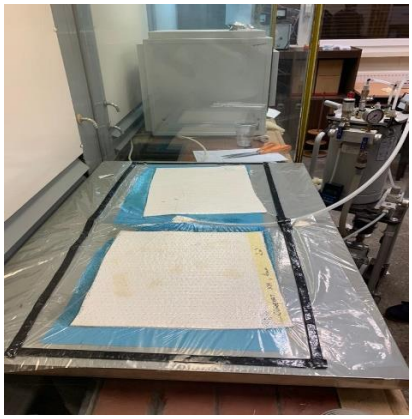

Fig. 11. Hand layup of 2D glass fiber

4.2.2. Manufacturing of 3D composite using vacuum infusion

Composite specimens were manufactured using the vacuum infusion. the sides are covered with vacuum bags, and sealant tapes are used to prevent air leakage. The air inside the sealed molds is fully extracted using vacuum pumps that generate pressure inside the mold. In the other side, the resin is infused into the fiber with the aid of a vacuum before the resin completely wets the fiber. post thermal curing was done at 80 °C for 5 hours. The sample was prepared on a flat plane metal surface to provide a smooth surface finish and vacuumed at 101.3 kPa for 1 hours and cure at room temperature for 12 to 24 hours. The CNT was mixed into the epoxy using magnetic stirring and embedded into the fiber 6 hours prior to vacuum infusion as seen in Figure 11.

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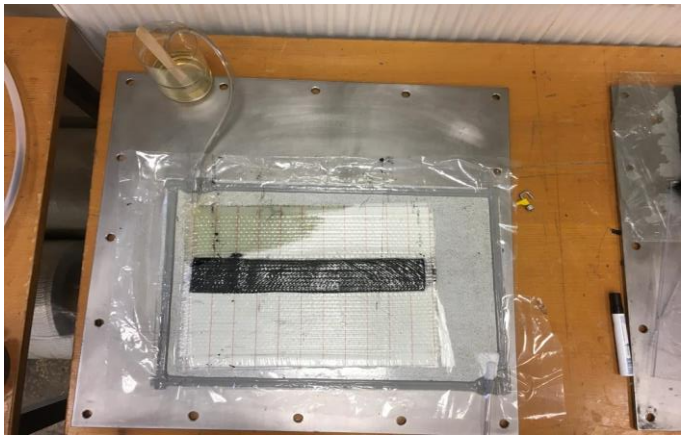

Fig. 12. Vacuum infusion of 3D woven glass fibres

The specimens are classified into two groups: group-1 consists of specimens without CNT infusion and group-2 consists of specimens with CNT infusion, as seen in Table 2. In addition, each specimen is assigned a code for specimen identification in the results and discussion section.

Table 2. Stackup, materials used, composition and orientation

	Group-1			**Group-2**		
Composition	Epoxy +2D GF	Epoxy + 3D GF warp	Epoxy+ 3D GF weft	Epoxy +2D GF +0.25 wt% CNT	Epoxy +3D warp+ 0.25 wt% CNT	Epoxy+3D weft+ 0.25 wt% CNT
Sample Codes	**S1**	**T1**	**U1**	**S2**	**T2**	**U2**
CNT wt %	0	0	0	0.25 wt %	0.25 wt %	0.25 wt %
Stack up	GF/GF	GF	GF	GF/GF	GF	GF
Fiber layers	40	1	1	40	1	1
Orientation	0 °	0 °	90°	0 °	0 °	90°
Manufacturing Method	Hand layup	Vacuum infusion	Vacuum infusion	Hand layup	Vacuum infusion	Vacuum infusion

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5.1. Static testing of investigation mechanical properties of 2D and 3D composites

5.1.1. Tensile testing

For the determination of ultimate tensile strength, tensile strain, and tensile modulus ISO 524-7 test standards are implemented, the table 3 represents the size of the specimen and the speed of the test is at 2 mm/min

Table 3. specimen size

Overall length (mm)	**Width (mm)**	**Thickness (mm)**	**Distance between grips (mm)**
250	25	3	150

Fig. 13. Specimens for tensile test

Before testing, each pure epoxy fiber sample is weighed individually, the weight is tabulated, and the average fiber volume fraction is determined, as seen in table 4.

Table 4. Average fiber content in tensile specimen

specimens	**2D epoxy GF**	**3D epoxy warp**	**3D epoxy weft**
% fiber content	64.70	46.62	50.12
Average specimen weight (g)	30.9	30	27.9

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5.1.2. Flexural testing

5 samples of each composite group were tested by a three-point bending method for flexural strength on the Tinius Olsen machine (Tinius Olsen, UK) with load cell capacity 25 kN according to ISO 14125 standard. The test speed was 2 mm/min.

Table 5. specimen size

Specimen length (mm)	Outer span (mm)	Width (mm)	Thickness (mm)
80	64	10	3

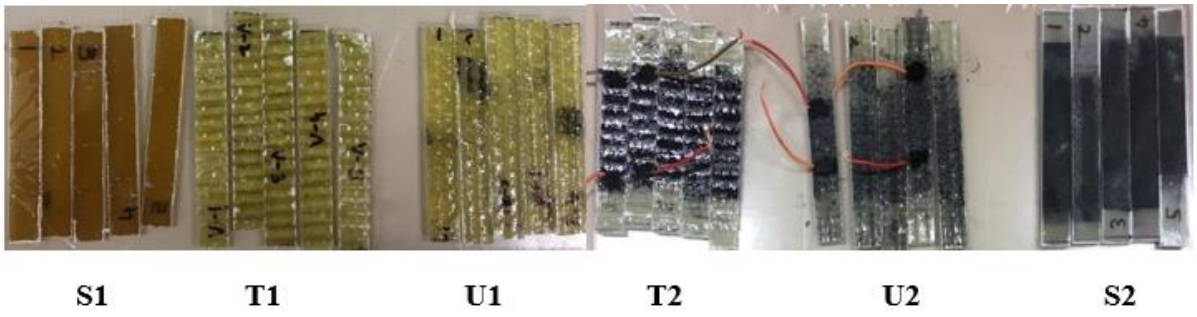

Fig. 14. Specimens for flexural test.

Before testing, each pure epoxy fiber sample is weighed individually, the weight is tabulated, and the average fiber volume fraction is determined, as seen in table 6.

Table 6. Average fiber content in bending specimen

specimens	2D epoxy GF	3D epoxy warp	3D epoxy weft
% fiber content	62.9	50.95	48.95
Average specimen weight (g)	7.6	6.5	6.8

5.1.3. Charpy impact test

The Charpy impact test can be used to determine the impact potential of a material. The material's behaviour can also be analysed under impact conditions to decide if it is brittle or tough, and it can be used to compare different materials. It is easy to use, dependable, and fast, and it can collect large quantities of data for this test. In this study, the unnotched specimen and edgewise effect norm ISO 179 was implemented.

Table 7. specimen size

Length (mm)	Width (mm)	Thickness (mm)	Span (mm)
80	10	3	62

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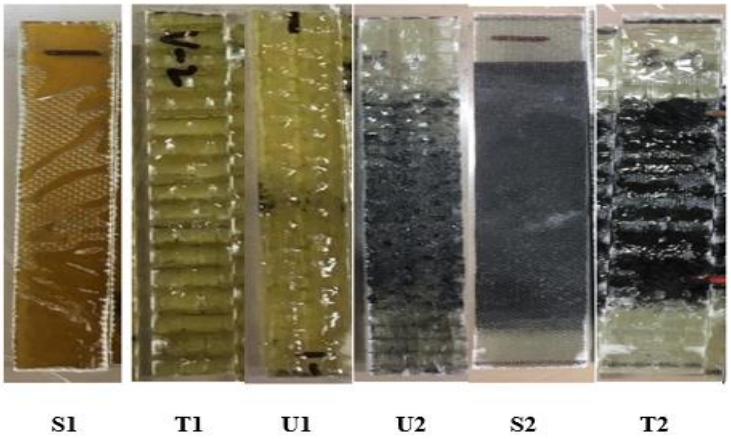

Fig. 15. Specimens for impact test.

Before testing, each pure epoxy fiber sample is weighed individually, the weight is tabulated, and the average fiber volume fraction is determined, as seen in table 8.

Table 8. Average fiber content of impact samples

specimens	**2D epoxy GF**	**3D epoxy warp**	**3D epoxy weft**
% fiber content	63.42	50.95	47.98
Average specimen weight (g)	7.57	6.5	7

5.1.4. Interlaminar shear test

The interlaminar shear test was implemented using ISO 14130 standards 5 samples from each batch was manufactured and tested at a constant speed of 2mm/min.

Table 9. specimen size

Thickness (mm)	**Overall length (mm)**	**Width (mm)**
2	20	10

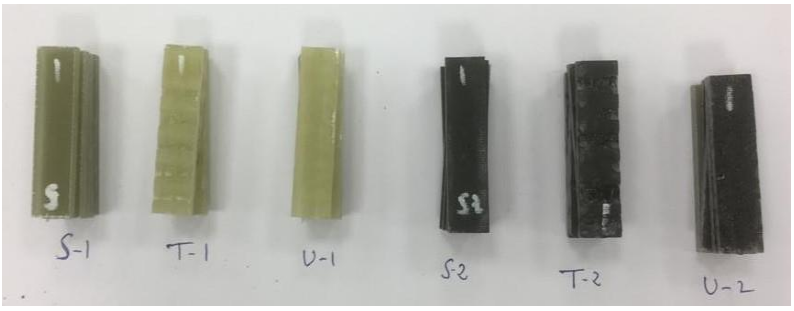

Fig. 16. Specimens for interlaminar shear test

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Before testing, each pure epoxy fiber sample is weighed individually, the weight is tabulated, and the average fiber volume fraction is determined, as seen in table 10.

