Kaunas University of Technology
Faculty of Mechanical Engineering and Design

The Development of Hybrid Nanoreinforced Polymer Composites for Applications in Automotive Structures

Master's Final Degree Project

Ajun Wilson
Project author

Assoc. Prof. Dr. Daiva Zeleniakienė
Supervisor

Kaunas, 2020

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Vehicle Engineering (6211EX021)

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Assoc. Prof. Dr. Daiva Zeleniakienė

Supervisor

Assoc. Prof. Dr. Vitalis Leišis

Reviewer

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Ajun Wilson

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Declaration of Academic Integrity

I confirm that the final project of mine, Ajun Wilson, on the topic „The Development of Hybrid Nanoreinforced Polymer Composites for Applications in Automotive Structures" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

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Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Study programme: Vehicle Engineering (6211EX021)

Task of the Master's Final Degree Projects

Given to the student: Ajun, Wilson

1. Title of the Project:

The Development of Hybrid Nanoreinforced Polymer Composites for Applications in Automotive Structures

Hibridinių polimerinių kompozitų su nanoužpildais, skirtų automobilių konstrukciniams elementams, tyrimas

2. Aim of the Project: To develop a nanoreinforced composite and find application in automotive structure**.**

3. Tasks of the Project:

1. To model, a nano reinforced polymer composite material using the Ansys software
2. To evaluate the changes in polymer considering the nano reinforcement;
3. To perform structural analysis for the developed material under different loading conditions;
4. To model an automotive structure using the developed material;
5. To perform crash analysis of the automotive structure modelled by the new hybrid nano reinforced polymer composite using Ansys.

4. Structure of the Text Part:

The structure of the text part includes Literature review, Methodology, Modelling, Analysis, Results and the conclusion.

5. Structure of the Graphical Part:

Tabulated results, plotted graphs, experimental results.

6. Consultants of the Project:

Author of the Final Degree Project	Ajun Wilson *(abbreviation of the position, name, surname, signature, date)*
Supervisor of the Final Degree Project	Assoc. Prof. Dr. Daiva Zeleniakienė *(abbreviation of the position, name, surname, signature, date)*
Head of Study Programmes	prof. Artūras Keršys *(abbreviation of the position, name, surname, signature, date)*

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SUMMARY

The objective of the thesis is to develop a new hybrid nano reinforced polymer composite which has good mechanical properties and was applied in automobiles. Based on the fact that polymer composite matrix is filled with nanoparticles makes it possible to improve mechanical behaviour of composite, the hybrid nano reinforced polymer composite is developed based on different orientations and in which the higher elastic properties were achieved in the multi-directionally oriented material. The requirement of the improvement of the vehicle such as fuel efficiency, better performance and the strength of the vehicle causes the industrial automobile manufacturers to develop new materials and restructure old ones and correctly choosing materials. In this study, the stiffness behaviour of Hybrid fibre reinforced polymer composite has been analysed considering the nano reinforcement. Stiffness is a resistance which an elastic body provides to deflection or deformation by an applied force. The results obtained concludes the fitness of material for usage. Considering the application of the developed material in an automotive structure, an automotive hood is modelled with developed material properties and it is analysed under crash condition. The material selection strategy for individual parts of the car body is the most critical and complicated process affecting many fields which bringing together technologists, manufacturers, materials experts, managers which economists, as individual parts of the car body have a major effect on total fuel usage, environment, drivability, service and, ultimately, total automobile health. The usage of composite materials in automotive materials improves the strength, weight reduction and recyclability of the material. In this research, hybrid composite is considered, in which carbon nanotubes are infused through which a better material property is achieved. Vehicle crash modelling using computer software has been an invaluable method for shortening vehicle construction time and reducing costs. It also impacts a car's crashworthiness enormously. This research talks about a car artificial crash test. The purpose of this study is to model a frontal impact accident and verify results, the developed material in which the weight reduction is achieved and also the material withstands crash conditions as the other materials. The study shows that the nano reinforced polymer composites have a better future in the production of automotive structures and can be utilised in better ways

Wilson, Ajun. Hibridinių polimerinių kompozitų su nanoužpildais, skirtų automobilių konstrukciniams elementams, tyrimas. /**Doc. Dr. Daiva ZELENIAKIENE**; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas fakultetas.

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

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Santrauka

Darbo tikslas - sukurti naują automobilių pramonei skirtą hibridinį polimerinį nanokompozitą, pasižymintį geromis mechaninėmis savybėmis. Polimerinio kompozito matricą užpildant nanodalelėmis buvo pagerinta kompozito mechaninė elgsena. Hibridinis nanokompozitas buvo kuriamas suklojant pluoštą skirtingomis orientacijomis ir tokiu būdu medžiagoje buvo pasiektos geresnės tampriosios savybės. Didesnės degalų taupymo poreikis, svorio mažinimas, aplinkos standartai ir politika skatina automobilių gamintojus sutelkti dėmesį į naujų medžiagų kūrimą ir senų medžiagų modifikavimą bei teisingą medžiagų pasirinkimą. Šiame tyrime buvo išanalizuotas hibridiniu pluoštu armuoto polimero kompozito standumas, atsižvelgiant į nano užpildų įtaką. Gauti rezultatai rodo naujos medžiagos tinkamumą pritaikyti automobilių gamybai.

Atsižvelgiant į sukurtos medžiagos pritaikymą automobilių konstrukcijose, buvo modeliuojama automobilio gaubto mechaninė elgsena ir analizuojama avarijos sąlygomis. Medžiagų parinkimo strategija atskiroms automobilio kėbulo dalims yra pats kritiškiausias ir sudėtingiausias procesas, paveikiantis daugelį sričių, prie kurių dirba technologai, gamintojai, medžiagų ekspertai, vadovai, ekonomistai. Kompozicinių medžiagų naudojimas automobilių dalims pasižymi geru stiprumu ir mažu svoriu. Šiame tyrime nagrinėjamas hibridinis kompozitas, kuriame užpildams naudojami anglies nanovamzdeliai, kurių dėka pasiekiamos geresnės medžiagos savybės. Transporto priemonių katastrofų modeliavimas naudojant kompiuterio programinę įrangą buvo neįkainojamas būdas sutrumpinti transporto priemonės konstrukcijos laiką ir sumažinti išlaidas. Šis tyrimas pademonstruoja automobilio dirbtinio susidūrimo testą. Šio tyrimo tikslas yra modeliuoti priekinio smūgio avariją ir patikrinti sukurtą medžiagą, dėl kurios pasiekiamas svorio sumažinimas. Tyrimas rodo, kad nanodalelėmis sustiprinti polimero kompozitai turi perspektyvų gaminant automobilių konstrukcijas.

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Introduction

The Automotive industry comprises a wide range of materials to produce automotive structures. Various materials are used in the production of these structures. steel, copper, aluminium, plastics and carbon fibres are some of the frequently used materials. To be used as automotive parts, the materials used should obtain certain factors. The factors include the resistivity of factors such as mechanical, chemical and thermal, also it should possess easy machining and durability. Steel and aluminium were the prime materials used to make frames and engine parts. These materials have high mechanical properties and also achieves the conditions required for the manufacturing of automotive structures. But, in recent years the demand for lightweight and fuel-efficient Vehicles was increased. So that the use of plastic and composite materials in manufacturing was also increased. Meanwhile, most of the Industrial manufacturers were also interested in the composite materials which are energy efficient [1].

Different high-end companies such as Mercedes-Benz, BMW, Lamborghini used FRP materials in their products to maximize performance by reducing their product weight[2]. Since the cost of the composites were extremely high comparing to the materials that frequently used in the automotive industry. Many considerations should be taken into account, and the composite materials can be used easily in vehicles such as sports cars and high-performance cars. But also, it can be used in the minimum priced passenger cars by efficiently utilising composite materials. Hybrid composites are the materials comprised of two or more matrix of fibre[3]. Hybrid composites are more suitable for economical usage of composite materials in automotive structures. These materials hold the balanced properties of mechanical strength comparing to conventional composites and regular materials. Hybrid materials were used as the parts that do not require maximum strength and stand between the balanced state of performance. Various automotive structures such as a hood, door panel and bumpers were made using hybrid composites[2].

Nanocomposites are composites in which the matrixes were reinforced with nanoparticles. In a study, it is said that reinforcement of nanoparticles in the composites produce better mechanical properties. A study in which amino-modified double-wall carbon tube was reinforced with the carbon fibre/epoxy composite and various testing were made and it results as maximum enhancement made by the flexural modulus. Also, flexural strength and the absorbed impact energy is improved [4].

Nanocomposite materials including CNT and others are studied in this study and their properties were discussed. This study involves the research of the nanofillers in the polymer matrix. The major aim is to investigate a new hybrid nano-reinforced polymer composites for the automotive structure applications.This process includes modelling of a new nano reinforced hybrid polymer composites, and their mechanical properties were analysed and the automotive structure is developed using the properties. Followed by that the new nano reinforced hybrid polymer composite will be compared with existing material of the particular automotive structure.

The following tasks are,

- To model, a nano reinforced polymer composite material using the Ansys software.
- To evaluate the changes in polymer considering the nano reinforcement.
- To perform structural analysis for the developed material under different loading conditions.
- To model an automotive structure using the developed material.
- To perform crash analysis of the automotive structure modelled by the new hybrid nano reinforced polymer composite using Ansys.

1. Literature review

Composite materials are constructed with multiple components. The polymer groups are made up of bound groups of monomers. The most important application of the polymer group is polymer composites, natural and synthetic are the two forms of polymers. The nano-sized fillers are reinforced with the polymer composites to attain a new material property, and they are said to be the Nanocomposites[5].

The nanoparticles are bounded with hundred of atoms. These materials contain various particles with different properties. They are sized around 1 to 100 nanometers, the use of nanomaterials in various applications are largely increased in recent years. These materials are abundant in nature and available from the natural reactions occurred. Some of these materials are said to be toxic and cause health effects. But more of these materials are user friendly. In this case, when selecting the material the toxicity of the material should also be enquired with the mechanical properties. The Nanomaterial was obtained in both crystalline and amorphous form [6]. The composite materials in which the polymeric nanocomposites are said to be the new grade material. The general properties of these materials are far better than the traditional micro composites [7].
In modern engineering, the polymer nanocomposites are used in various applications. The polymers have only limited uses for the manufacture of goods and structures. When the polymer reinforced with a filler material and it is said to be the polymer nanocomposite. The properties of the material are completely depended upon filler material. The material was used in transportation and safety, they are used in weight reduction and also reduces the operating cost of transportation. Nowadays composite material is also used in space and aircraft industry. It is also used in Tissue engineering; it is mainly concerned with the replacement of the tissues which is caused by accident or sickness. The process in which a scaffold will be attached to the cells which are provided. The nanofibers give good condition to the growth of the cells. So that the cells attached to that grow along with them. These materials are also used in UV protection, they are used in the development of sunscreens, cosmetics, clothing etc. The polymer nanocomposites are also used as the energy storing devices in solar energy production. Materials like metals have issues like weight, wear and physical rigidity the polymer nanocomposites are used as the EMI shielding which includes shielding buildings, rooms and cabinets[8]. The polymer nanocomposites are still developing because of their unique properties. Most important applications of polymer nanocomposites are mentioned in Figure 1.

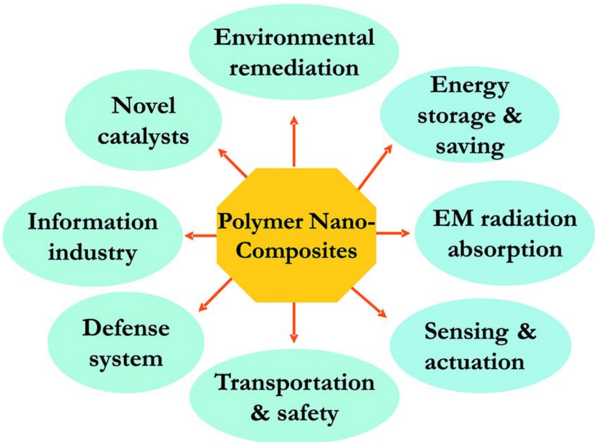


Figure 1: Application of polymer nanocomposites [9]

To know about the features and behaviour of the polymer nanocomposite material the properties should be studied. The density of the material is less than one-sixth compared to the steel. The young's modulus value is comparable to diamond. They also exhibit resilience so that the material can spring back to its shape and also can withstand bending. It was thermally stable in both air and vacuum, in case of the other materials such as metals lower value was obtained[9]. There are multiple materials under the nanocomposites and each has individual properties and its characteristics.

1.1. Hybrid composites

Hybrid composites are composite materials that perform at a balanced state of performance. Which has versatile properties like they are lightweight, lowcost, and also flexible. The hybrid composites are made from both natural and synthetic fibres. These materials are used in different sectors such as the automotive and its related field of production and also in different manufacturing sectors. In the automotive industry, there is a growing demand for lightweight vehicles to increase the efficiency and performance of the vehicles. In that case, composite materials were initialised. The composite materials weigh less than the commonly used materials but mechanical strength is much larger than the normally used materials in automotive industries. The hybrid composites were considered not just because of the average cost[2]. It also performs well compared to other materials. The manufacturing of these hybrid composites is based on the arrangement of fibre materials. Reinforcement of hybrid composites are classified into,

- Inter-ply hybrids: Such hybrid composite forms have two or three layers which do not interact with the hybrids.
- Intra-ply hybrids: This type, where the fibres tend to mix in almost the same surface.
- Intermingled hybrids: Either material mixed at random and made a hybrid shape, there is no material concentration within the substance.
- Selective hybrids: Such hybrid composites, in which the reinforcements are used in positions required to improve the strength with the laminates.
- Super hybrid composites: These composites, in which the plates were arranged in a specific arrangement with metal plates.