Table 10. fiber content in interlaminar shear specimens

specimens	**2D epoxy GF**	**3D epoxy warp**	**3D epoxy weft**
% fiber content	58.18	47.15	43.07
Average specimen weigth (g)	2.2	1.9	2.08

`

5.2. Tensile Test Results and discussion

From figure 17 The stress vs strain graphs of each specimens. From the figure below we chan observe that there are three comparision graphs of pure vs 0.25 wt % CNT embedded specimens of 2D glass fibers, 3D glassfiber (warp direction) and 3D glass fiber (weft direction). On comparision of S1 vs S1 the stress of S2 decreases by 1.19% and the strain rate decreases by 25% providing the data that CNT embedded 2D glass fiber shows reduced tensile property over the 2D epoxy glass fiber.

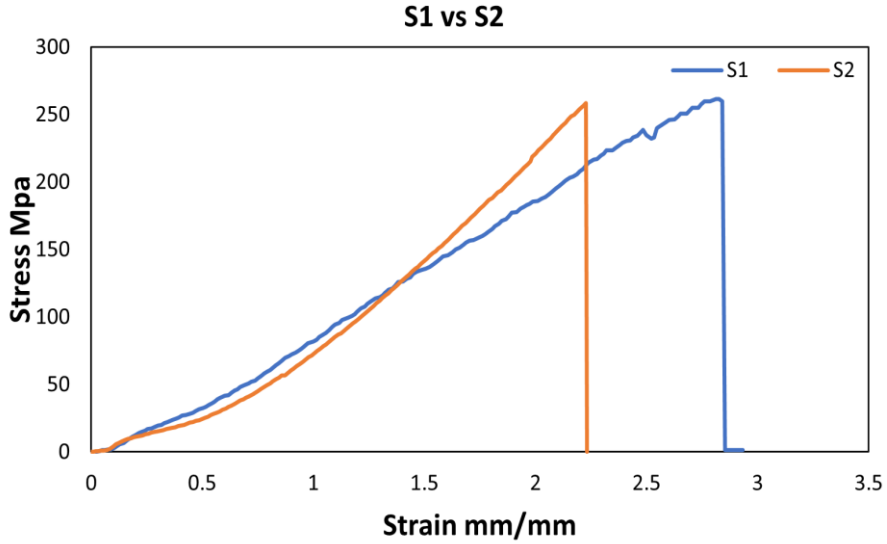

Fig. 17. Stress vs strain curve of 2D epoxy GF and 2D epoxy GF 0.25wt% CNT

On comparing the T1 & T2 specimens the results are similar to 2D where the ultimate tensile strength (UTM) is reduced by 21.6% in T2 specimen and aslo with reduced strain properties by 31.8% in figure 18

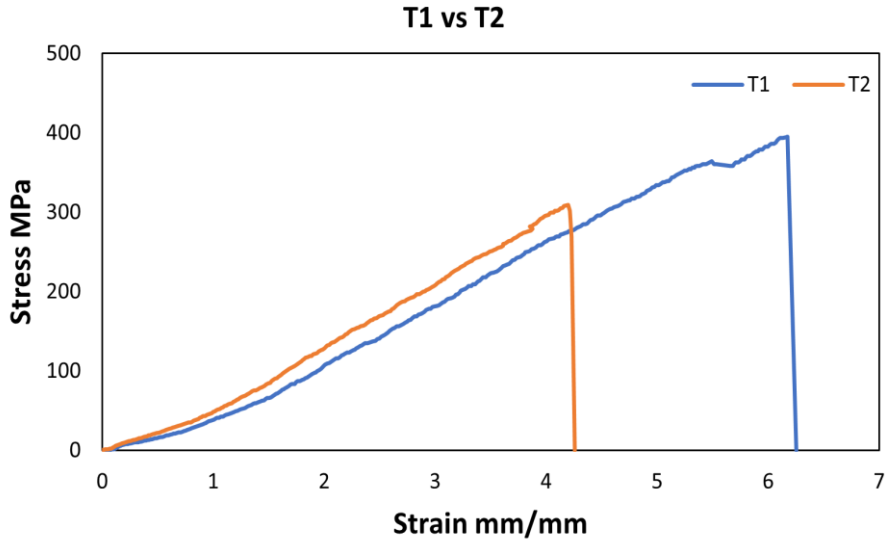

Fig. 18. Stress and strain curve of 3D epoxy GF warp and 3D GF warp 0.25wt% CNT

From Figure 18, U1 & U2 the CNT embedded U2 sample shows increase in UTM with 14.46% increase over epoxy 3D weft samples(U1). And increased strain rates of 51.1% in conclusion

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the 0.25wt % CNT increases tensile properties in the weft direction of the 3D composite

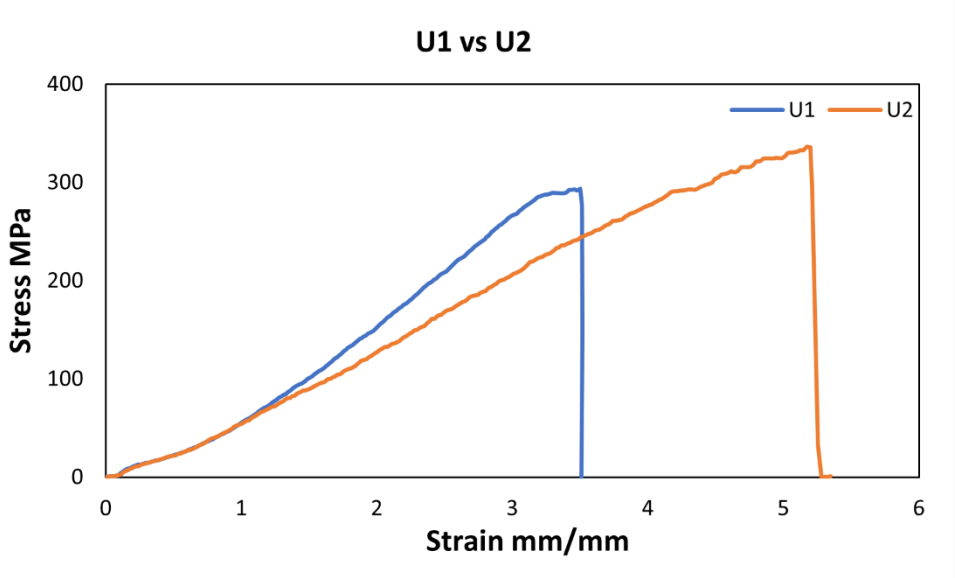

Fig. 19. Stress and strain curve of 3D epoxy GF weft and 3D GF weft 0.25wt% CNT

The comparison of 2D, 3D warp and 3D weft from the figure 20. It is observed that the ultimate tensile stress of T1 and U1 when compared with S1, are significantly higher at 50.8% and 12.1% respective. T1 and U1 has improved results than 2D glass fiber. On comparing T1 and U1 specimens the ultimate tensile strength of T1 increase by 25.6%.

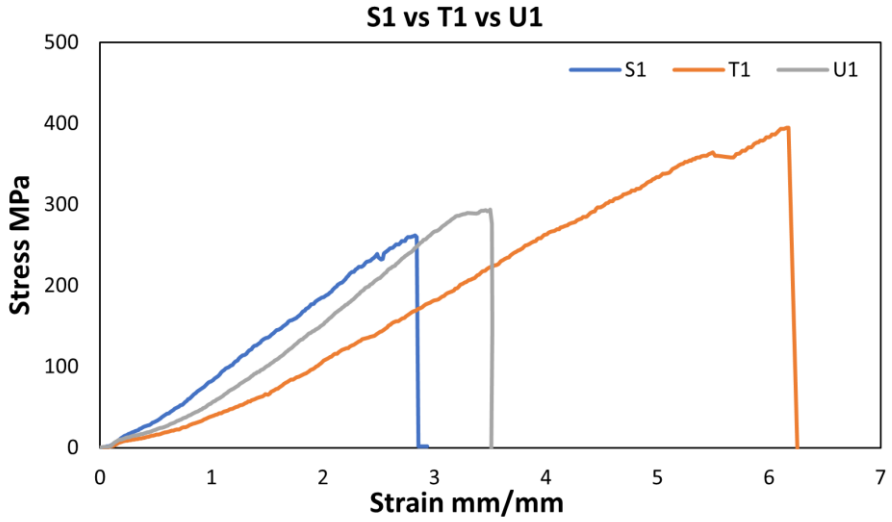

Fig. 20. Stress and strain curve of 2D epoxy GF & 3D epoxy GF warp & 3D epoxy GF weft

The comparison of 2D, 3D warp and 3D weft embedded with 0.25 wt % CNT from the figure 21. It is observed that the ultimate tensile stress of T2 and U2 when compared with S2, are significantly higher at 52.8% and 30 % respective. T2 and U2 shows tensile properties improved when compared with 2D glass fiber embedded with 0.25wt % CNT. On comparing T2 and U2 specimens the ultimate tensile strength of T2 improved by 14.8%. T2 and U2 are proven to have significantly greater elastic properties when compared with S2 specimens.

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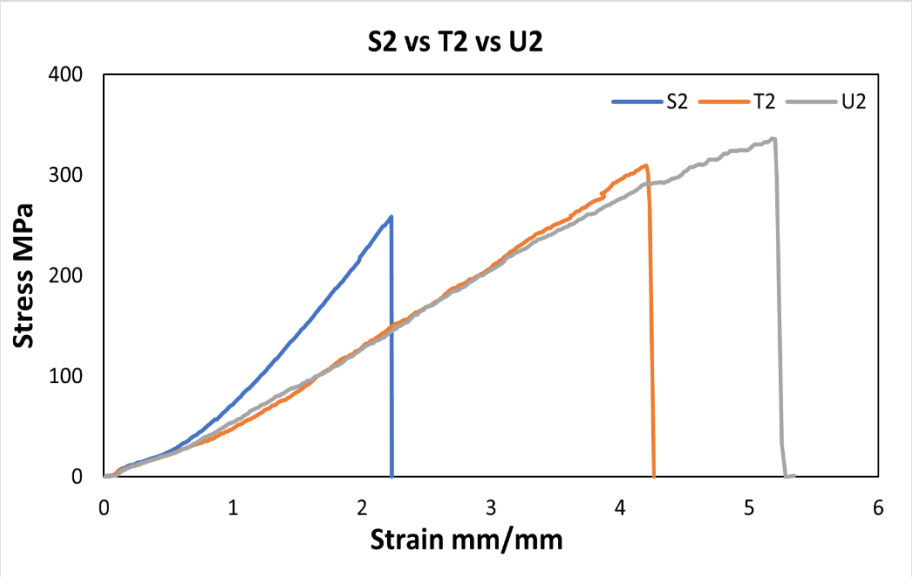

Fig. 21. Stress and strain curve pf 0.25wt% CNT of 2D GF & 3D GF warp and 3D GF weft.

The stress and strain were calculated using the following equation

$$\sigma = \frac{F}{A} \tag{1}$$

Where, σ- ultimate tensile strength (Mpa), F- force (N), A- cross sectional area(mm)

$$\varepsilon = \frac{\Delta L_0}{L_0} \tag{2}$$

Where, ε- strain value (%), L_0- gauge length of specimen (mm), ΔL_0- increase specimen length (mm)

Table 11. calculated tensile data

Samples	**Ultimate Tensile Strength (Mpa)**	**Force at break (N)**	**Strain (mm/mm)**
2D epoxy GF **(S1)**	261.74	15345.8	2.93
2D epoxy GF 0.25wt% **(S2)**	258.61	19245.27	2.31
3D epoxy warp **(T1)**	394.87	27971.3	6.25
3D warp 0.25 wt % CNT **(T2)**	309.54	22723.65	4.26
3D epoxy weft **(U1)**	293.71	22154.9	3.51
3D weft 0.25 wt % CNT **(U2)**	336.209	25370.63	5.34

The addition of 0.25 wt % CNT has improved the the tensile strength of 3D weft sample (U2), where as the tensile properties of 3D glassfiber warp (T2) and 2D glass fiber(S2) embedded with 0.25wt % CNT were significantly reduced.

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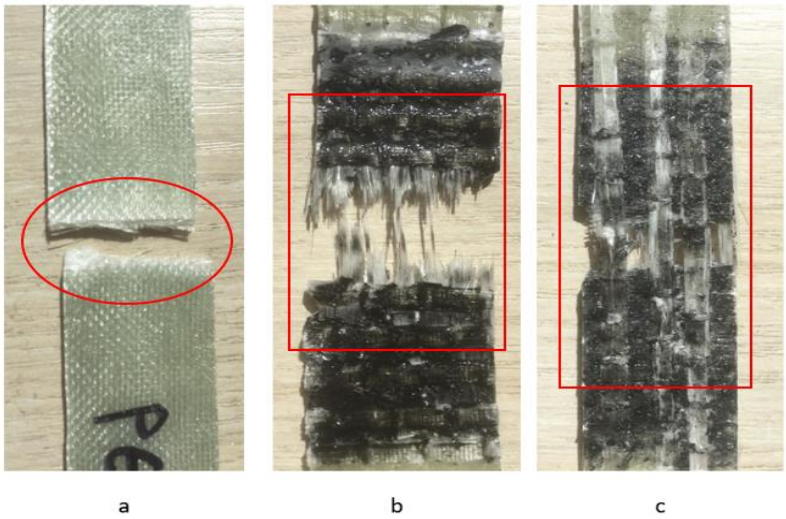

Fig. 22. Tensile specimen after breaking a) 2D epoxy GF, b) 3D GF warp 0.25wt% CNT and c) 3D GF weft 0.25wt% CNT

From Figure 22 (a) we can observe that 2D epoxy GF breaks without any fibre pull-out or damage to the matrix the material exposing limited elastic properties.

From Figure 22 (b) we observe that when 3D epoxy warp 0.25 wt% CNT breaks under tensile loading the matrix and the epoxy are able to hold the composite and it can be observed individual strands of fibre being pulled out from the fabric when the specimen reaches the ultimate tensile stress.

From Figure 22 (c) it is observe that when 3D epoxy GF weft 0.25 wt% reaches its ultimate tensile stress, the matrix breaks completely whereas the fibres are still intact and still bonded to the composite individual strands of glass fibre absorbing the energy before breaking.

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5.3. Flexural test results and discussion

According to the graphs in, Figure 23, the stress and strain of S2 have increased by 5% and 2%, respectively, as compared to 2D epoxy GF(S1) and 2D GF 0.25wt % CNT (S2) .
the infusion of CNT improves the flexural properties of S2

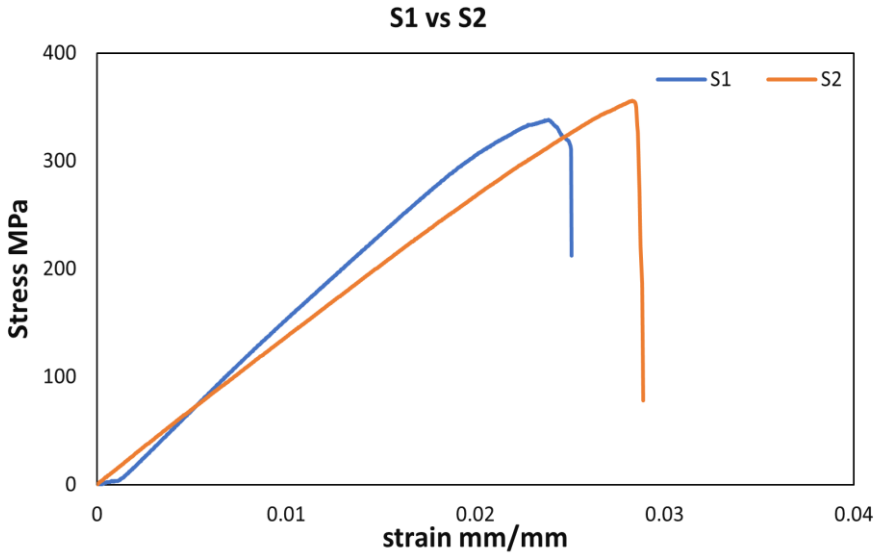

Fig. 23. Stress and strain curve of 2D epoxy GF and 2D GF 0.25 wt% CNT

In Figure 24, the flexural stress and strain of T2 decrease by 18% and 9%, respectively, as the effects of 3D GF warp(T1) and 3D GF warp 0.25 wt% CNT (T2). The flexural properties are reduced when CNT is infused in the warp direction

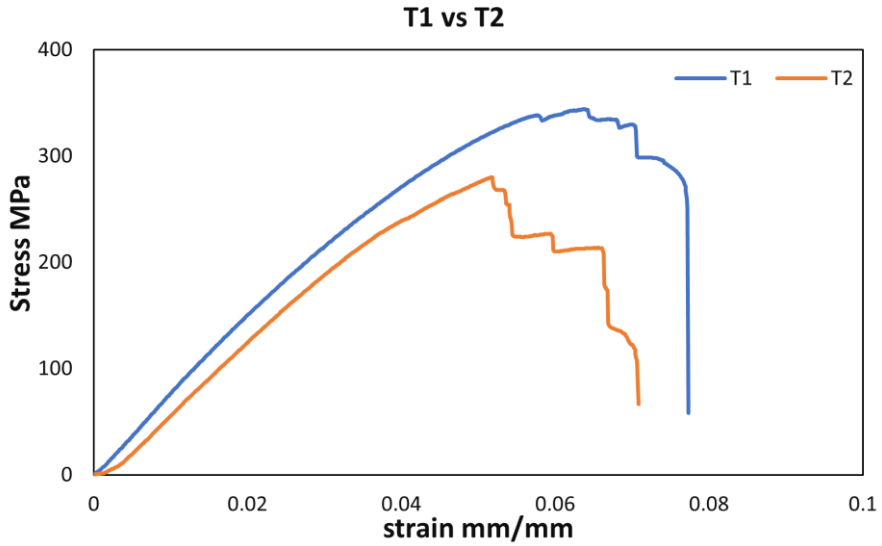

Fig. 24. Stress and strain curve of 3D epoxy GF warp & 3D GF warp 0.25 wt % CNT

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In Figure 25 , the graph of 3D GF(U1) weft & 3D GF weft 0.25 wt % CNT (U2) the infusion of CNT has marginally improved the flexural stress of U2 by 6%. The infusion of CNT in the weft directions improves the flexural properties