1.2. Nanofillers

Nanofillers are used as reinforcement materials for enhancing the mechanical properties of the matrix. Nanotechnology has become the admired field of material development and investigation. Nanofillers are said to be additives in solid form, and most of the nanofillers are available or extracted from nature. There are various types of nanofillers and each provides different characteristics and enhance variable properties.

1.2.1. Graphene

Graphene is a solitary carbon layer portrayed by a 2D honeycomb structure of sp2 hybridized carbon particles, this structure leads to display higher electrical conductivity in the surface and also produces better elasticity and the heat resistance is reduced. The major challenge is the breaking of graphite to the individual part which is said to be the graphene. But the stripping technique makes the process easier and also expensive[10]. So that it can only be used in large scale graphene production. Various strategies such as concoction adjustment of graphene which is placing potassium between the graphene to peel the graphene easier[11]. The shedding of graphite is also possible by utilizing intercalation specialists pursued by microwave heating[12]. Graphite oxidation is another strategy performed, by which the graphene oxide (GO) is obtained. The oxidation process is utilized by solid acids and the functionalities. The graphene is dispersed in water using epoxides and hydroxyls. Whether that is true or not, graphene oxide is non-conductive and it should be belittled to recreate the electrical conductivity by substance medications. e.g., utilizing hydrated hydrazine or by thermal annealing [13]. The graphene oxide can be functionalized synthetically with concoction breeds such as amines, isocyanates, diisocyanates, or alkyl lithium reagents by improving the dissolvability and upgrading the connections of polymeric networks[14]. Considering the carbon nanotube, the utilization of oxidizing systems and covalent modification can cause imperfections in the arrangement of the graphene layer. Despite the graphene oxide has been decreased, the electronic properties are changed based on the deformities. Subsequently, another probability is to utilize a non-covalent functionalization such as using surfactants and getting comparative outcomes showed up for the carbon nanotube. The use of the surfactant on the graphene layers enables water-soluble dispersion and aggregation resistance to corrosion. In an examination, it is known that the acquired stripping of graphite is better than extracting graphene by cationic surfactants in acidic corrosive with gentle ultrasonication [15].

Deformity occurrence becomes the major issue in the extraction of graphene, so another strategy has been introduced to acquire a deformity free graphene. In this strategy, without using the surfactants or substance adjustment the sonication is performed in appropriate solvents. But this strategy also has a few downsides. A strong dissolvable bubbling will interrupt the structure statement containing graphene. Also, this system is utilized to scatter the end material legitimately in a polymer yet the polymeric framework. [16]

1.2.2. MXenes

A different category of two-dimensional material has raised as the counterpart of the graphene which is said to be the MXenes. The synthesis of these materials was conducted by the selective etching process, this process is performed in the A layers at maximum room temperature. From the known strategy, the maximum stage powered is mixed with hydrofluoric corrosive (HF) for a specified time and it is washed with water till it reaches the required Ph range. Subsequently, the peeled layers like graphite are recovered and they are named as MXenes. For instance, an effective arrangement of 2D Ti_3C_2 was performed by peeling of Ti_3AlC_2 in half HF at required conditions.

The above plan of action in which Al atoms were displaced by O, OH or F molecules accordingly accompanies within the $M_{n+1}X_n$ layers. This bond starts to lose its strength when making their detachment into a simple process. Other than that the substitution of these layers attached by either two different bonds. This process enhances simple delamination of MXenes using the hydrogen fluoride which is conditioned at different stages using various solvents. Note that the delaminated MXenes in the TEM test this shows better results compared to the graphene utilisation. [17]. In specific cases, the solid etching agents are utilized at elevated temperature condition and that provides the extraction of carbide-determined carbon particles from An and M. In general, the exploratory conditions should be upgraded to achieve high return and brilliant MXenes, for example, the heat produced, the size of the molecule at the different stages and the focus of hydrogen fluoride. Layered MXenes offers exceptional properties for the transport of organic, physical, electrical and particles which guarantee a higher possibility of its usage in the future.
Wide work has been performed on this material investigating their usage in recent years in catalyst identification, vitality storage gadgets and adsorption considerations[18]. Inferable from the non-

required properties such as the limited semiconducting feature and the other defects, MXenes shows different profitable features which include the conductivity of the electrical parameters. And it can also be used as the filler material which promotes the material properties and also provides the material to withstand high elastic loads. But also there is a major drawback which is higher quantities of the Mxenes used as filler leads to reduce the properties because when using it as a filler the more quantity of it leads to agglomerate. The synthesis process of the MXene is listed in Figure 2.

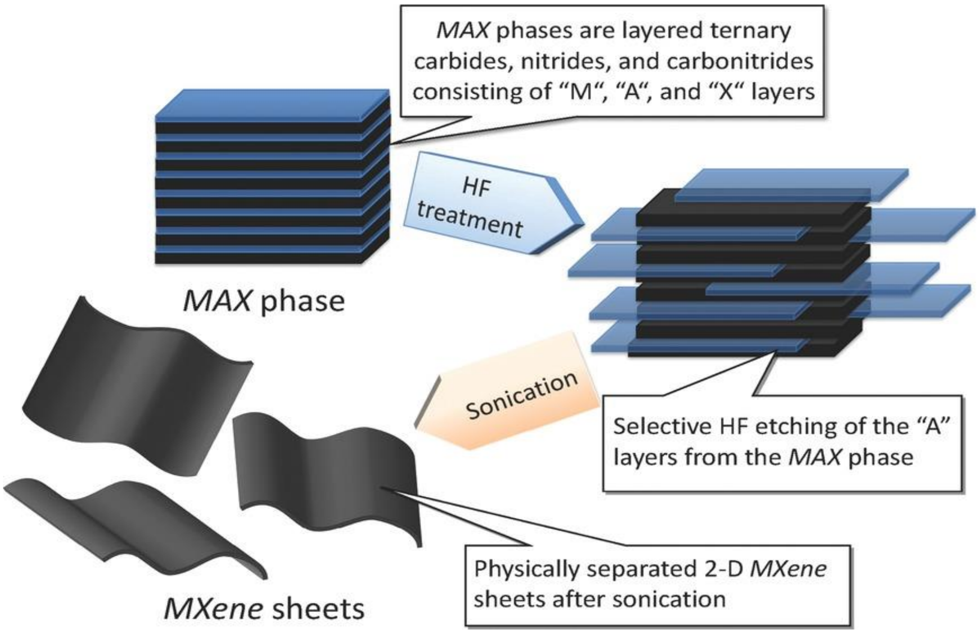


Figure 2:synthesis of MXene [21]

Electronic properties:

It is apparent from the above exchange that the external region of the discarded M and X layers are typically artificially eliminated or modified with O, F or OH functional groups in the watery condition of HF arrangements [19]. This surface functionalization leaves notable effects on MXenes' electronic and particle conducting properties which are legitimately matched to the conductivity and heterogeneous forms of electron exchange occurring on their surfaces. MXenes subsequently showcases fluctuating electronic action contingent on its functionality. For example, All perfect MXenes (M2X) are metallic due to its proximity of Fermi vitality at d orbitals of Metal progress. Some MXenes does not fulfil the required properties upon functionalization. Ti3C2, for example, is a carbide whereas Ti3C2F2 and Ti3C2OH2 are known as semiconductors. In several MXenes the p-groups of C or N (X) are below the d-groups of M's isolated by a small band opening Upon functionalization, new groups are formed under the Fermi vitality due to the hybridization between p orbitals of end bunches with d metal transition orbitals M [20]. Moreover, due to the lower electronegativity, M turns out to be effectively charged by the gift of electrons to X and the ending gatherings (F / O) in any way. From the above process, it structures the semi-conducting idea of different MXenes, e.g., Sc2CF2, Sc2COH2, Sc2CO2, Ti2CO2, Zr2CO2 and Hf2CO2, because to the transfer of Fermi energies towards the target of the hole between d groups of M and p X. The metallic to semiconductor behaviour is additionally based on the shift of MXenes periods T and H (honeycomb) materials where there is a distinction between the nuclear stacking successions of M molecules[21].

Mechanical properties:

Various experiments have been made to learn the mechanical properties. One of the previous studies of carbides and nitrides (Mxenes) discovered recently [22] are discussed in this section In the paper the MD analysis of 2D Tin+1Cn MXenes' and their behaviour on loading effects was studied. The goal of this study is to measure and compare the structural properties and elastic properties of the 2D Tin+1Cncarbides by high end molecular dynamic analysis with those extracted from the data on single-crystal cells[23]. They develop a clear and accurate approach in the missing of a unique force field for MXenes that could be utilized in the later study of the Mxene properties. With that approach, we will gain new insights into MXenes fracture modes.

Using the dynamic molecular simulation the properties of the 2D titanium carbides (MXenes) under tensile loading conditions were studied and they were simulated based on the modelling conditions. The stress and strain produced in the material create a linear curve. Young's modulus from these initial stress curve regions by linear fit is similar to previously published data[23]from DFT. The findings were replicated at various strain levels and known not to be considered to the strain rate within the produced range. The layers in the Mxenes decides the mechanical properties of the 2D Tin+1Cn atomic structure under tensile loading condition. This show the failure occurs at different n (layer thickness) for Tin+1Cn. For the thinnest Ti2C carbide the higher elastic modulus was produced. If the edge of the boundary seems to be visible in the region, it can be considered that due to the higher energy available in the surface of vacuum, the Mxene shrinks itself. The Ti4C3 as a test specimen in which, the material undergoes breakage and produce small pieces, and the small pieces regain its original shape which is flat because the tension produced is not enough to bare the highest stiffness of the Mxenes. The determined RDFs indicate that the local Tin+1Cn structure in all the samples remains intact after a fracture. A small increase in yield stress and the critical strain was observed with increasing rate, suggesting that Tin+1Cn MXenes can possess a typical metal defect formation and plastic deformation mechanism [24].

The MXenes studied are nearly twice as weak as atomically thin graphene with Young's modulus of $E = 1.0 \pm 0.1$ TPa [25]. Simultaneously, the elastic constant obtained for Ti2C is approximately twice that of $E = 0.33 \pm 0.07$ TPa [26] of MoS_2. Another 2D crystal with a similar structure. MXenes can thus be the preferred option among other 2D materials, beyond graphene, as potential materials for nanodevices with high mechanical property requirements or as reinforcement for composites.

Although the measured Young's moduli are similar to those previously obtained by DFT, we cannot say that other mechanical properties, such as yield stress and related strain, are reproduced correctly by classical MD in the absence of experimental data. However, apart from the good agreement with DFT results, our simulations have reproduced strain-rate effects, which are also observed in metal and graphene experiments [27]. In general, we conclude that the classical MD approach used correctly describes the mechanical behaviour of the two-dimensional titanium carbides and can be used in further investigation of the structural and mechanical properties of other bare and surface finished MXenes. Further efforts should be concentrated on the development and parameterisation of a consistent area of the force field (ReaxFF [28]or similar), Which could be used for traditional MD simulations of various MXenes.

1.2.3. Carbon Nanotubes

Based on their improvement times, carbon materials can be divided into three classifications: classic carbons, modern carbons, and nano carbons [29]. Classic carbons incorporate manufactured graphite squares primarily used as electrodes, carbon blacks, and actuated carbons, for which before the 1960s technology strategies were developed carbon materials were created during the 1960s, not quite the same as these great carbons: carbon filaments from different backgrounds, including vapour-developed carbon strands; synthetic vapour-delivered pyrolytic carbons affidavit forms; Glass-like carbons with high hardness and gas permeability; isotropic carbons of high thickness produced by isostatic pressing; For example, intercalation mixes with different functionalities, high electrical conductivity; And as straight carbon sheets, jewellike carbons. These carbon materials recently created are named new carbons. Several fullerenes with shut-off shell structure, carbon nanotubes with nanometer distances and graphene chips of just a few particle thicknesses have considered nanotechnology.; these are delegated nanocarbon.

However, if these carbon materials are viewed from a surface perspective, they may be divided into two groups: nanotextured carbons and nano-sized carbons. [30]. Most carbon materials in the modern carbon classification are called nanotextured carbon, since their nanotexture is regulated using various methods to produce them, given the basic controls. Again, fullerenes, carbon nanotubes and graphene may be considered nano-sized carbon since the shell size of fullerenes, the distance between carbon nanotubes and the graphene chip thickness are on the nanometer scale. Carbon blacks in large carbon are made of particles of nano-size but are usually not assigned nano carbons because they have different applications as mass, not as individual particles of nano size. The classification of the carbon materials is summarized in figure 3.

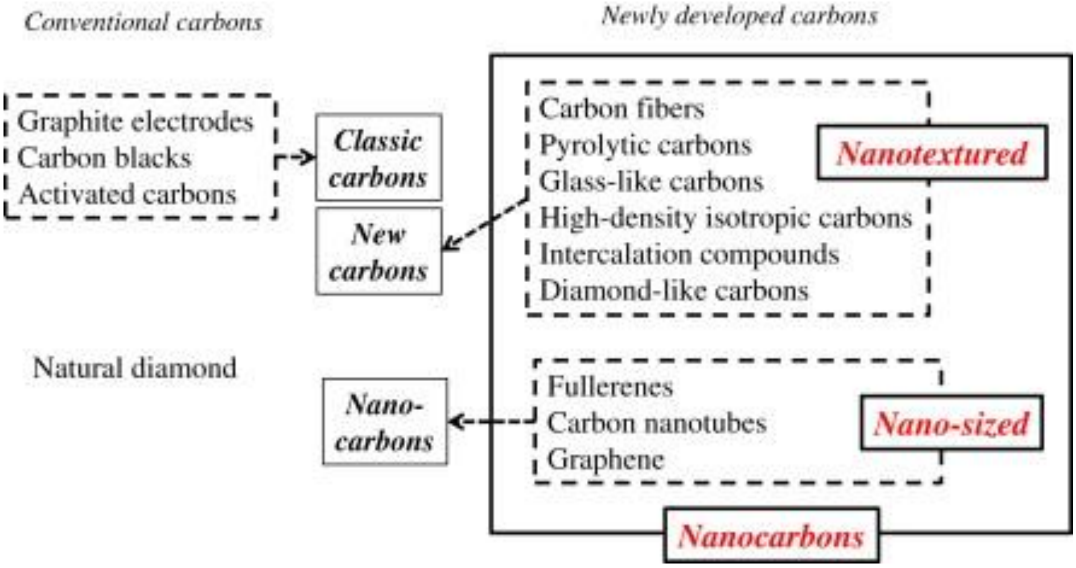


Figure 3: classification of carbon materials [31].

In the carbon literature, the rolling of a single layer of plane graphite also known as graphene structures itself into a single tubular shape known as a single-walled carbon nanotube. A multi-walled nanotube (MWNT) results in nesting of several SWNTs. Journet and Bernier[32] Detailed the key methods used for carbon nanotube generation. It is known that the single-walled and multi-walled CNT‘s are formed subliming the graphene in a circular segment which is electrified and released in an idle gas environment between two graphite terminals. This is a rational approach for acquiring meanwhile fairly large measures of low yield CNTs. Then again, laser graphite removal performed to gain more nanotubes, yet the amount produced was very less. And also the study from which it is known that the proximity of the resource material changed additional to the graphical goal, the production of single-walled carbon nanotubes were produced. Additionally, in a study [33] it is showed that brilliant SWCNTs can be obtained by methane concoction vapour at a defined temperature using a catalyst. Also, it is said that there is an irrelevance in the writing of the production of carbon nanotubes, the amount changes based on various aspects such as the reagents and the others. It is conceivable these fillers have higher elastic modulus, breaking down the big writing.

Electrical properties:

The major intriguing feature single-walled nanotubes are their behaviour towards the electric response is delicately depends on the chiral vector C, so the structure of the vector changes significantly. It is perhaps also the most important application property of nanotubes, because of the diffusion in the electrical junction where the metal gets closer to the semiconductor material, it gets free using only one element which is known as carbon[34]. Another essential property is electrical conductance, the conductance of mass semiconductors is contaminated by and large surface states. Nanotubes do not reveal surface conditions because their base content graphite is 2D at first and has no chemically responsive bonds. At this point, nanotubes use the process of shrinking itself up to frame a chamber that has no edges to dispose of the edges [35].

Mechanical properties:

As discussed above the carbon nanotubes have better electrical properties. But when considering the mechanical properties it's even more intriguing. To determine the mechanical properties, an SWNT rope was positioned between the edge of an atomic force microscope and the surface at which the single-wall nanotubes were formed, and rigidity was studied by eventually evacuating the atomic force microscope edge from the region [36]. The tensile loading experiment is given in the figure: 4.

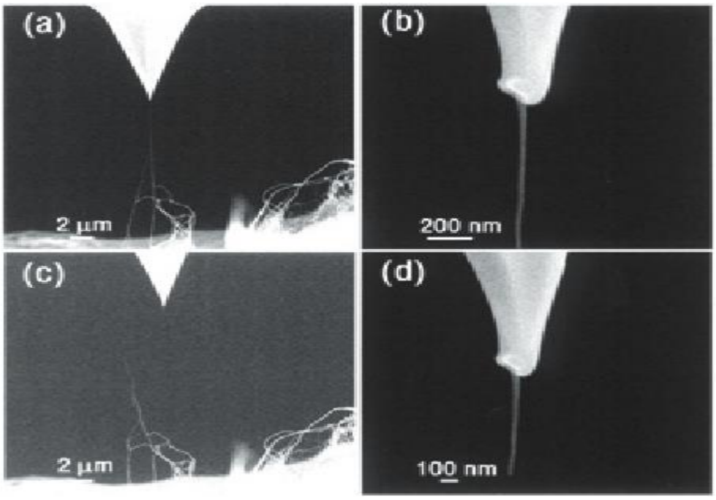


Figure 4:SEM images of the tensile loading experiment [35]

Both hypothetical estimations [37] and probes SWNTs [38] and MWNTs [36] brought about higher Young's modulus with lower esteems for SWNTs than for MWNT. For correlation, steel just has Young's modulus of 200 GPa yet its thickness is multiple times as high. So also, high qualities are given in for the nanotube. The elasticity produced by the nanotubes were much higher than the steel.

Generally speaking, a recognizable object is not as solid as its segments because tiny breaks gradually become larger, the substance is effectively broken when the left side of Figure 5 appears. In the off chance that a material made of a few carbon nanotubes should be restricted to such specific breaks and should not expand into other nanotubes that might make the nanotube product nearly as dense as nanotubes itself noticeable.

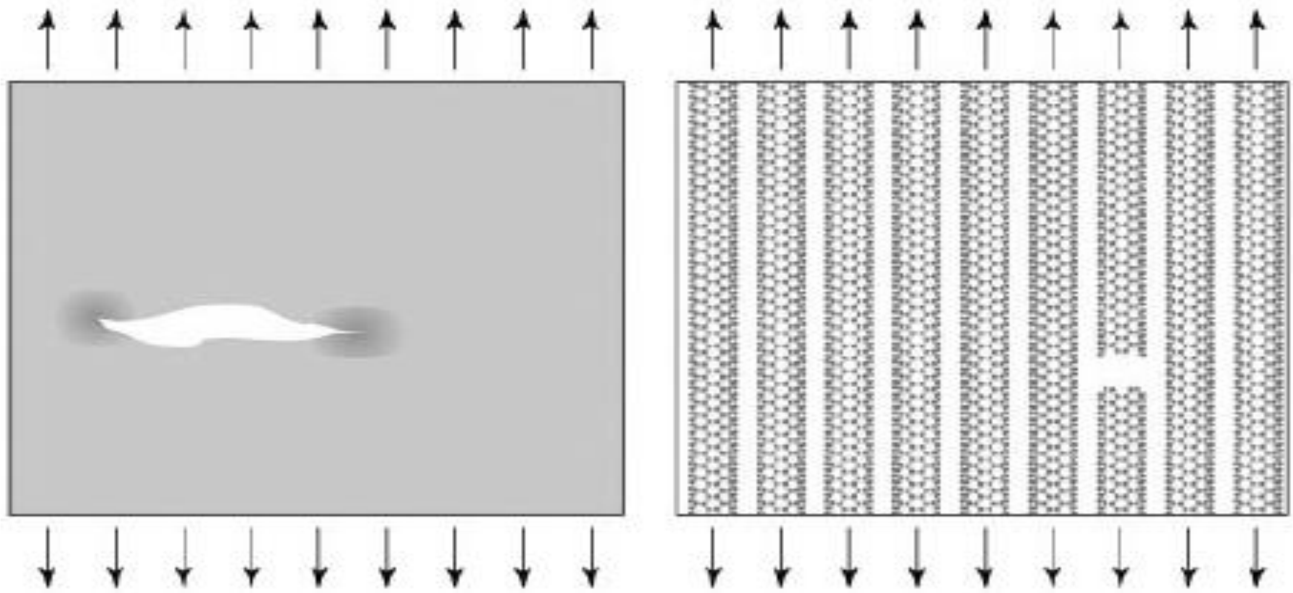


Figure 5: crack produced in conventional material and carbon nanotubes.[39]

1.2.4. Nano clays

Nano clays are the nanoparticles most widely found filler material. Such compounds are known to be the refined clays and are related to it as phyllosilicates as the shape of fibre-like hydrous silicates. Phyllosilicates have been classified into four clusters whose basic difference is the crystalline structure. chlorite [40].

Montmorillonites are by far the most analyzed and used to make polymeric lattices based on nanocomposites. This decision is common owing to its large proportion of perspective and the exceptional intercalation / shedding properties.

Most of the nanocomposites which are made of clay can accept two fundamentals that are based on the stages, in which the active region accommodated to the polymer region stabilized or exfoliated. the different possible morphologies that can be acquired when the dirt is spread in a polymer frame is represented in figure 6.

The off chance that the infiltration of polymer chains paves the way for limited silicate layer construction below 20–30 Å.The structure is described as polymerized; if the polymer basin prompts silicate tactoid cracking, the last structure is characterized as a shed. The very first contains multilayer polymer/silicate with a recurring range of only several nanometres; the other consists of different transition state within the polymer network[41].

The best blend of property enhancements was seen in most cases in exfoliated nanocomposites in light of the single tactoid's high surface territory. Again, the potential of normal clusters to translocate inside the active layer often relies on the technique of nanocomposite planning, Since the nano clay alteration is not necessary to achieve a maximum shedding of the layers.

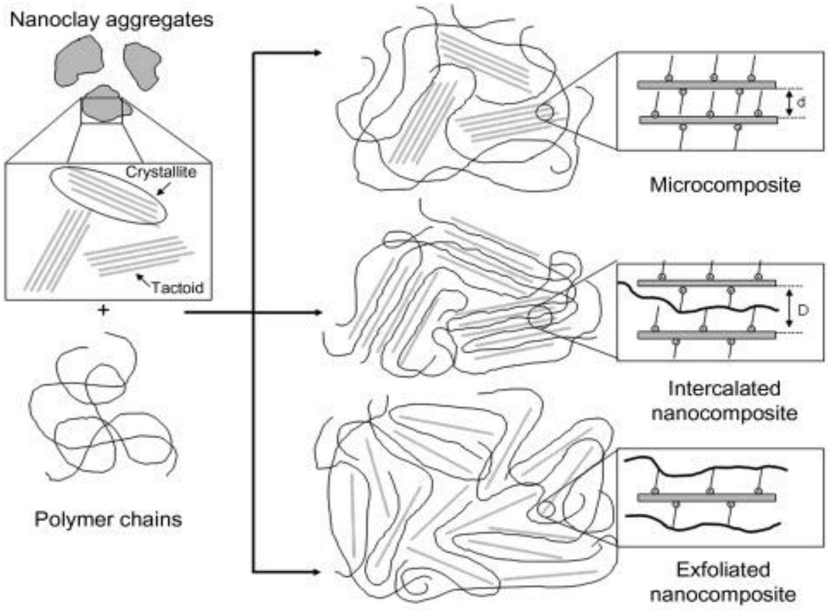


Figure 6: Dispersion of clay in the polymer matrix [42]

1.2.5. Carbon nanofibers

CNFs were first identified with carbon fibre production reactors, Rendered in bounty but compressed and collected across the fibres into a layer of carbon. Existing procedures for generating carbon nanofibre using a reactor that is held at a required temperature and supported by flammable emission of methane, iron pentacarbonyl and hydrogen sulfide. Iron particles, obtained from iron pentacarbonyl degradation, once dissipated and facilitated with sulphur, they were used as precursors to produce nanofibers. Some other ways to manufacture carbon nanofibres include polymer electrospinning, e.g. polyacrylonitrile, trailed through warm treatment in idle air or chemical vapour deposition.

CNF 's structure and condition can differ depending on the catalysts and production systems. Vapour-developed carbon nanofibers provided by them, as outlined by Tibbets et al. (2007), revealed an open core embraced by lined graphenes. A study in which it is said that the carbon nanofibers in which the reduction of hydrocarbon is performed based on various impulses. The carbon nanofibers never display an empty centre and it is fabricated by the layers of graphene [43].
Furthermore, the functionalization process can be performed with carbon nanofibers externally to increase additional strength of interface's fibre – polymeric network bond using chemical and physical connections. The basic treatment in vapour-developed nanofibers is solid acid oxidation that renders the filaments dispersible in water [44]. Different creators [45] United fragrant (ether-ketone) bunches on the outside of nanofibers revealing that modification improved the relation with aliphatic and sweet-smelling polymer grids allowing superior dispersion.

1.2.6. Nano Oxides

Silica, alumina and nanometric particle titanium are the frequently used polymeric nano oxides. These particles are described by small measurements which are around seven to forty nanometre, high explicit surface area, and round non-porous structures are large [46]. The method, which enables the obtaining of fine molecule oxides, consists at hydrolysis at high temperature. Nano silica fragments, for example, are produced by silicon tetrachloride hydrolysis, which occurs at extreme temperatures. Alumina and titanium nanoparticles can be detected independently through high-temperature hydrolyzation of aluminium trichloride and titanium tetrachloride. It is called fumed oxides that are structured along these sides. Different processes besides producing nanometric oxides are sol-gell systems or precipitation strategies; these methods also allow the acquisition of permeable nanometric particles.