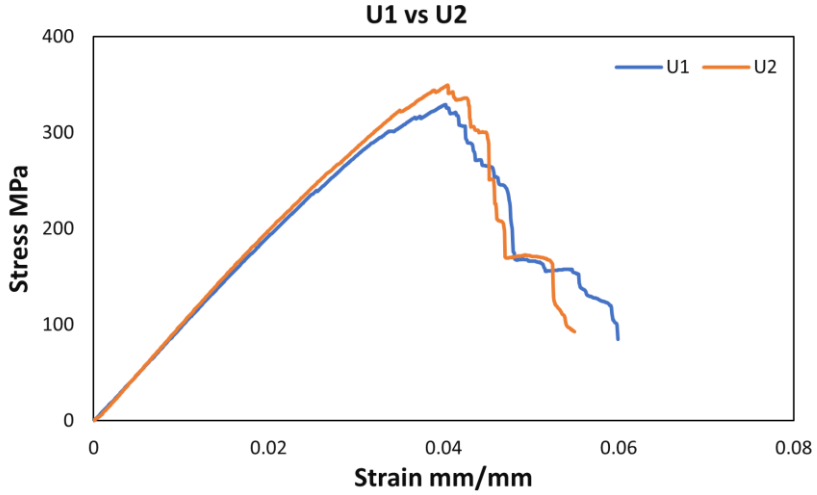

Fig. 25.stress and strain curve of 3D epoxy weft and 3D weft 0.25 wt% CNT

The comparison of epoxy composites S1, T1 and U1 from the figure 26. It is observed that the flexural stress of T1 increased by 1.91% and the strain % has improved by 208% and for U1 the stress decreased by 2.5% but the strain % improved by 136% when compared with S1 specimens. And on analysing T1 and U1, the stress decreased by 4% and the elongation is reduced when compared to T1.

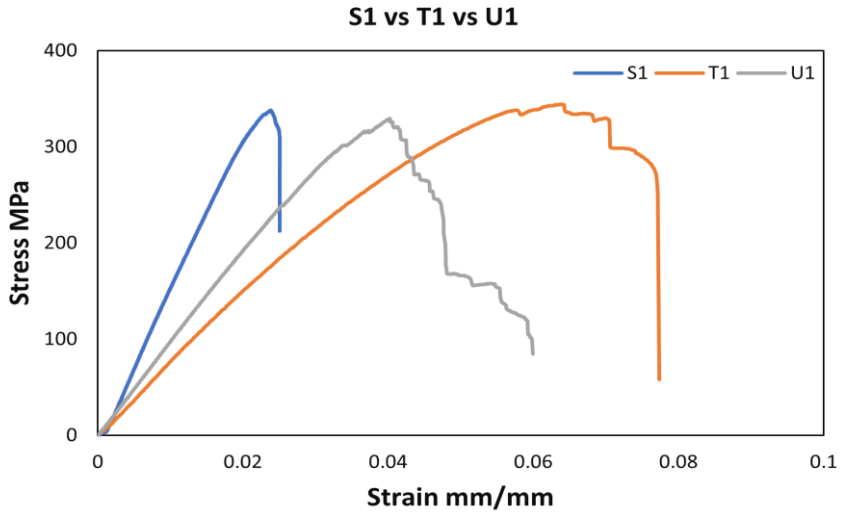

Fig. 26. Stress and strain of 2D epoxy GF & 3D GF warp & 3D GF weft

The following Figure 27 depicts a comparison of 2D, 3D warp, and 3D weft embedded with 0.25 wt.% CNT. In terms of flexural stress, there is no discernible difference between S2 and U2, despite the fact that U2 has improved flexural strain. When the T2 and U2 results are compared, the U2 specimen has significantly greater resistance to force, while the strain is decreased by 22% over the T2 specimen.

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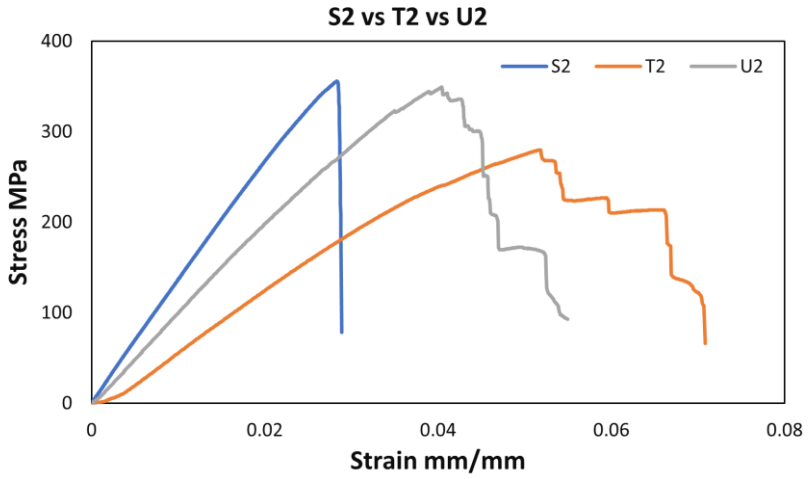

Fig. 27. Stress and strain of 0.25 wt % CNT. 2D GF & 3D GF warp & 3D GF weft

The stress and strength were calculated using the following equations

$$\sigma_f = \frac{3FL}{2bh^2} \tag{3}$$

where, σ_f-flexural stress (Mpa), F- load (N), L- span (mm), h-thickness (mm),b- width (mm)

$$\sigma_f = \frac{F_{max}}{bd^2} \tag{4}$$

where, F_{max} - maximum force (N), *b*- breadth (mm), *d*- thickness (mm)

Table 12. Flexural calculation

Samples	**Maximum Stress (Mpa)**	**Force at break (N)**	**Strain (mm/mm)**	**Flexural strength (Mpa)**
2D epoxy GF **(S1**)	337.90	375.64	2.5	226.26
2D GF 0.25wt% **(S2**)	355.78	583.47	2.8	352.72
3D epoxy GF warp (**T1)**	344.36	508.32	7.7	311.7
3D warp 0.25 wt % CNT **(T2)**	280.04	466.5	7.0	279.87
3D epoxy GF weft **(U1)**	329.33	538.82	5.9	338.4
3D weft 0.25 wt % CNT **(U2)**	349.33	566.88	5.4	360.2

According to Figure 28, the flexural strength of S2 and U2 specimens embedded with 0.25 wt % CNT improves by 55% and 6.4 % respectively when compared with S1 and U1 specimens, while the flexural strength of T2 specimen embedded with CNT declines by 10% when compared with T1. The calculated flexural properties are mentioned in Table 12

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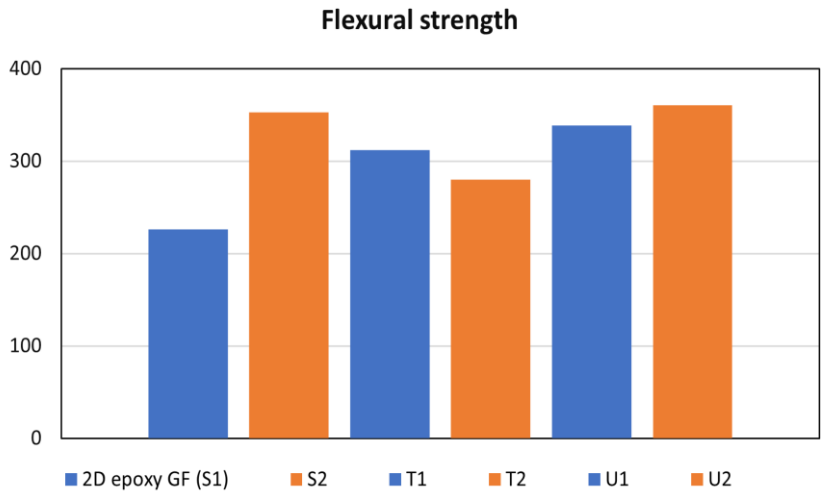

Fig. 28. Bar chart of Flexural strength

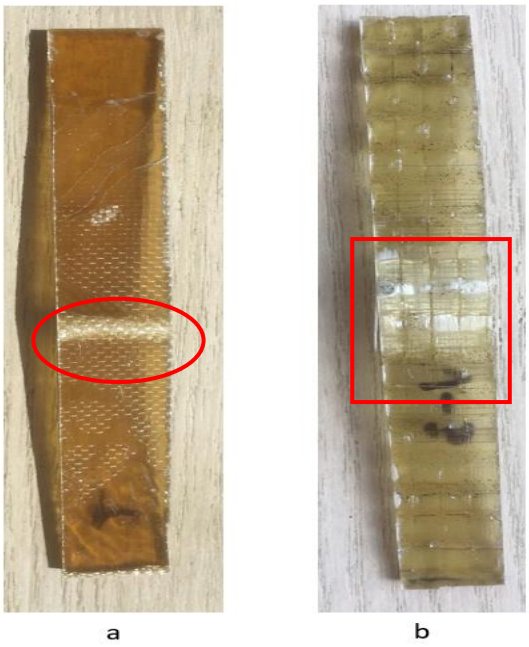

Fig. 29. Propagation of damage in **a)** 2D glass fiber and **b)** 3D glass fiber weft composite

In figure 29(a) the area marked by the red circle is a point where the load is applied on 2D epoxy GF and It is evident there is clear delamination visible at the point of loading, but propagation of damage through the fibre or the matrix is minimal.