1.2.7. Nano carbides

Carbides are hard compounds Typically employed as an unmanageable substance for elevated temperatures, or as abrasive powders. They are carbon mixtures and a metal or semimetal component that expect a variety of crystalline arrangements. Silicon carbide and boron carbide shows a structure like a precious stone, exhibiting the most remarkable carbide hardness, particularly boron carbide is said to be the denser material than jewellery and boron nitride. Most of the carbides are delivered from a modern perspective in an electric-bend heater where the relative oxides are allowed to respond with (carbon-warm decrease) [47]. Afterwards, the carbides are extracted to create the perfect grain scale.

1.2.8. General application of nanofillers

The nanofillers are identified as solid type additives and are used as an additive in various applications. Nanofillers are used in polymer composites to decrease residual stresses. These phenomena were obtained in the polymer composites during the heating and cooling phases of the manufacture due to the natural consistency of the matrix's physical and mechanical properties. The residual stress was generated on a small scale by the mismatch in the coefficient of thermal expansion and the elastic modulus between the fibres and the inner membrane [48]. When these difference between them increases the residual stress also increases. The nanofillers reduces residual stresses in the material.

In materials such as wood, the nanofillers are often used as coatings. Also, fillers are indeed a common part of the coating materials, whether to necessarily diminish the quality or even improve the hardness and rigidity of a polymer matrix. Typical wood surface fillers contain calcium carbonate, barium sulphate, talc and the various minerals made from silicate. Development of the properties with these fillers will always come with two downsides when they are micron-size, Loss of durability and loss in coating device clarity, restricting their use to surface paints and stained coatings. Over recent years, Research in nanomaterials has gradually grown in various development industries like the building industry. Insulation materials and certain innovations based on Nano are now available on a wide scale [49].

The carbon nanofillers were used for insulating ceramics machining. Stone crushing is common for the treatment of tough ceramics. Developing micro-components requires an alternative process, and then the addition of carbon nanotubes greatly improves the electrical properties of ceramic insulation, enables the use of electrical discharge machining to produce complicated parts. Also, the properties of the ceramic improved[50]. The above ones are some of the nanofillers' applications.

1.3. Nanofillers in fibre reinforced polymer composites

In the last 15 years, fibre-reinforced polymers, a new grade of high-quality, lower intensity has arisen as useful systems for key design applications in construction [51]. Growing demands for extraordinary materials have prompted the origin of composites because it is possible to integrate significant properties of various material kinds. Today, material design in the nuclear and atomic dimensions transforms the materials area and manufacturing [52].

The development of nanomaterials like Nano clays, carbon nanotubes gives new composite materials hope. The idea of using nanocomposites as a polymer matrix with fibre-reinforcing with a synthetic material was seen quite effectively. The researcher‘s main goal is to deliver smaller, lighter, tougher, and inexpensive materials. Some of those fibre reinforced polymer composites are explained in the following subsections.

1.3.1. Polyamide Nanocomposites

Nylon-6-based polymer nanocomposites were extracted that revealed the potential of nano clays as polymer reinforcement by Automotive researchers. The researchers reported that Nano clays also influenced the particle aggregation but also induced differential expression. Recognizing these effects, multiple sources have developed nanocomposites with improved properties using a variety of fillers and different fabrics.[53]

Mechanical properties:

Liu et al. [54] Throughout his study, he said that the storage elasticity module increased by 100 per cent when the dirt material was up to eight per cent of weight throughout the correlation of polyamide 11. In another study, a nanocomposite is developed using an organoclay which is polymerised. This material consists only of less weight mud and has had a half improvement in quality and an enhance in warm bending temperature, an expansion of maximum strength and minimum expansion in impact resistance [55].

1.3.2. Polyurethane Nanocomposites

Poulin [56] In his investigation he utilized conductive complex Polyaniline as well as sulfonated urethane to mix different phases of carbon nanotubes into polyurethane for nanofibre-contain handling. Composite nanofillers and films were formed by arrangement blending using the homogeneous SWCNTs / PU scattering.

In another study, [57] it is said that the manufacture and analysis of the melt-extrusion cycle of CNT / PU composite fibres, using synthetically functionalized multi-walled carbon nanotubes. Better distribution in polyurethane with multi-walled carbon nanotubes was achieved at a small fraction of weight and significantly improved overall mechanical properties. Mechanical tests concluded that the tensile strength increased compared to pure polyurethane thermoplastic.

1.3.3. Polypropylene Nanocomposites

There was a great deal of excitement regarding the possibility of developing nano-composite products including specialized characteristics of cheap price. Work on such products already exists for more than two decades. Great attention has been given to the composites of nano-platelets [58]. The minimal synthetic reagents such as polypropylene, mainly due to low tolerance to compression. The compression intensity of extruded polymer nanocomposites is usually modified to enhance the output efficiency of the surrounding matrix in the shear and the fabric asymmetry throughout the polymer by optimizing process variables, the polypropylene nanocomposites are most commonly used as the matrix material in the polymeric materials [53]

1.3.4. Polyesters Nanocomposites

Chandradass et. al. [59] Throughout this analysis, the fibre is effectively filled with esterified epoxy resin lined with the natural filler at room temperature alone utilizing manual designing techniques. The hybrid composites were produced by different stages: organoclay was blended with vinyl ester pitch in the initial step and the final phase was the manual processing method to create composites comprising four continuous fibre tangle layers (CSM).
Jawahar and Balasubramanian [60] in his studies performed research developing a hybrid composite material using the clay as fillers. The developed material is tested and the results show that the mechanical properties were improved, the test was performed infusing the filler at different volume fraction, and it is noted that under infusion of filler the laminates showed the best properties.

1.3.5. Hybrid Nanofillers

In a polymer matrix body, this particular class of composites requires the use of one or more different components to be hybridised, many of which are substantially different in their physical and chemical properties compared to those mixed. Single component nanofiller has demonstrated several efficiency drawbacks, which can be solved with two separate components by hybrid nanofillers. In these cases of hybridization, multiple attempts have been made and they are explained below;
In research [61] Montmorillonite (MMT)/Graphene Oxide (GO) hybrid nanofillers were developed by self-assembly and then integrated by electrospinning into the polyacrylonitrile (PAN) nanofibers. A study of the architectures of MMT/GO hybrid nanofillers was carried out using X-ray diffraction (XRD), atomic force microscopy (AFM), and transmission electron microscopy (TEM). The MMT / GO composite nanofillers exhibited stronger thermal and mechanical properties compared with MMT.

The other research [62] In which the improved PVA composite GO-SiO2 hybrid nanofillers is produced. This method is achieved by inserting the polyvinyl alcohol into the hybrid nanofiller disintegrated in water. The hybrid filler material was produced shows better performance in the distribution of the polyvinyl matrix, but in the case of graphene oxide and the silicon, the results were comparatively poor. It is found that the hybrid fillers produce a strong bond with the polyvinyl matrix. The material is developed considering one volume per cent of the hybrid nanofillers. And in this case, the mechanical properties of the developed material showed better performance. This illustrates the combined effect of graphene oxide and silicon dioxide.

1.4. Finite element modelling of FRP composites.

Fibre-reinforced polymer composite (FRP), because of its unique features, goods are ideal for a broad range of applications, which also include lightweight, high power, low electromagnetic and thermal conductivity and corrosion resistance, but also the capacity to create tailored forms and adapt mechanical properties. Although FRP composites have been used in industries such as aerospace, maritime and automobile production, and wind turbines for several decades, their application to civil engineering, especially building projects, has become more recent in contrast. Simulation of these products based on their mechanical properties and fatigue and simulation using finite element analysis.

The finite element approach of structural design has been known of modern times as the widely recognized form of study. This approach in structural designing refers to the growth of the calculations performed to explain the impact produced in a standard structure. The finite element is approached based on the study of matrices which are grouped and also they are symmetric. The geometric complexity of the framework is not limited, as the mass and rigidity matrices are built with simple shapes from the inputs of the real numerical simulation [63].

Usually, the sum of parameters in the manufacturing of composites is immense. Also, the specifications of the process and system design, Additional aspects that should be examined are the highly nonlinear and orthotropic nature of the substance and the fibre-directional machining. Throughout this way, it is rather detailed, repetitive and un-practical to determine by exams alone on the perfect machining response. Finite element simulation is applied to predict metal working reactions, and composites are being subjected to a related process. The advantage of this approach depends on its ability to display the process to achieve the study and to play out a parametric report by fluctuating the information factors appropriately. Industrially available, minimal part research programming device, the symmetrical machining of unidirectional carbon fibre reinforced polymer and glass fibre-reinforced polymer composites was demonstrated, and applications such as ANSYS were also used[64].

The properties used during FE simulation are given in Table 1.

Table 1: Common material properties used in the simulation.

Fibre (carbon)	Elastic constants (tension)	E_{11} = 235 GPa, E_{22} = 14 GPa, G_{12} = 28 GPa, t_{12} = 0.2
	Elastic constants (compression)	E_{11} = 110 GPa, E_{22} = 14 GPa, G_{12} = 28 GPa, t_{12} = 0.2
	Tensile strength	X_t = 3.59 GPa, Y_t = 0.35 GPa
	Compressive strength	X_c = 1.8 GPa, Y_c = 2.73 GPa
	Shear strength	S = 0.38 GPa
	Diameter	d = 10 μm
Fibre (glass)	Elastic constants	E = 72 GPa, t_{12} = 0.22
	Tensile strength	σ_t = 3.4 GPa
	Diameter	d = 10 μm
Matrix (epoxy)	Elastic constant	E = 3.1 GPa, t12 = 0.33
	Tensile strength	σ_t = 70 MPa
Fibre–matrix interface	Normal strength	160 MPa (UD-GFRP), 167.5 MPa (UD-CFRP)
	Shear strength	34 MPa (UD-GFRP), 25 MPa (UD-CFRP)
	Work of separation	50 N/m (UD-GFRP), 50 N/m (UD-CFRP)
EHM (UD-CFRP)	Elastic constants	E_{11} = 140 GPa, E_{22} = 11 GPa, G_{12} = 6 GPa, t_{12} = 0.38
EHM (UD-GFRP)	Elastic constants	E_{11} = 35.9 GPa, E_{22} = 4.55 GPa, G_{12} = 3.83 GPa, t_{12} = 0.33

In research [65] A model was created, based on the finite element. The chip shape mechanisms for composites consisting of glass and carbon fibre reinforced polymer (FRP) have been studied. Critical differences were identified for both materials while evaluating predicted harm done by machining the sample. Whereas in the scenario of GFRP harm went way outside the system and beyond the toolbar, in the situation of CFRP, the failure happen in a far narrower region. Fibre design affects both the method of shaping the device by which the fundamental harm is caused.

1.5. Application of Nanoreinforced polymer composites in Automotive structures

Advanced vehicle systems must be strong enough to withstand severe impact loads while delivering occupant safety at the same time. Of this purpose construction materials required of crashworthy systems, for example, must be differentiated utilizing the capacity to absorb electricity. Advanced automotive structures must be robust enough to endure extreme impact loads while also ensuring passenger protection. Traditionally metallic materials were added to crash-resistant systems because of their capacity to withstand plastic deformations. Composite products, on the other side, do not show plastic deformations because they are normally fragile. However, if properly built, they will consume large volumes of energy from impact by gradually crushing and delaminating.

Viana [66] demonstrated that particle stiffness influenced the polymer matrix properties. Although soft/elastic fillers increased impact durability, these fillers at the same time. the polymer mix elasticity modulus. The development of the filler material in a polymer further increases the strength of both the resilience of impact and also the elasticity modulus.

Various particles such as carbon nanotubes and the above-mentioned particles were commonly used as a filler to develop the material properties. Such materials are reinforced in the polymer matrices. A major improvement in the impact power of polymeric nanocomposites was achieved by the introduction of amino-functional multi-wall nanotubes. [67]

The automotive industry is the world's biggest user of construction products [68]. Expanding the power and durability of automotive components produced is a significant and critical subject of materials science. Improving the automotive industry, extending the needs for the consistency and protection of used goods, involves new systems to be developed and used. While the production of asset prerequisites promotes rivalry amongst producers of different materials to create new kinds and boost efficiency [69]. Reducing the mass is very necessary for building a vehicle. This helps the basic characteristics of the automobile to be preserved, utilizing less powerful engines which consume less fuel and emit fewer harmful substances into the atmosphere. In reality, the speed of the vehicle is decreased, and less energy has to be expended on slowing or stopping. Reducing the weight of the car also lowers the pressure on the suspension components, thereby increasing their service life [5].

It is necessary to decrease its mass when making a vehicle. This enables the preservation of the vehicle's essential characteristics, use fewer powerful engines that use less power and send less harmful compounds into the air. The inactivity of the vehicle also decreases and it is important to spend less vitality to accelerate or brake it[70]. Bringing down the vehicle's heaviness often diminishes the heap on the sections of the suspension which creates their life expectancy. Reducing the car's weight is attributed to the requirement to use modern, lightweight yet more robust components, which are typically more costly. However, at the same time vehicles are more sophisticated and thus more complicated for practical purposes. Current lightweight building products like modern modules and active and passive protection devices would be balanced by weight, decreased risk and continued growth in comfort rates [6]. New light development materials, including new units, should be partly explained by weight, and dynamic and uninvolved safety frameworks decreased the danger and constantly improved solace levels [71]. Lightweight technologies are being used increasingly in the vehicle, aviation and construction fields, as the use of low thickness materials enables the simple load of products to be reduced. The usage of materials in automotive structures are explained below in figure: 7.