From Figure29 (b) it is observed that observe that the delamination of the fibre/matrix and the propagation of damage through the composite is significantly higher in 3D epoxy GF warp than in 2D epoxy GF.

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5.4. Charpy impact test results and discussion

The impact strength as mentioned in Figure 30. There are no significant difference in between S1 and S2 specimen. However, the 3D specimens have better impact strength much significant that 2D specimens. CNT infused 3D specimens T2 and U2 have improved strength compared to T1 and U1 specimens at 51% and 92% respectively. In conclusion the 2D specimens are more brittle in nature when compared to 3D fiber composites

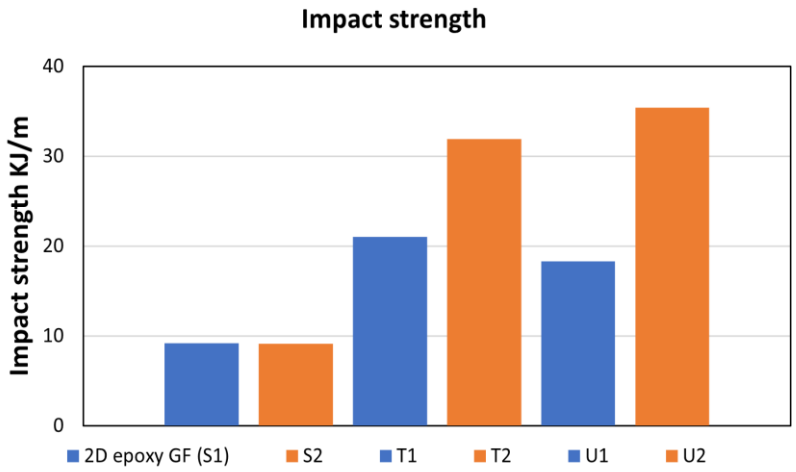

Fig. 30. Bar chart of impact strength

From Table 13, when comparing the results of impact energy absorbed by T1 and U1 is double that of S1 specimen. The addition of 0.25wt % CNT in S2 specimen decreased the specimens impact energy absorption. Whereas the impact energy absorption of 3D epoxy warp and weft embedded with 0.25 wt % CNT (T2 and U2) has significantly improved energy absorption by 21% and 11% respectively

The impact strength is calculated using the following equation

$$a_{CU} = \frac{w_B}{bh} \cdot 10^3 \quad (5)$$

Where, h-thickness (mm), b- width (mm), w_B- energy at break (J)

Table 13. average energy absorbed & impact strength.

samples	Average energy absorbed (J)	Average impact Strength (KJ/m^2)
2D epoxy GF **(S1)**	0.446	9.1
2D GF 0.25wt% CNT **(S2)**	0.474	9.1
3D epoxy warp (**T1)**	0.88	21
3D warp 0.25 wt % CNT **(T2)**	1.068	31.9
3D epoxy weft **(U1)**	1.656	18.3
3D weft 0.25 wt % CNT **(U2)**	1.85	35.3

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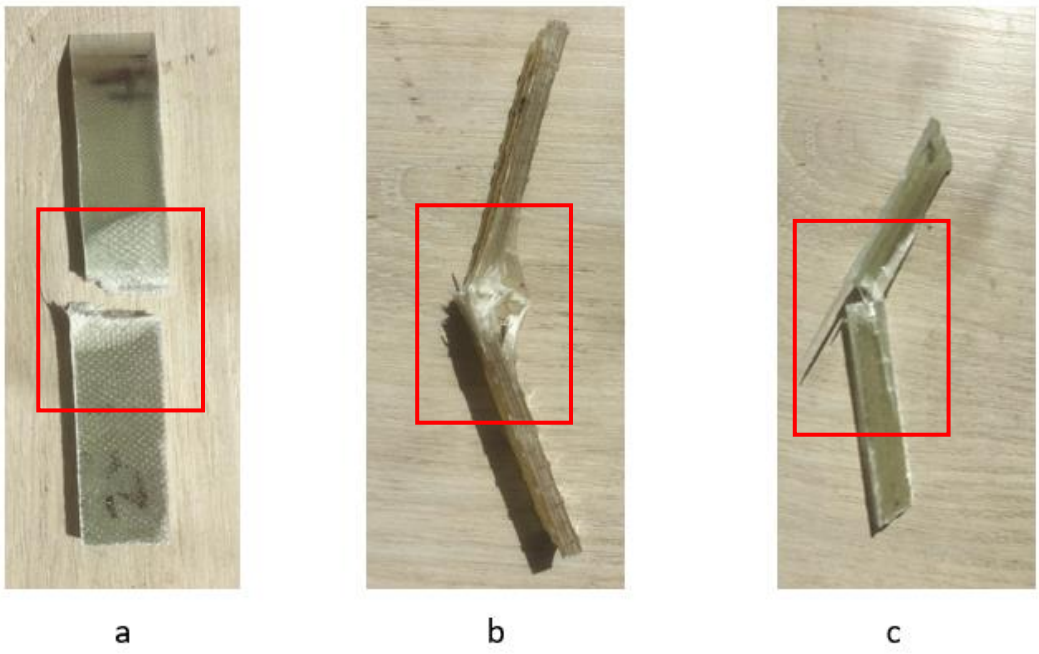

Fig. 31. propagation of damage in **a)** 2Depoxy GF composite**, b)** 3D epoxy GF warp, **c)** 3D epoxy GF weft

From Figure 31 (a) It is clear that under impact load, the 2D epoxy GF breaks entirely at the point of contact, with only minimal energy propagation through the fibres/matrix, resulting in a brittle material.

From Figure 31 (b) it is observed that due to impact loading on 3D epoxy GF warp there is maximum delamination in fiber/matrix. However, the specimen did not break completely resulting in a stiff material

In Figure 31 (c) similar results are obtained to figure 31 (b), where under impact loading, 3D epoxy GF weft shows visible fibre pull-outs without completely breaking and delamination of fiber/matrix.

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5.5. Inter laminar shear test results and discussion

From the Figure 32 , the laminar shear properties of S2 the force at break increases by 6% over S1 specimen due to infusion of CNT there are no significant difference in elongation.

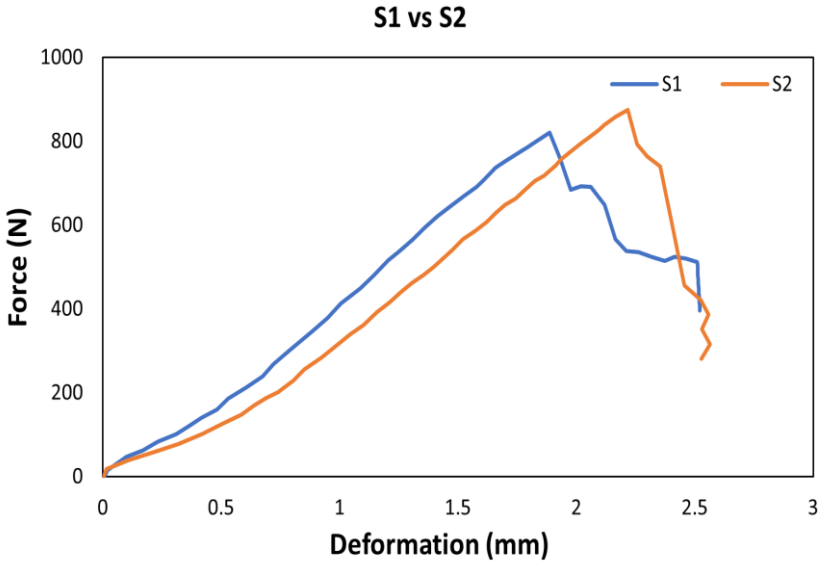

Fig. 32. Force vs deformation curve of 2D epoxy GF and 2D GF 0.25wt % CNT

figure 33 the maximum force resisted by T2 than T1 decreased by 18% and elongation increased by 7% .