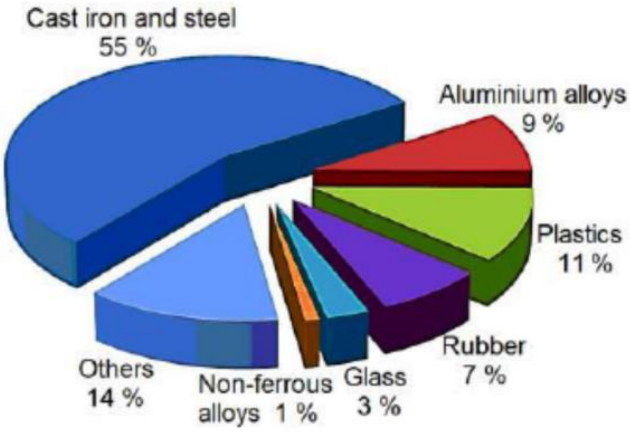


Figure 7: Parts used for the manufacturing of automotive structures [72]

The automotive industry is an industry which is intensive in materials. Currently, a large range of metals, fillers, and plastics are required to fulfil the different product specifications. The key forces in the procurement of products are expense and efficiency. Materials are chosen by determining the best cost-performance combination required to satisfy the product specifications. This fact has contributed to the enhancement of the different forms in which new products can be updated[73]. Examples of these research methods include auxiliary materials, elective metals and chemicals, fillers fortifying and composites with glass fibres. Each of such methodologies has its limitations. Structural plastics also need post-forming surface changes and long process durations, which are extremely costly. Lightweight metals and their alloys are gradually being used for weight control, especially in non-cosmetic systems. However, these metals have the same manufacturing drawbacks as steel and iron and typically add expense.
For eg, reinforcing fillers like talc, mica, and calcium carbonate adds higher rigidity while still growing weight and melting viscosity, and decreasing hardness, visual transparency, and surface strength. Glass-fibre reinforcement offers strong rigidity and correspondingly decreased processing complexity and expense. To raise modulus and boost dimensional stability, these typical reinforcements and fillers must be used at high loading speeds, thereby losing weight, hardness and surface strength. The nanocomposite materials are therefore used to obtain a lightweight structure and to achieve improved efficiency[70].

2. Methodology

The major aspect of the research is the hybridization of a nanofiller and the fibre-reinforced polymer composite. The process in which various nanofillers and their properties have been studied, in which the carbon nanotubes are highly regarded as the polymer composite filler. Modelling of nano reinforced polymer composites is approached based on Representative volume element (RVE) modelling. And the composite layup technique is considered for the development of the Hybrid composite material.

2.1. The methodology of Development of hybrid Nanoreinforced Polymer composites

An RVE model is generated considering the element size of the fillers infused in a polymer matrix. Also, the model represents the yield value of the material which represents the whole. The nanofillers are infused into the matrix and it develops a property, which gains additional improvement in factors such as elastic and thermal parameters. The development process of the RVE model in software is represented in figure 8.

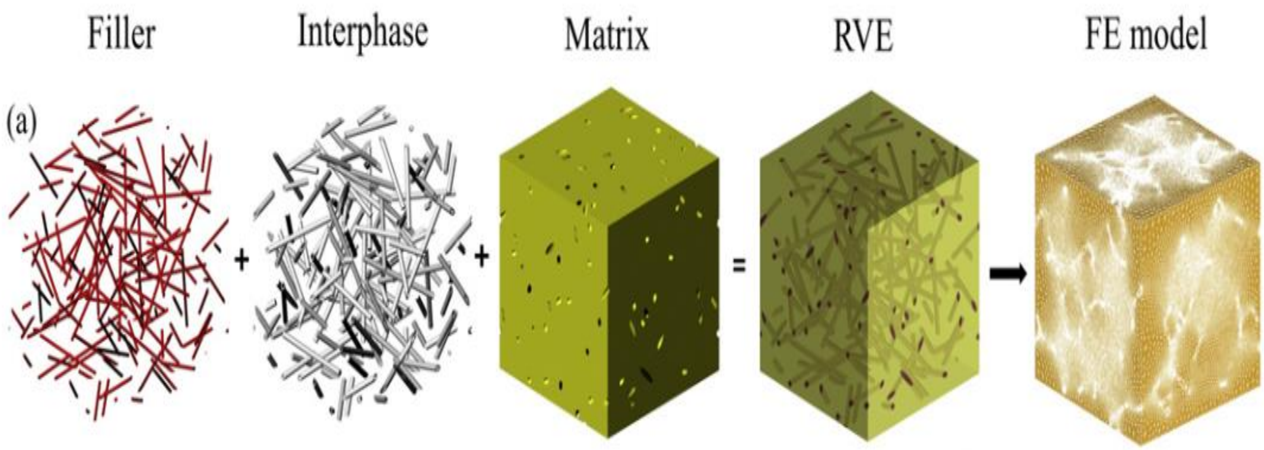


Figure 8: Development process of RVE model in Computational software[74]

The fibre orientation of the material is considered in developing a hybrid composite. The orientation of the material can be considered along all 360 degrees to obtain the maximum strength over directions. Most of the composites are considered as anisotropic material because of their different material property along the direction. In this case, when modelling a hybrid composite the fabric is aligned along multiple directions to understand the material property. The major purpose of modelling this material is to find application in automotive structure. As studied from the literature, it is known that to be used as automotive part material should achieve various strengths. The mechanical property is the principal property to be achieved. The mechanical testing is carried out on the material produced within different loading conditions to evaluate the elasticity module that shows the material's rigidity. So that the material under multiple orientations in which the better one can be evaluated. The fibre orientation along 0^0 and 90^0 are mentioned in Figure 9.

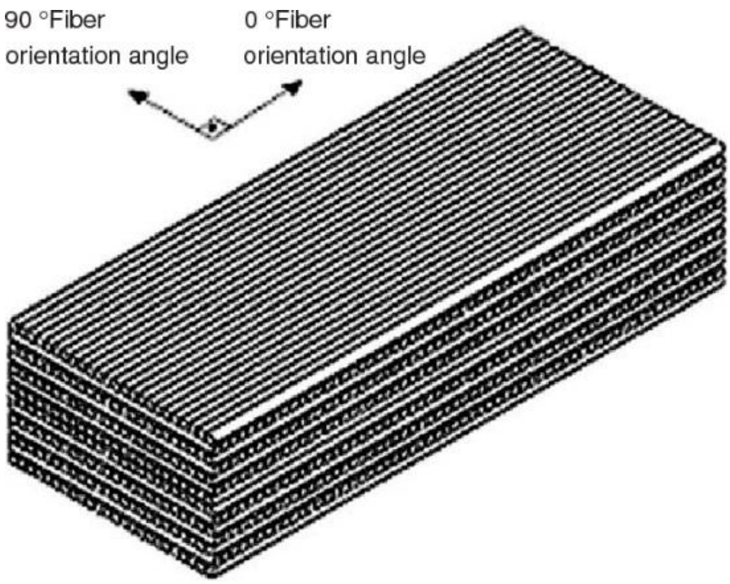


Figure 9: Fibre orientation of 0^0 and 90^0 [75]

2.2. The methodology of structural analysis of polymer composites

The FRP composite material which is modelled will undergo the various testing process. The structural analysis is performed in Ansys under tensile and flexural loading of the material. The specimen will be prepared in Ansys Design Modeller, the load of max 8000 N will be applied to the material considering end time and various steps, the results obtained will be graphically represented. The meshed tensile and the flexural model of the material is represented below in figure 10. The analysis is performed to find the stress or strain produced under a given load.

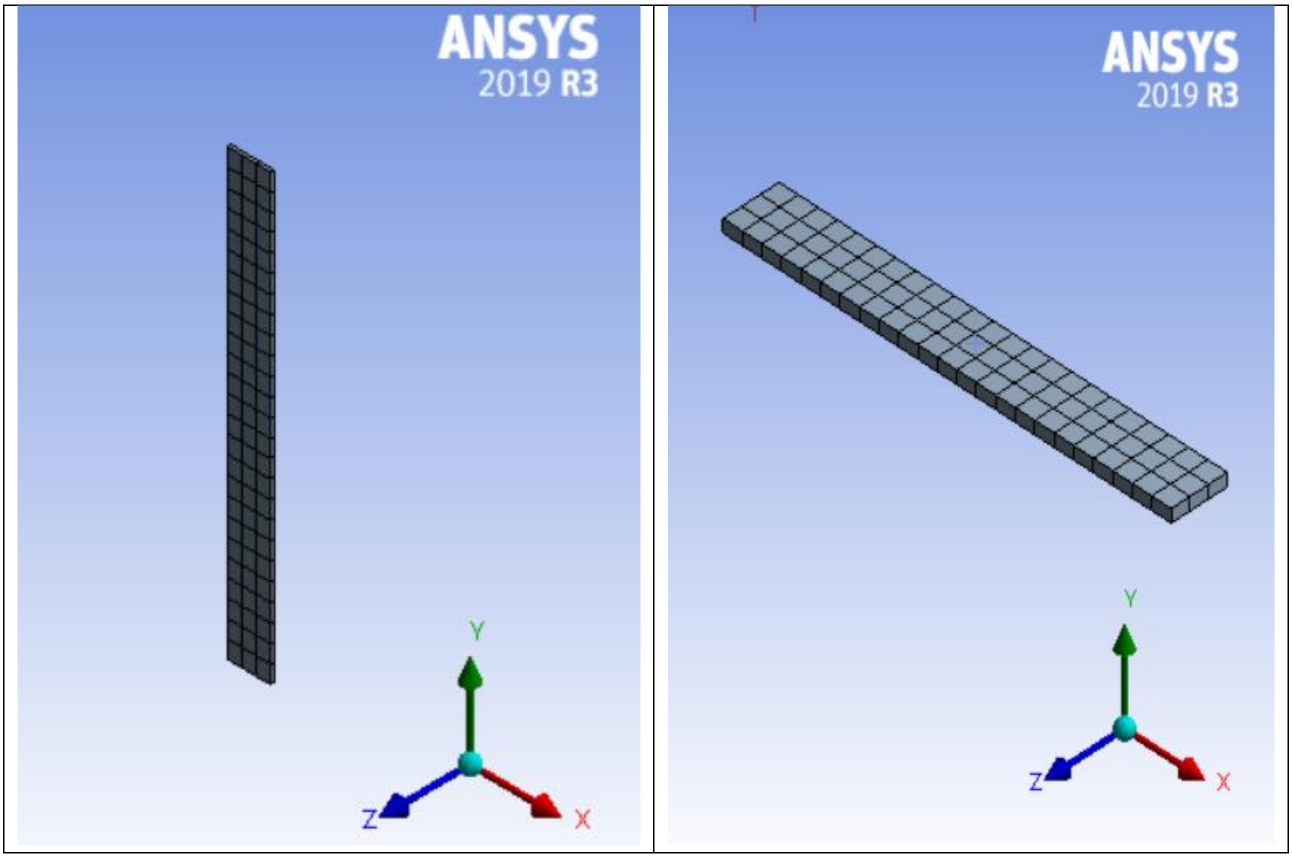


Figure 10: Meshed part for structural analysis

2.3. The methodology of Crash analysis of Hood

From the structural analysis, the best-performed material will be considered from the result obtained. To know the material application in automotive structure, a hood model is considered. There are strong and cheaper materials available in the production. But this nano reinforced hybrid composites mainly find an application on weight reduction and higher strength. So, the modelled material by which the hood is developed and the analysis conducted. The modelled hood is represented in Figure 11.

The crash test is performed based on the frontal impact occurs in the hood. The analysis in which the nano reinforced hybrid composite material and the commonly used Aluminium material for the hood is compared. The following tests were performed,

- Modelling of Hood with the developed material and the existing material
- Frontal crash under a standard velocity condition.
- Comparing the results

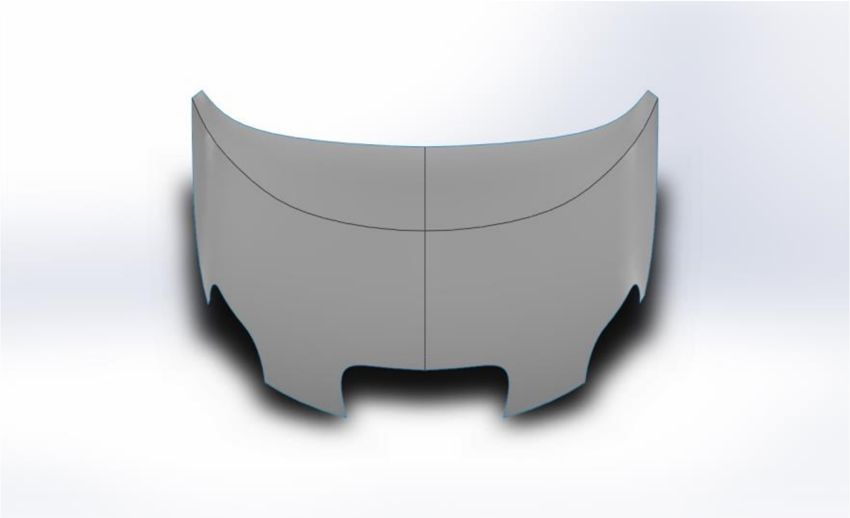


Figure 11: Hood model.

The modelled hood is configured and the material is assigned by the Ansys ACP. In which the material is oriented based on the ply arrangement. The ply-wise fibre direction is represented in figure132.

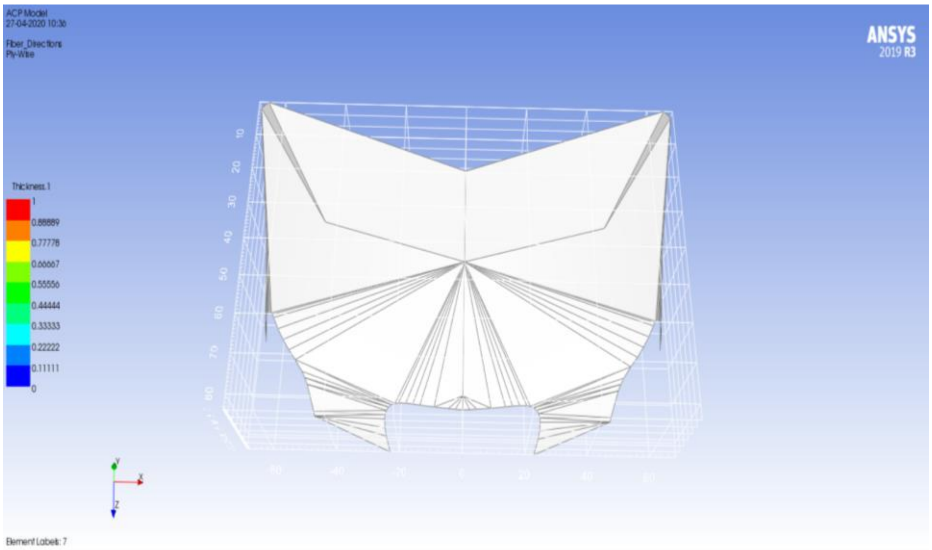


Figure 12: Ply-wise fibre direction

The analysis in which a concrete wall setup is designed to perform the crash test. The developed hood is imported in Ansys. The finite element software performs various analysis and in this research, the crash analysis is performed in Ansys explicit dynamics. Setup of a concrete wall and the hood is assembled and the boundary conditions were given. A test velocity of 64 km/h in which the crash of the hood is analysed. The European new car assessment program (NCAP) performs a frontal crash at a speed of 64 km/h in which the vehicle directly hits into a concrete structure. The material properties are tabulated below,

Table 2: Material property of the Concrete wall

Density	2300 kg/m^3
Young‘s modulus	30 Gpa
size	4.5m x 2.5m x 0.5m
Stiffness behaviour	Rigid

The dimension of the hood modelled is 1.638 m x 1.242 m and with a thickness of 3 mm. The commonly used materials in the automotive industry for developing hood are Aluminium, Steel, carbon fibre and glass fibre composites. In this analysis, the most used aluminium material is compared with the developed nano-reinforced polymer composites.
The frictionless body interaction is provided to the hood body and the wall so that the impact between the wall and the hood was found. The mesh was performed with the physical preference of explicit and the maximum element size of the mesh is 0.232 m. The relevant setting is set to fine and a smooth meshing type is performed.
Following to the mesh conditions applied, fixed support is provided at the non-crash end of the hood and under initial conditions, a velocity of 17778 mm/s is applied. The meshed hood and wall setup is represented in figure 13 & 14.

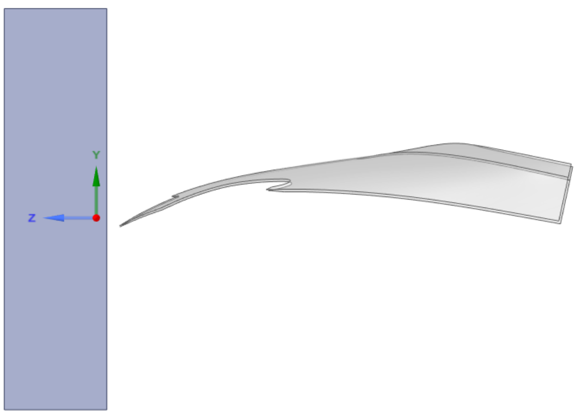


Figure 13: Hood and wall set up for crash analysis (Side view)

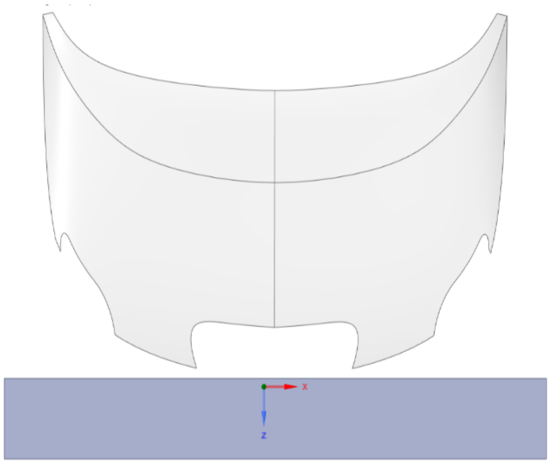


Figure 14: Hood and wall set up for crash analysis (top view)

The crash analysis is performed and its results were analysed in the following sections.

3. Modelling and Experimental Analysis

This section represents the modelling and analysis of the polymer composites reinforced by nanofillers using finite element analysis, A representative volume element model is developed to find the modelling properties of the nano reinforced material. The analysis in which the developed material undergoes s of the properties, which is used in macroscopic modelling. To develop an RVE model the factors such as phase properties, fibre orientation, the volume fraction and the geometry should be considered, and the volume fraction defines the volume percentage of the mixture of fibre and particles in the element.

3.1. Development of Epoxy infused with Nanofillers

The nanoparticle infusion in the Epoxy material is represented below in Figure 15.

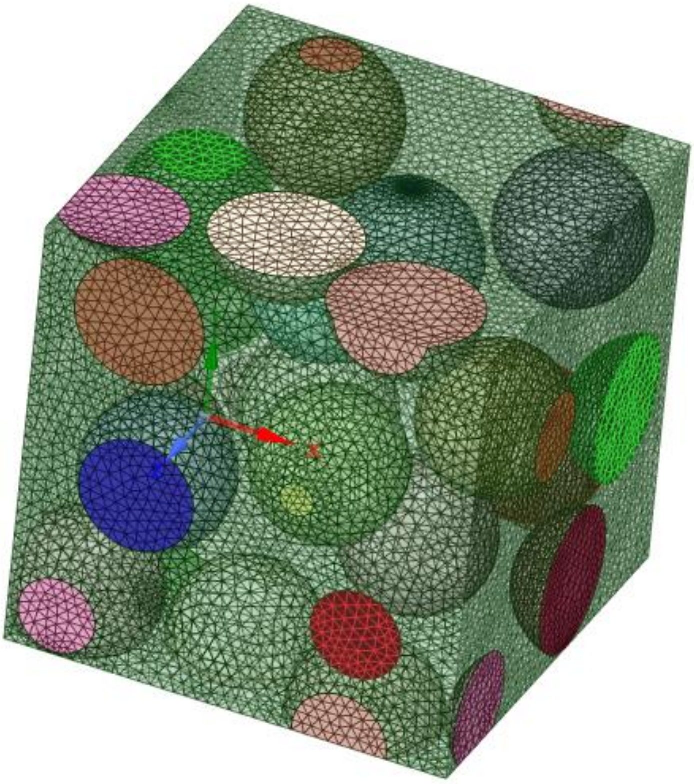


Figure 15: RVE model of CNT infused Epoxy resin particle

The modelling properties of the model is considered based on the dimension and the regarding factors of material. following properties were considered for the modelling[76]. The modelling of the material in an RVE model computes the thermal and elastic properties.

Volume of RVE = Total volume/volume fraction

The materials used for modelling and its properties are tabulated below in table 3.

Table 3: Modelling properties

Material	Density	Young's Modulus	Poisson's Ratio
CNT	2260	2.7×10^5 MPa	0.3
Carbon Fiber (Fabric)	1800	2.3×10^5 MPa	0.3
E-Glass (Fabric)	2600	7.3×10^4 MPa	0.22
Resin-Epoxy	1160	3.78×10^3 MPa	0.35

3.1.1. Development of nano reinforced polymer composite materials

In the computational software, the Fibre-reinforced polymer composite is modelled both with pure epoxy and with the impact of nanoparticles. An RVE model is developed using input material properties.

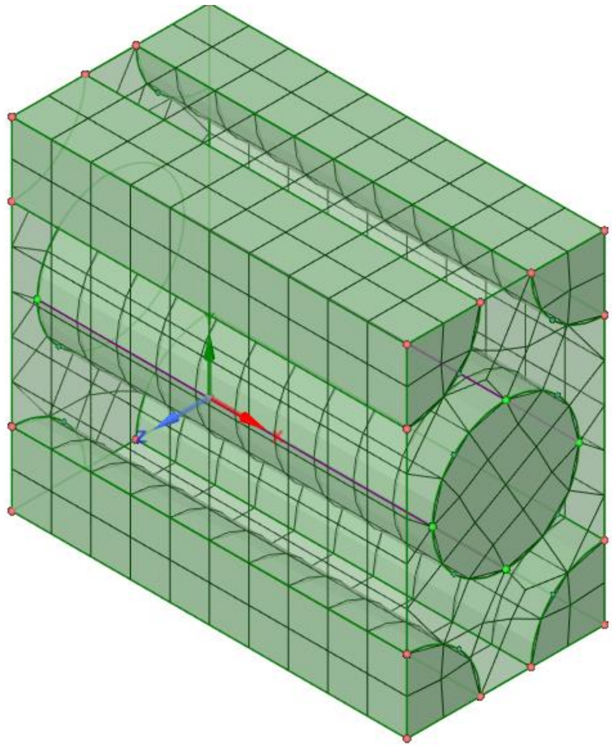


Figure 16:RVE of composite material infused with CNT

Figure 16 represents the RVE of polymer composite material infused with CNT which is modelled in Ansys. The plain fabric is reinforced with the matrix to achieve its maximum strength and also to obtain its required properties. In this section, the effect of nanoparticles on the fibre reinforced polymer composites are analysed.

3.2. Development and structural analysis of Hybrid composites

In this section, the nano reinforced Hybrid composites are developed by the reinforcement different fabrics. The hybrid material is developed based on different laminate orientations. And those materials were investigated with the mechanical loading and the results were investigated. Figure 18 represents the stack-up of the material and the polar properties obtained along with directions

3.2.1. Development of Hybrid Nano reinforced polymer composites

From the obtained modelling values of the nano reinforced materials, a hybrid composite is developed using Ansys ACP. It is developed using different orientations to achieve strength in multiple directions.

Two different layups were approached considering 0- and 90-degree orientation.

- ($CF_0/GF_0/CF_0/GF_0$)
- ($CF_0/GF_{90}/CF_0/GF_{90}$)

The different fabric laminations are approached to develop the influence of material properties in.

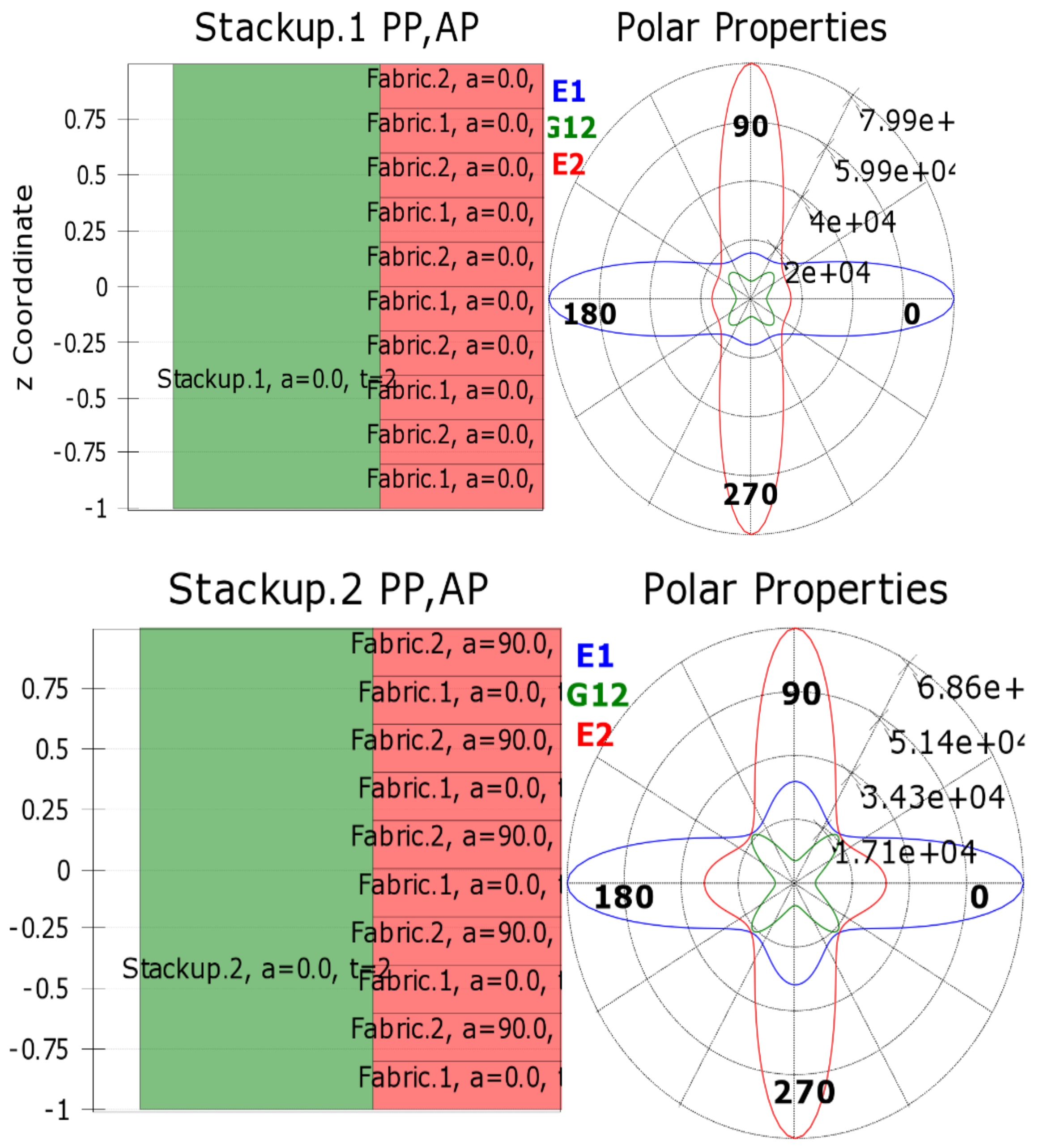


Figure 17: Stackup of Nano reinforced polymer composites

multiple directions. In this research, the two stack-up are considered as two different material and they were imported to the testing setup and analysed under different process to obtain the required properties of the material. While modelling in Ansys ACP the influence of the polar properties along orientation is obtained and the stack-up is represented in Figure 17