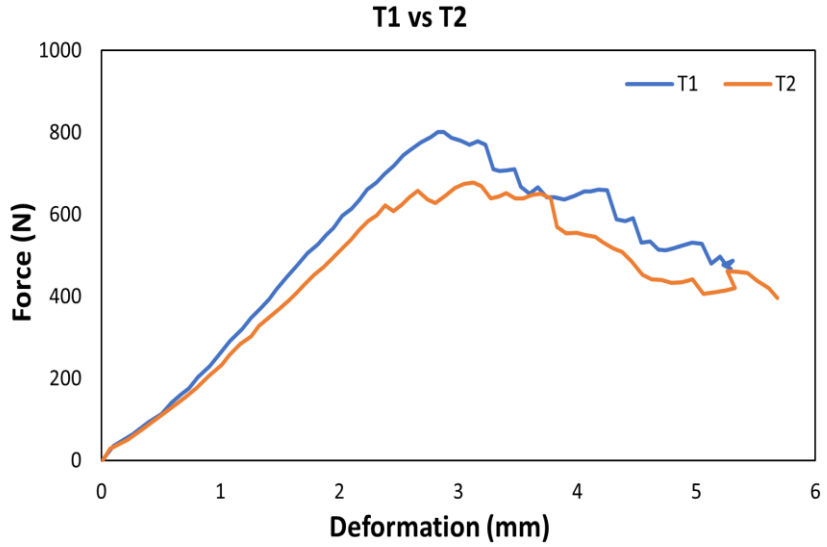

Fig. 33. Force vs deformation curve of 3D epoxyGF warp and 3D GF warp 0.25 wt% CNT

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In Figure 34, the interlaminar shear of U2 increases by 37% over U1 and a 4% increase in elongation

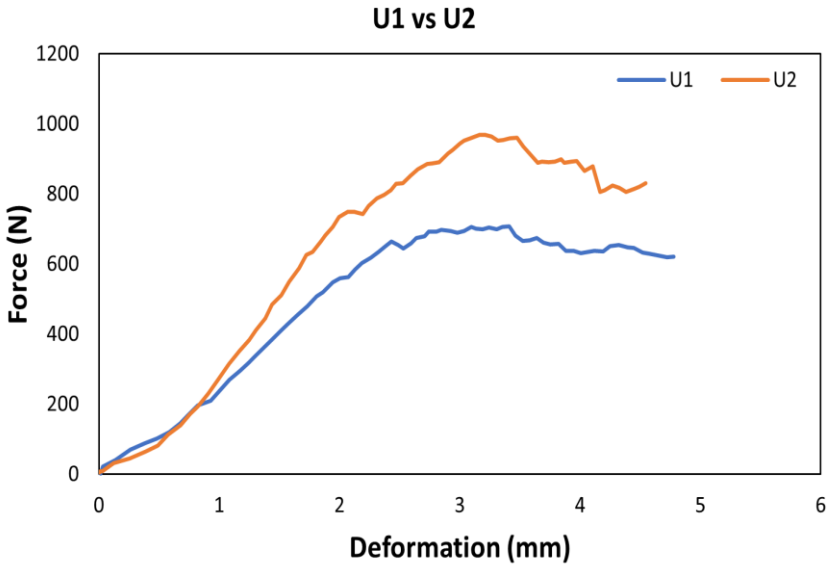

Fig. 34. Force vs deformation curve of 3D epoxy GF weft and 3D GF weft 0.25 wt% CNT

In figure 35, The S1 specimen has the maximum resistance to force at 820.92 Mpa but when compared to T1 and U1, 2D epoxy GF(S1) breaks immediately after reaching Maximum force, in 3D composites the interlaminar shear is significantly higher as the force propagates through layer by layer which can be seen in the graph the difference in elongation of S1 and T1, U1 composites where the difference is 108% and 80% respectively.

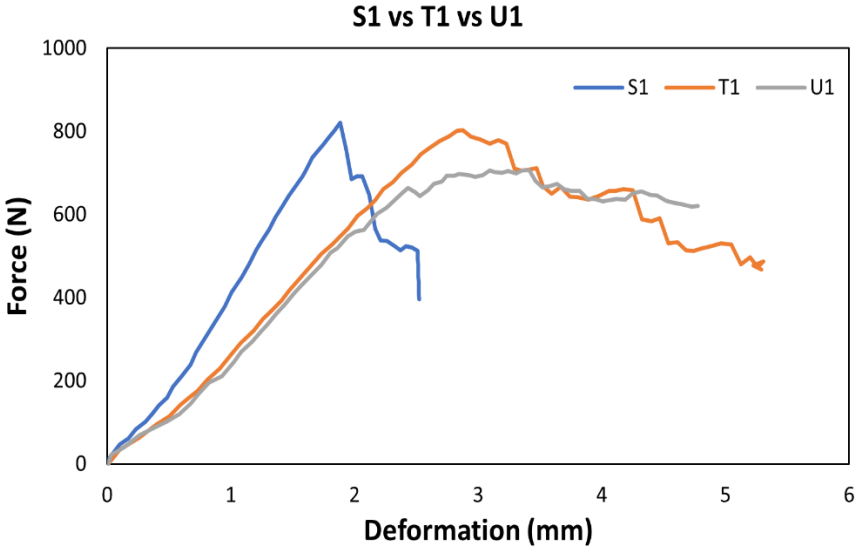

Fig. 35. Force vs displacement of epoxy GF & 3D warp & 3D weft

The comparison of S2, T2 & U2 specimens in figure 36. the infusion of 0.25 wt% CNT increased interlaminar shear properties of U2 by 10% and 47% than S2 and T2, respectively. And the elongation of U2 over S2 and has increased by 86% and decreased by 17% when compared with T2

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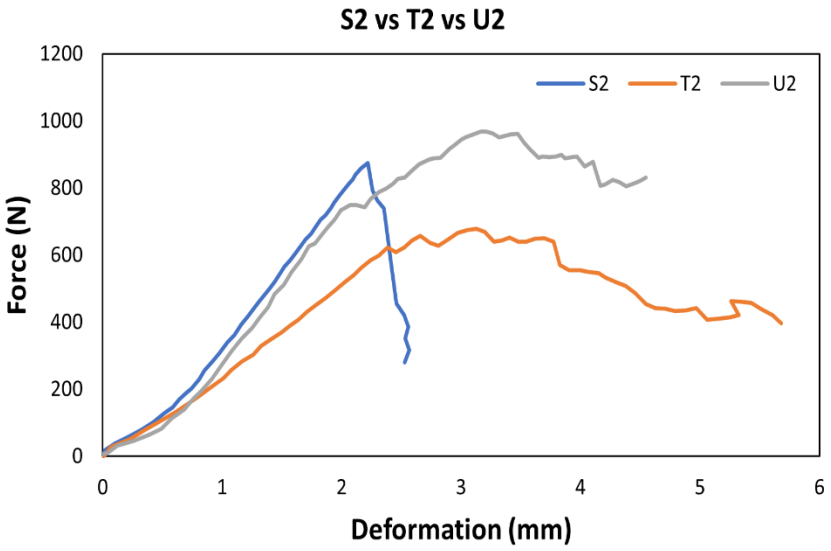

Fig. 36. Force vs displacement curve of 0.25 wt % 2D CNT GF & 3D warp & 3D weft

Interlaminar shear strength is calculated using the following equation

$$\tau = \frac{3}{4} \cdot \frac{F}{bh} \tag{6}$$

Were, F- maximum load (N), b-width (mm), h-thickness (mm)

Table 14. calculated interlaminar shear values

samples	Force at Break (N)	Deformation (mm)	Interlaminar shear (Mpa)
2D epoxy GF **(S1)**	820.92	2.52	184.70
2D epoxy GF 0.25wt% **(S2)**	874.26	2.52	196.72
3D epoxy warp (**T1)**	802.1	5.29	180.47
3D warp 0.25 wt % CNT**(T2)**	657.34	5.68	152.58
3D epoxy weft **(U1)**	706.3	4.5	159.08
3D weft 0.25 wt % CNT **(U2)**	969.12	4.7	218.05

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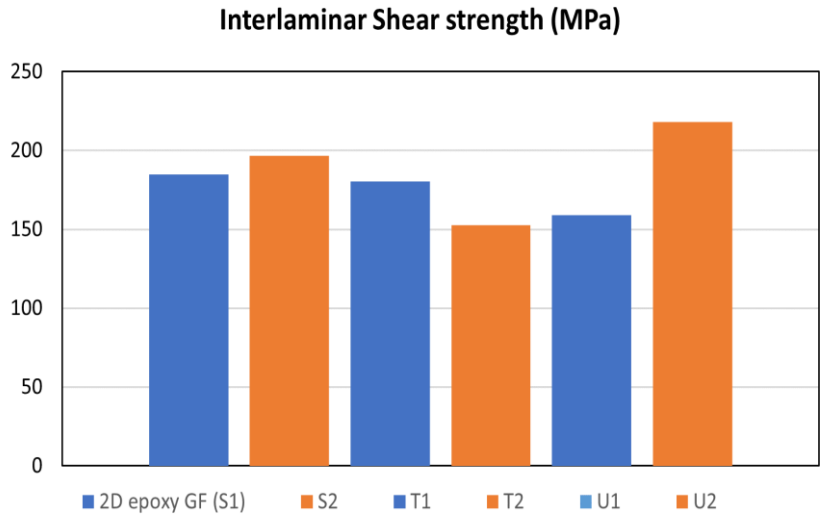

Fig. 37. Interlaminar shear strength

From Figure 37, the interlaminar shear strength of 0.25 wt% CNT embedded 2D glass fibre (S2) has increased by 6% when compared with 2D epoxy GF (S1). However, in comparison to 3D epoxy warp (T1), 0.25 wt% CNT 3D warp (T2) shows a decrease in shear strength by 15%. The shear strength of U2 increases by 37% when compared with U1 when infused with 0.25 wt% CNT.

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Discussion

The static analysis of 2D and 3D fiber composites with and without CNT yielded improved results in 2D composites and in the weft direction of 3 composites. During the manufacturing of 3D specimens with 0.25 wt% CNT nano fillers, it was difficult to distribute the nanofillers on the fiber sheet as its CNTs did not disperse adequately in the epoxy, and agglomeration of carbon nanotubes was noticeable**.**

Based on the results, it is clear that by infusing CNTs, the mechanical properties of 2D and 3D glass fibres can be optimized to achieve necessary properties. However, the majority of nanomaterials used have multi-functional properties and can be used in composites not just to produce a new material but also to improve mechanical and thermal properties. According to the results, the behaviour of the fiber and damage propagation in 2D and 3D fibres can be analysed further using ultrasonic analysis or SEM to better understand the failure mechanism.