3.2.2. Analysis of the Hybrid nano reinforced polymer composites

Structural analysis of the material developed is carried out using Ansys. The linear testing such as tensile and Flexural analysis is performed to understand the stiffness and to find the elastic modulus of the material at a given load.

3.2.2.1. Structural Analysis under tensile loading

The test specimen was prepared, which is a rectangular box with a dimension of 250 x 25 mm and the material thickness of 2 mm.

The material was stacked up using Ansys ACP with different orientation angles and then the tensile test is performed using Explicit dynamic Analysis. The tensile loading conditions were applied and then the part has meshed. The loading conditions in which a force of 500 N to a maximum load of 8000 N was applied.

The testing is performed for the Hybrid nano reinforced polymer composite considering two different material orientation and from which the stress-strain produced and the displacement of the test specimen is obtained. The stress, strain and displacement of the material is represented in figure 18,19 and 20

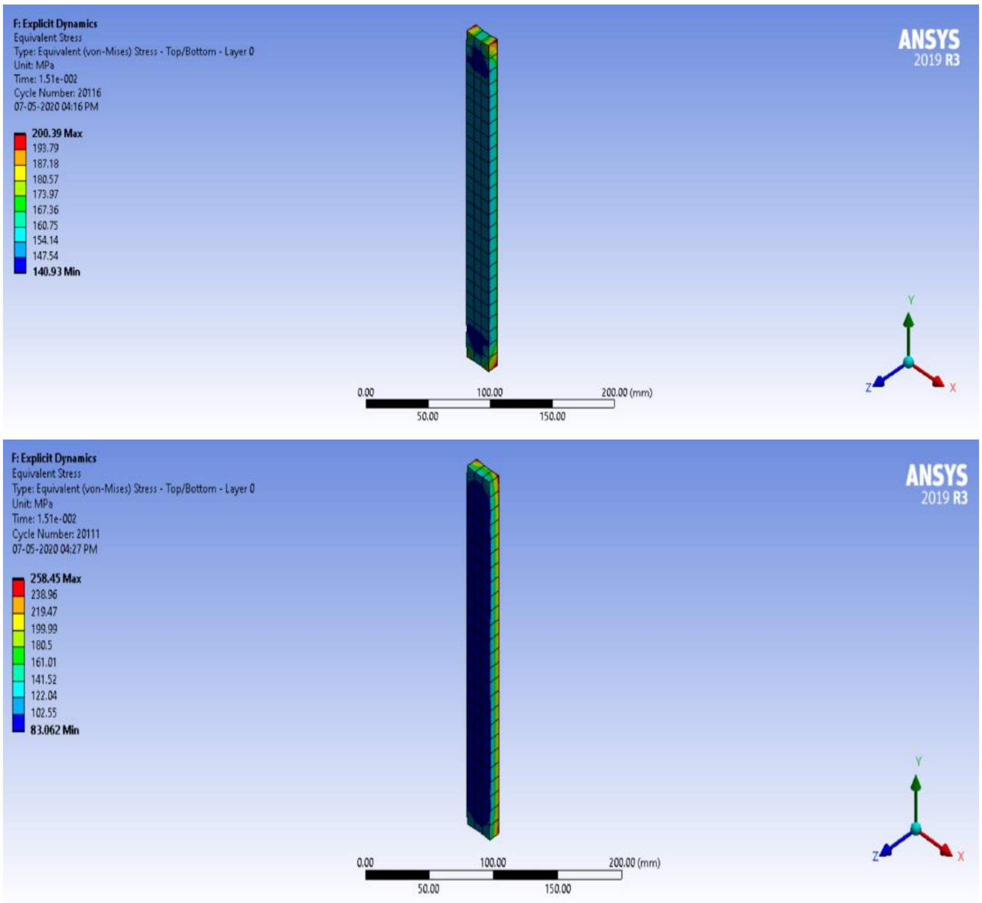


Figure 18: Stress variation between Material 1(above) and 2(below)

The maximum stress obtained from the given load limit for the Material 1 is 200.39 MPa and in the Material 2 is 258.45.s

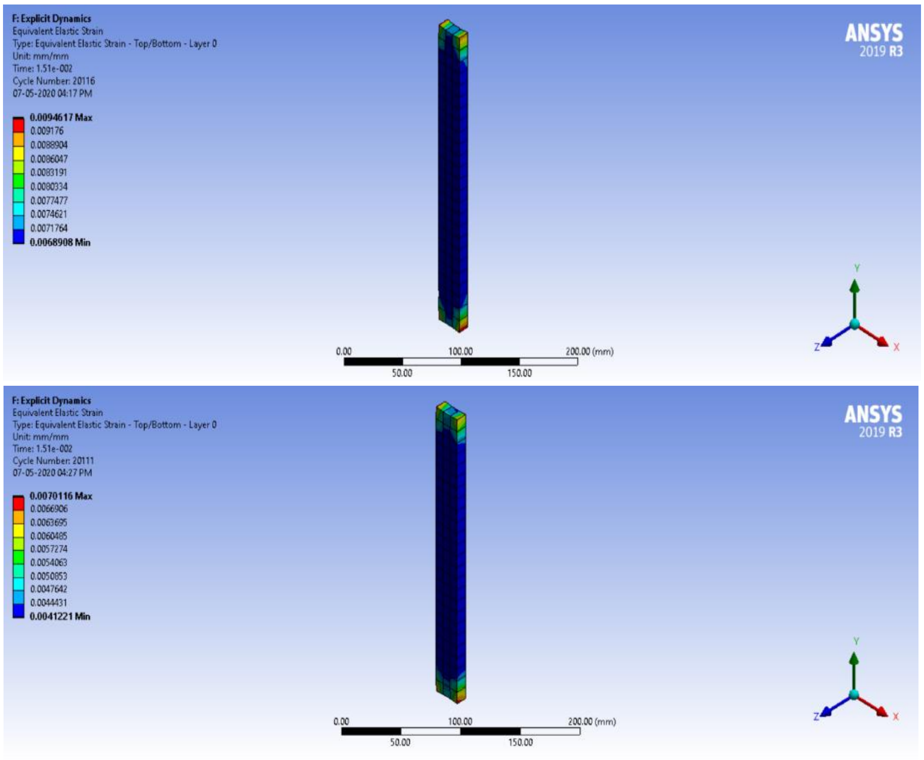


Figure 19: Strain variation between Material 1(above) and 2(below)

The maximum stress obtained from the given load limit for the Material 1 is 0.0094617 and in the Material 2 is 0.0070116 MPa.

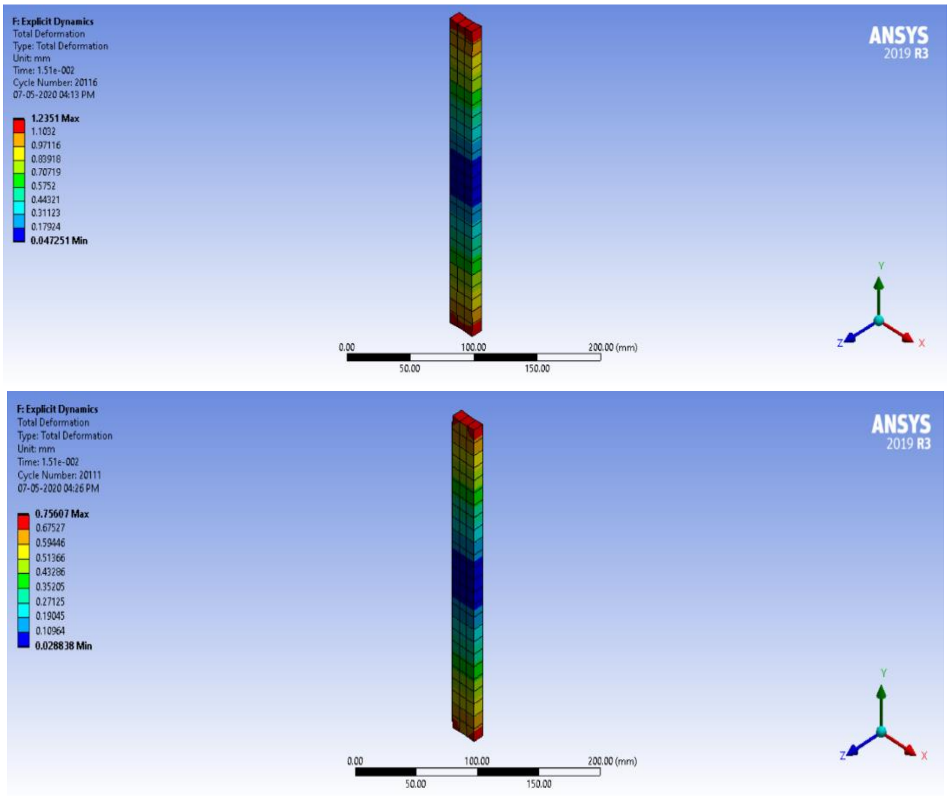


Figure 20: Deformation on Material 1(above) and 2(below) for the applied force.

The Material 1 in which the major deformation takes place of 1.2351 mm, and in material 2 the deformation takes place is 0.75607 for the given maximum load.

From the obtained value the Stress-strain graph and the Force-Displacement graph is created and also the Elastic modulus is also formulated.

The young's modulus of the material is defined by the stress and strain value produced in a material when a force applied to it. The young's modulus is determined by

E = Stress/Strain

The young's modulus calculated for material 1 and 2 are,

	Material 1	Material 2
Young's modulus	2.12×10^4 MPa	3.69×10^4 MPa

So, it can be said that under tensile loading the material 2 has a higher elasticity comparing to the material 1.

3.2.2.2. Structural analysis under flexural loading

The flexural loading is performed. In this process as previously held, the material was stacked up using Ansys ACP and the flexural specimen is modelled and tested under flexural testing condition. The load is applied under three-point bending condition. As in the previous case, a maximum load of 8000 N was applied and tested for both material specification. The stress, strain and deformation produced under flexural loading are represented in figure 21,22 and 23.