The vacuum infusion method of resin infusion into 3D fibres was much more effective than the hand layup method used to manufacture 2D fibres. Further research should be performed to manufacture several layers of 2D fibres using vacuum infusion.

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Conclusion

In this study, 2D and 3D composites were tested under various mechanical conditions to simulate the loads acting on an automotive structure. The properties of pure epoxy and nanofiller specimens were assessed. Experimentation is carried out to determine the right material mix that can be used in a vehicle structure for improved mechanical properties.

1. Tensile tests were conducted on 2D and 3D epoxy GF and CNT embedded composites, and 3D GF weft embedded with CNT increased Ultimate tensile strength and strain by up to 14% and 52%, respectively, over the 3D epoxy GF. When the pure epoxy GF 2D and 3D samples were compared, the 3D epoxy GF had an exponential increase in both ultimate tensile stress and strain S1 and U1 (as seen in Table 2), and when 0.25 wt percent CNT embedded composites of 2D and 3D polymer composites were compared, the 3D epoxy GF had an exponential improvement in both ultimate tensile stress and strain S1 and U1 specimens.3D polymer composites have improved mechanical properties and have significant elastic properties.
2. The flexural test is performed using the ISO standards the flexural stress and strain of 2D and 3D weft infused with 0.25wt % CNT increased by 5%, 2.8 % and 6%, 8.4% respectively over pure epoxy GF 2D and 3D samples. Furthermore, the comparison between 2D epoxy GF and 3D epoxy GF (warp and weft) The 3D weft had improved flexural properties by 2% and on comparing 2D and 3D (warp and weft) embedded with 0.25 wt% CNT, 2D GF (S2) flexural stress increased by an overall 22% over 3D samples (T2 and U2). The flexural strength was highest in 2D epoxy embedded with CNT (S2), whereas all the 3D samples had much significant flexural elongation
3. The impact analysis is performed using Charpy testing with impact on the edgewise direction. 2D composites epoxy matrix and CNT embedded specimens showed brittle behaviour whereas and breaks at contact. The 3D composites (warp and weft) had exponential improved impact strength and were much resistant to impact and the specimens broke partially absorbing the energy significantly better.
4. Interlaminar shear test were performed to observe shear strength of 2D and 3D pure epoxy and CNT embedded polymer composite. It was observed that 3D weft embedded with CNT had the highest shear strength 218.05 Mpa followed by 2D GF embedded with CNT at 196.72 Mpa. The interlaminar laminar shear was much more significant in 3D polymer composites than 2D polymer composites where the specimen reaches maximum force it completely breaks
5. On comparing the mass of 2D and 3D composites. 3D composites had an average of 9% reduction in weight in tensile specimens 14% in bending, Charpy impact specimens and interlaminar shear.

In conclusion, when tested experimentally, 3D polymer composites and 2D composites embedded with CNT showed improved mechanical properties and can be considered a legitimate alternative to metals and traditional fiber composites in vehicle structures in exchange for increased stiffness and weight.

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Appendices

Appendix 1. Tensile test results

2D epoxy Glass fiber (S1)								
No	L	L_t	t	m	b	F	σ	Ɛ
	mm	mm	mm	g	mm	N	MPa	%
1	250	150	2.6	31.15	23.18	12740.2	210.53	3.0
2	250	150	2.6	30.71	22.77	15553.8	259.82	2.4
3	250	150	2.8	30.99	22.89	14417.8	225.3	2.5
4	250	150	2.6	31.15	23.03	16065.8	261.4	2.9
5	250	150	2.5	30.56	23.23	10450.6	174.5	1.7
Mean						13845.64	226.31	2.5
Std. deviation						2287.0	36.3	0.51

3D Glass fiber, epoxy warp (T1)								
No	L	L_t	t	m	b	F	σ	Ɛ
	mm	mm	mm	g	mm	N	MPa	%
1	250	150	3.1	29.95	24.6	19285.5	244.6	3.9
2	250	150	3.1	30.15	24.8	31284.1	394.8	6.2
3	250	150	3.3	29.99	24.6	30869.1	374.0	5.4
4	250	150	2.9	30.15	24.8	16533.8	222.2	3.48
5	250	150	2.6	29.88	24.7	26760.7	413.9	5.36
Mean						24946.64	329.9	4.868
Std. deviation						6733.3	89.5	1.13

3D Glass fiber, epoxy weft (U1)								
No	L	L_t	t	m	b	F	σ	Ɛ
	mm	mm	mm	g	mm	N	MPa	%
1	250	150	3.4	27.74	24.8	22702.3	311.2	4.6
2	250	150	3.5	27.5	24.8	24368	336.2	5.3
3	250	150	3.5	28.11	24.9	6298	288.1	3.84
4	250	150	3.1	28.38	24.9	21787	293.2	4.6
5	250	150	3.3	27.95	24.6	19459.1	262.0	3.6
Mean						18922.88	298.14	4.388
Std. deviation						7276.8	27.61	0.67

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2D Glass fiber, 0.25wt% CNT (S2)								
No	L	L_t	t	m	b	F	σ	Ɛ
	mm	mm	mm	g	mm	N	MPa	%
1	250	150	3.3	33.74	24.6	21113.1	255.2	2.5
2	250	150	3.4	32.5	24.8	18296.6	212.6	1.9
3	250	150	3.4	32.94	24.7	15150.6	176.5	1.7
4	250	150	3.3	33.28	24.3	18326.1	298.5	2.2
5	250	150	3.1	32.54	24.8	16825.1	212.1	1.8
Mean						17942.3	230.98	2.02
Std. deviation						2200.48	46.92	0.32

3D warp Glass fiber, 0.25 wt % CNT (T2)								
No	L	L_t	t	m	b	F	σ	Ɛ
	mm	mm	mm	g	mm	N	MPa	%
1	250	150	3.5	31.62	23.2	23667.6	287.0	4.2
2	250	150	3.4	32.4	22.9	22917.1	292.8	5.6
3	250	150	3.2	31.47	23.1	18929.4	254.5	3.6
4	250	150	3.5	31.5	23.0	22658.2	274.1	3.9
5	250	150	3.2	30.51	23.1	25612.9	345.3	4.45
Mean						22757.04	290.74	4.35
Std. deviation						2432.6	33.8	0.76

3D Glass fiber weft, 0.25 wt % CNT (U2)								
No	L	L_t	t	m	b	F	σ	Ɛ
	mm	mm	mm	g	mm	N	MPa	%
1	250	150	3.2	29.44	22.4	22625.8	309.0	4.6
2	250	150	3.2	28.75	22.3	24368	336.2	5.3
3	250	150	3.0	30.08	22.3	6298	288.1	3.8
4	250	150	3.3	29.18	22.5	22228.5	293.2	4.4
5	250	150	3.3	29.25	22.4	19459.1	262.0	3.7
Mean						18995.88	297.7	4.36
Std. deviation						7313.2	27.3	0.65

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Appendix 2. Flexural test results

2D epoxy Glass fiber (S1)									
No	L	Ls	t	m	b	F	σ	Ɛ	σ_f
	mm	mm	mm	g	mm	N	MPa	%	MPa
1	80	64	2.7	7.52	14.3	381.7	332.3	2.5	229.0
2	80	64	2.7	7.48	14.3	370	323.7	2.4	222
3	80	64	2.6	7.46	14.3	370	341.9	2.5	222
4	80	64	2.7	7.93	14.2	367.5	337.9	2.4	220.5
5	80	64	2.7	7.74	14.3	396.2	359.0	2.5	237.7
Mean						377.08	338.96	2.46	226.24
Std. deviation						12.03	13.12	0.054	7.20

3D Glass fiber, epoxy warp (T1)									
No	L	Ls	t	m	b	F	σ	Ɛ	σ_f
	mm	mm	mm	g	mm	N	MPa	%	MPa
1	80	64	2.9	6.57	14.6	560	433.7	6.6	336
2	80	64	3.1	6.79	15.0	612.8	393.0	7.6	367.6
3	80	64	3.0	6.49	14.5	522.5	375.4	8.1	313.5
4	80	64	3.1	6.38	14.9	518.6	334.7	8.0	311.1
5	80	64	3.3	6.76	15.2	365	222.9	8.1	219
Mean						515.78	351.94	7.68	309.44
Std. deviation						92.40	80.42	0.63	55.42

3D Glass fiber, epoxy weft (U1)									
No	L	Ls	t	m	b	F	σ	Ɛ	σ_f
	mm	mm	mm	g	mm	N	MPa	%	MPa
1	80	64	3.4	6.51	13.9	475	280.2	6.0	285
2	80	64	3.3	6.94	13.9	589.2	356.2	6.5	353.52
3	80	64	3.3	7.26	14.0	525.8	314.2	6.0	315.48
4	80	64	3.2	6.77	13.9	636.7	406.9	6.2	382.02
5	80	64	3.3	6.88	13.8	588.3	367.2	5.0	352.98
Mean						563	344.94	5.94	337.8
Std. deviation						63.01	48.9	0.56	37.81

2D Glass fiber, 0.25wt% CNT (S2)

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No	L	Ls	t	m	b	F	σ	Ɛ	σ_f
	mm	mm	mm	g	mm	N	MPa	%	MPa
1	80	64	3.4	7.9	14.9	603.3	335.8	3.0	361.9
2	80	64	3.1	7.82	15.0	612.2	394.6	2.9	367.3
3	80	64	3.2	7.79	14.7	514.7	324.4	2.7	308.8
4	80	64	3.2	7.81	14.9	632.4	386.1	2.9	379.4
5	80	64	3.2	7.79	15.0	579.2	341.3	2.6	347.5
Mean						588.3	356.4	2.82	352.9
Std. deviation						45.3	31.6	0.16	27.2

3D Glass fiber warp, 0.25 wt % CNT (T2)									
No	L	Ls	t	m	b	F	σ	Ɛ	σ_f
	mm	mm	mm	g	mm	N	MPa	%	MPa
1	80	64	3.3	7.15	14.1	568.3	344.6	5.7	340.98
2	80	64	3.3	6.68	14.3	445	273.2	7.0	267
3	80	64	3.3	6.82	14.4	477.5	277.0	7.1	286.5
4	80	64	3.2	7.37	14.1	454.5	285.6	7.8	272.7
5	80	64	3.3	7.06	14.5	370	271.0	7.6	222
Mean						463.06	290.28	7.04	277.8
Std. deviation						71.31	30.8	0.82	42.7

3D Glass fiber weft, 0.25 wt % CNT (T2)									
No	L	Ls	t	m	b	F	σ	Ɛ	σ_f
	mm	mm	mm	g	mm	N	MPa	%	MPa
1	80	64	3.5	7.04	14.3	604.4	432.6	5.7	362.64
2	80	64	2.9	7.15	14.3	594.2	429.8	5.7	356.52
3	80	64	3	7.26	14.4	605.8	447.4	5.3	363.48
4	80	64	3.0	6.85	14.2	632.5	472.1	5.1	379.5
5	80	64	2.9	6.74	14.4	566.7	418.9	5.4	340.02
Mean						600.72	440.1	5.4	360.43
Std. deviation						23.71	20.54	0.26	14.22

Appendix 3. Charpy impact test results

2D epoxy Glass fiber (S1)							
No	L	Ls	t	m	b	w_B	a_{CU}

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	mm	mm	mm	g	mm	J	KJ/m2
1	80	62	3.3	7.52	14.8	0.45	9.4
2	80	62	3.3	7.48	13.9	0.55	10.6
3	80	62	3.3	7.46	14.2	0.4	8.4
4	80	62	3.5	7.93	14.7	0.4	8.0
5	80	62	3.2	7.47	14.3	0.43	9.1
Mean						0.446	9.1
Std. deviation						0.061	1.00

3D Glass fiber, epoxy warp (T1)							
No	L	Ls	t	m	b	w_B	a_{CU}
	mm	mm	mm	g	mm	J	KJ/m2
1	80	62	3.3	7.15	14.8	1.3	26.3
2	80	62	3.3	6.68	13.9	1	21.3
3	80	62	3.1	6.82	14.2	0.7	15.6
4	80	62	3.4	7.37	14.7	0.8	15.6
5	80	62	3.3	7.06	14.3	0.6	12.5
Mean						0.88	18.26
Std. deviation						0.27	5.50

3D Glass fiber, epoxy weft (U1)							
No	L	Ls	t	m	b	w_B	a_{CU}
	mm	mm	mm	g	mm	J	KJ/m2
1	80	62	3.5	6.51	13.7	1.5	30.7
2	80	62	3.5	6.94	14.3	1.52	30.2
3	80	62	3.7	7.26	14.5	1.66	30.6
4	80	62	3.6	6.77	14.6	1.5	28.9
5	80	62	3.6	6.88	14.5	2.1	39.6
Mean						1.65	32
Std. deviation						0.25	4.30

2D Glass fiber, 0.25wt% CNT (S2)							
No	L	Ls	t	m	b	w_B	a_{CU}
	mm	mm	mm	g	mm	J	KJ/m2
1	80	62	3.6	7.9	14.3	0.5	9.5

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2	80	62	3.5	7.82	14.4	0.5	9.8
3	80	62	3.6	7.79	14.4	0.5	9.6
4	80	62	3.6	7.81	14.4	0.4	8.6
5	80	62	3.5	7.79	14.4	0.4	8.0
Mean						0.46	9.1
Std. deviation						0.054	0.76

3D Glass fiber warp, 0.25 wt % CNT (T2)							
No	L	Ls	t	m	b	w_B	a_{CU}
	mm	mm	mm	g	mm	J	KJ/m2
1	80	62	3.4	6.57	14.6	0.8	17.8
2	80	62	3.4	6.79	14.8	0.9	18.5
3	80	62	3.3	6.49	14.8	1.0	21.0
4	80	62	3.3	6.38	14.8	1.1	21.9
5	80	62	3.5	6.76	14.6	1.3	25.7
Mean						1.02	20.98
Std. deviation						0.19	3.13

3D Glass fiber weft, 0.25 wt % CNT (T2)							
No	L	Ls	t	m	b	w_B	a_{CU}
	mm	mm	mm	g	mm	J	KJ/m2
1	80	62	3.4	7.04	14.9	2.6	50.8
2	80	62	3.5	7.15	14.8	2.1	40.2
3	80	62	3.5	7.26	14.8	1.7	32.5
4	80	62	3.3	6.85	14.8	1.2	23.8
5	80	62	3.6	6.74	14.8	1.6	29.3
Mean						1.84	35.32
Std. deviation						0.53	10.49

Appendix 4. Interlaminar shear test results

2D epoxy Glass fiber (S1)								
No	L	Ls	t	m	b	F	Ɛ	τ
	mm	mm	mm	g	mm	N	mm	MPa
1	40	20	3.3	2.3	10	1017.17	3.1035	228.8
2	40	20	3.1	2.1	10	825.3	2.4788	185.6

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3	40	20	3.2	2.2	10	952.14	2.8221	214.2
4	40	20	3.2	2.2	10	948.85	2.7064	213.4
5	40	20	3.2	2.2	10	953.96	2.4474	214.6
Mean						939.484	2.71	211.32
Std. deviation						69.87	0.26	15.7

3D Glass fiber, epoxy warp (T1)								
No	L	Ls	t	m	b	F	Ɛ	τ
	mm	mm	mm	g	mm	N	mm	MPa
1	40	20	3.0	1.9	10	992.3	5.4175	223.2
2	40	20	2.9	1.8	10	952.3	5.8096	214.2
3	40	20	2.9	1.9	10	800	5.1593	180
4	40	20	2.9	1.9	10	764.7	5.363	172.05
5	40	20	3.1	2	10	782.6	5.7863	176.0
Mean						858.38	5.50	193.09
Std. deviation						105.69	0.28	23.76

3D Glass fiber, epoxy weft (U1)								
No	L	Ls	t	m	b	F	Ɛ	τ
	mm	mm	mm	g	mm	N	mm	MPa
1	40	20	2.9	1.9	10	663.2	5.1102	149.2
2	40	20	2.9	2	10	731	6.6977	164.4
3	40	20	2.9	1.9	10	742.9	5.1	167.1
4	40	20	2.9	1.9	10	805.4	6.6	181.2
5	40	20	3.0	1.9	10	762.2	5.4258	171.4
Mean						740.94	5.80012	166.66
Std. deviation						51.84	0.78	11.66

2D Glass fiber, 0.25wt% CNT (S2)								
No	L	Ls	t	m	b	F	Ɛ	τ
	mm	mm	mm	g	mm	N	mm	MPa
1	40	20	3.5	2.4	10	981.89	2.6324	220.9
2	40	20	3.5	2.4	10	884.52	2.3799	199.0
3	40	20	3.5	2.4	10	940.59	2.932	211.6
4	40	20	3.5	2.5	10	976.99	2.6016	219.8

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5	40	20	3.2	2.4	10	923.72	2.8032	207.8
Mean						941.54	2.6	211.82
Std. deviation						40.17	0.2	9.0

3D Glass fiber warp, 0.25 wt % CNT (T2)								
No	L	Ls	t	m	b	F	Ɛ	τ
	mm	mm	mm	g	mm	N	mm	MPa
1	40	20	3.4	2.2	10	871.6	6.6748	196.1
2	40	20	3.4	2.2	10	661.7	5.885	148.8
3	40	20	3.4	2.2	10	806.2	6.1963	181.3
4	40	20	3.2	2.1	10	916.8	7.2761	206.2
5	40	20	3.3	2.1	10	674.6	5.9018	151.7
Mean						786.1	6.38	176.82
Std. deviation						114.7	0.59	25.84

3D Glass fiber weft, 0.25 wt % CNT (U2)								
No	L	Ls	t	m	b	F	Ɛ	τ
	mm	mm	mm	g	mm	N	mm	MPa
1	40	20	3.0	2.1	10	1049.9	5.0973	236.2
2	40	20	3.0	2	10	1182	6.2561	265.9
3	40	20	3.0	2	10	1066.7	5.9495	240.0
4	40	20	3.1	2.2	10	843.2	6.0123	189.7
5	40	20	3.0	2.1	10	928.4	4.7411	208.8
Mean						1014.04	5.6	228.12
Std. deviation						131.1	0.65	29.50