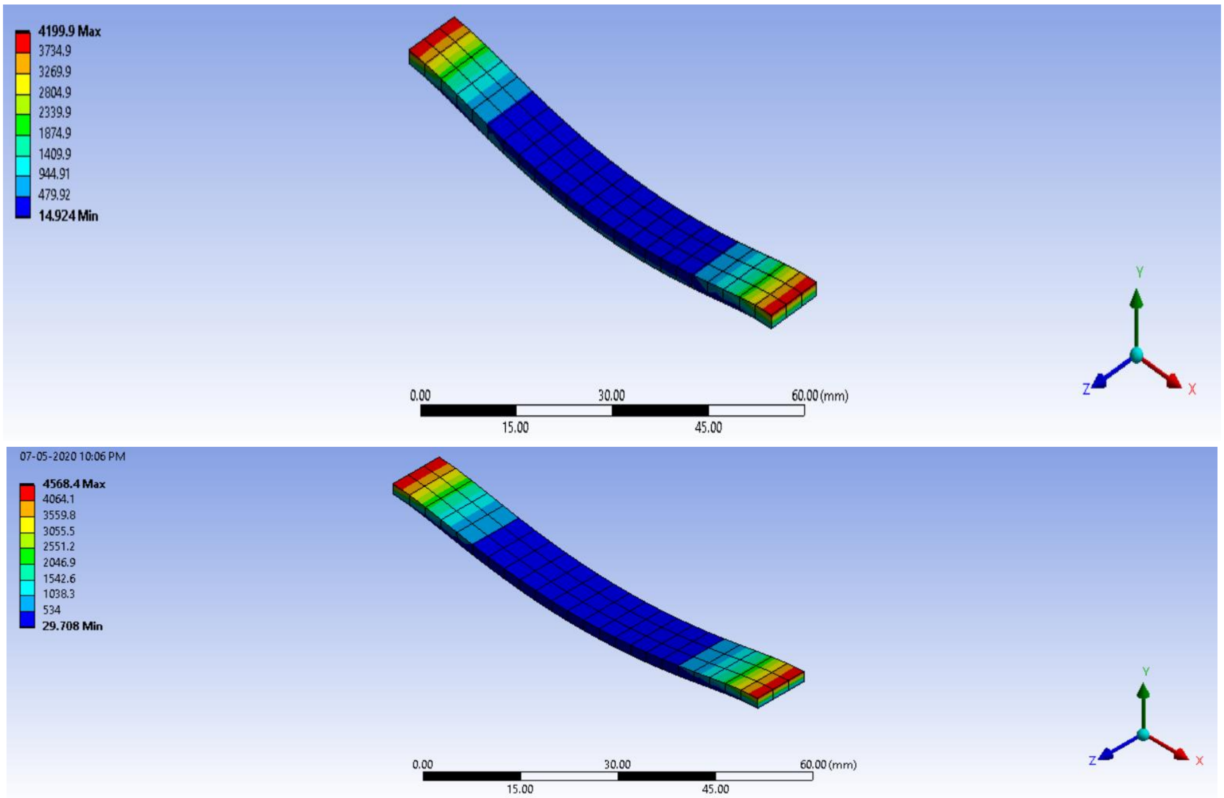


Figure 21: Stress variation between Material 1(above) and 2(below)

From the analysis maximum stress of 4199.9 Mpa for Material 1 and 4568.4 Mpa for material 2 is obtained

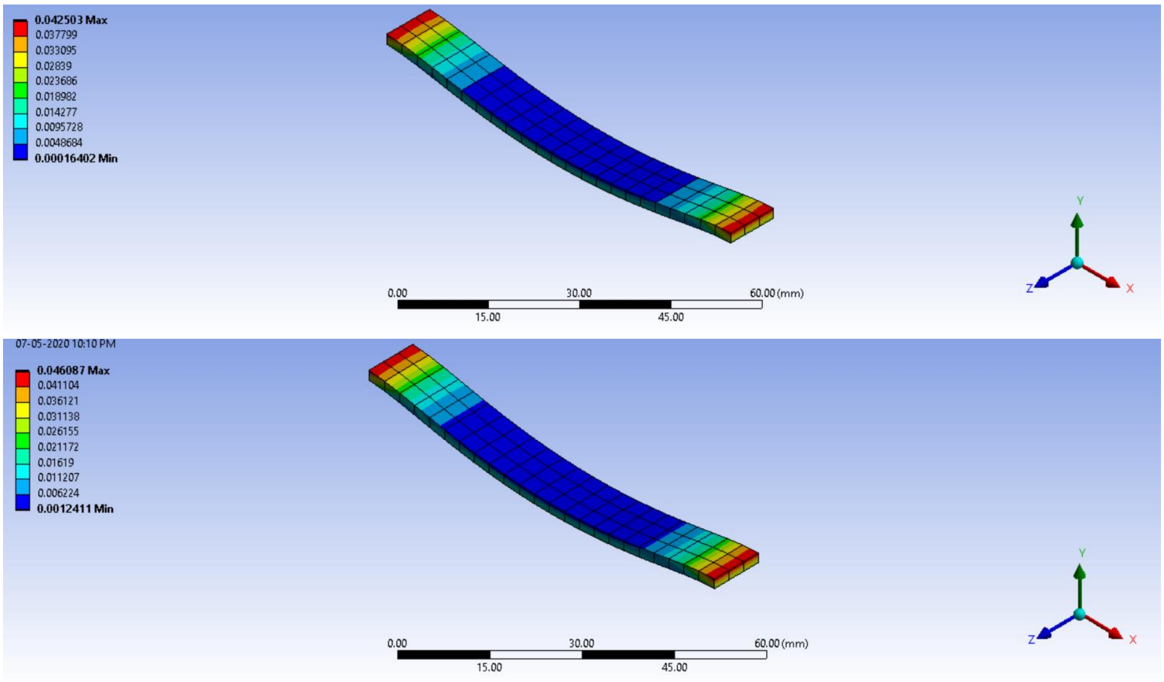


Figure 22: Strain variation between Material 1(above) and 2(below)

A maximum strain of 0.042503 and 0.046087 are obtained for Material 1 and 2 is produced.

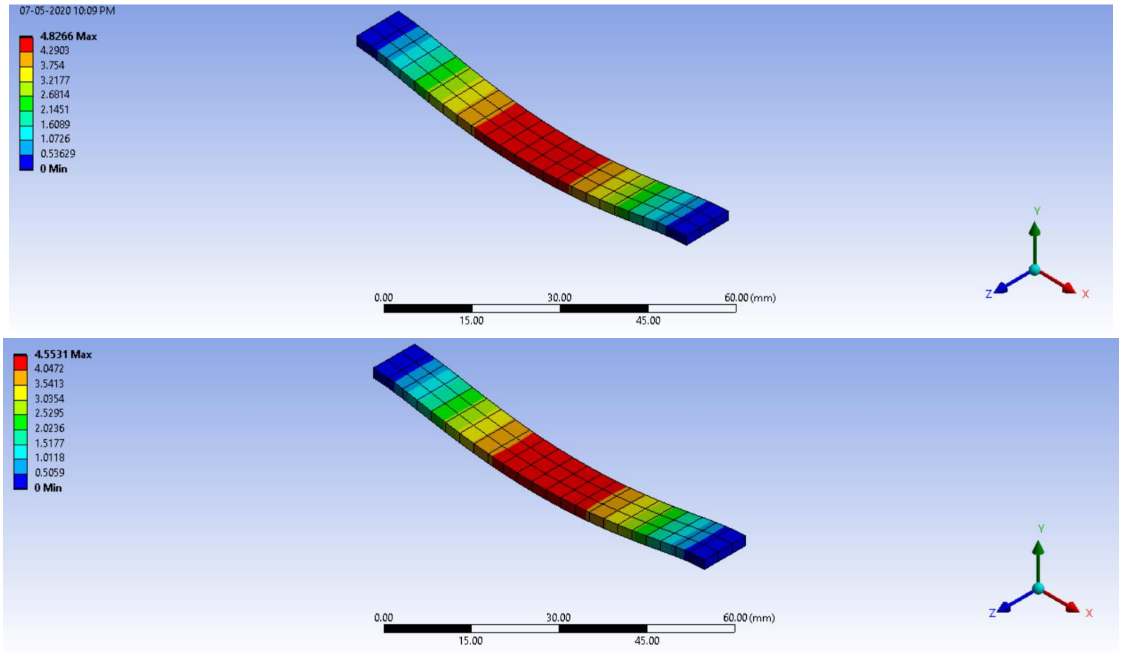


Figure 23: Deformation on Material 1(above) and 2(below) for the applied force.

For the given load, the displacement of both the material is almost similar. Deformation of 4.8266 mm and 4.5531 mm takes place for both material 1 and 2.

The flexural modulus is formulated and also the stress-strain graph and the force-deformation graph is generated.

The flexural modulus of both materials is tabulated below, and it shows that under flexural loading both the materials provide almost similar elasticity. But, considering the data Material 2 provides higher elasticity and known as a stable material under bending condition.

	Material 1	Material 2
Young's modulus	9.88×10^4 MPa	9.91×10^4 MPa

From the Mechanical testing under both tensile and flexural condition, Material 2 satisfies the condition of

3.3. Analysis of Hybrid nano-reinforced polymer composite in automotive structure

The major aspect of an automotive structure is withstanding issues. To understand the developed material to be used as an automotive part it should be analysed based on the effects produced in the structure. In this research, a hood structure is developed, so the obvious issue arose in a hood structure is the crash. So this part is considered to be analysed under crash conditions.

3.3.1. Crash analysis of Hood

As mentioned in the methodology, the crash analysis is performed. The most commonly used material as an automotive part is Steel, aluminium and carbon fibre reinforced composite material. In this research, the crash analysis of the hood structure is performed with the developed hybrid nano reinforced polymer composite along with the aluminium and the carbon fibre material. the meshed body of the crash analysis is represented in figure 24.

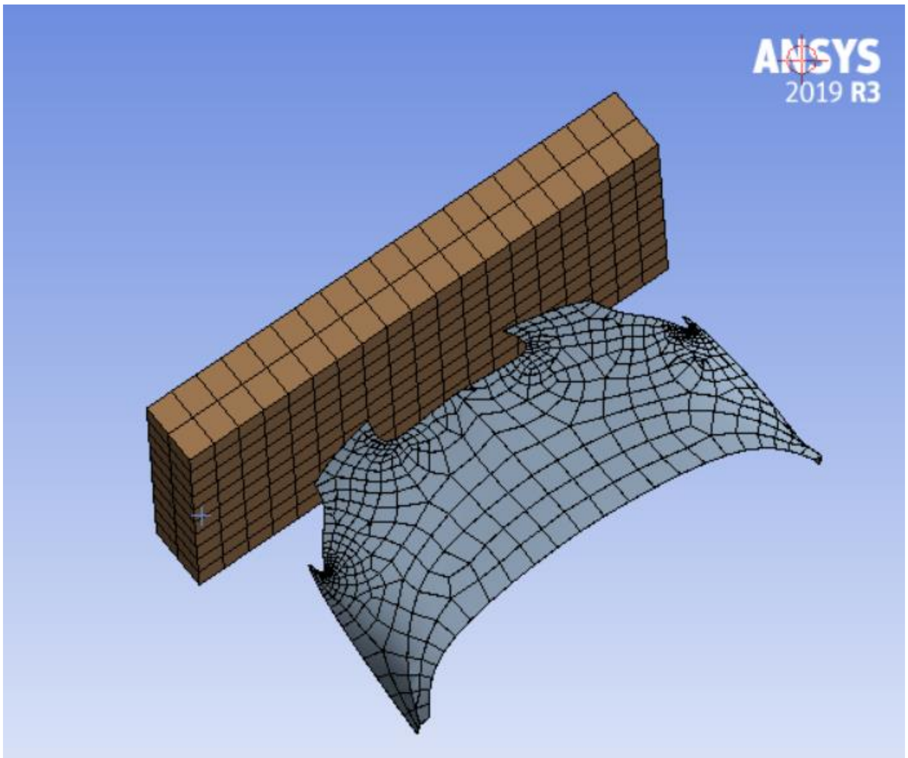


Figure 24: Meshed crash analysis setup

The material to be tested in the crash analysis is tabulated below

Material	Aluminium	Carbon fibre	Nano reinforced Hybrid composite
Orientation	Normal	$(CF_0/C_{F45}/CF_{-45}/CF_{90})$	$(CF_0/GF_{90}/CF_0/GF_{90})$

Case 1: Crash Analysis of hood (Aluminium)

Under a test velocity of 17778 mm/sec, the hood structure deformed. The stress and strain produced in the structure is represented below,

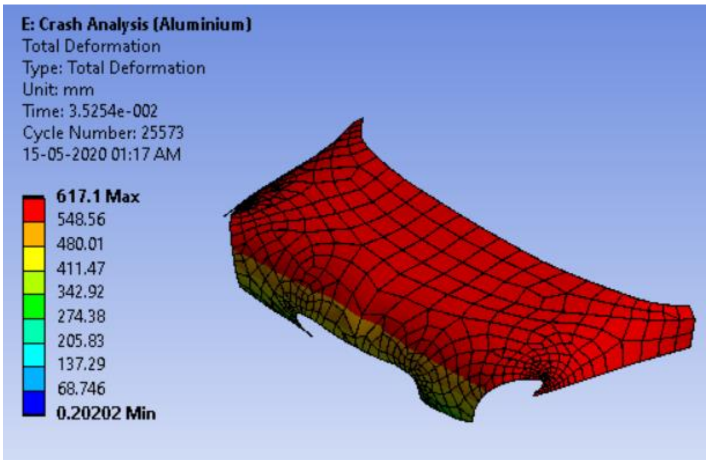


Figure 25: deformation produced in the hood by crash test(aluminium)

The hood in which a maximum deformation of 617.1 mm is produced.

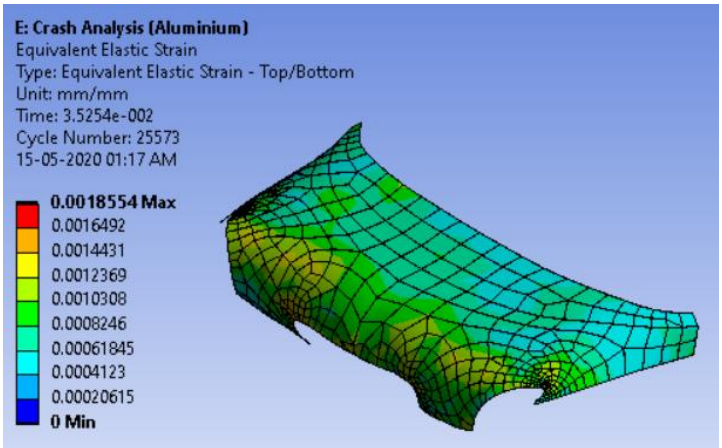


Figure 26: Strain produced in the hood by crash test (aluminium)

The maximum strain produced by the crash is 0.001855.

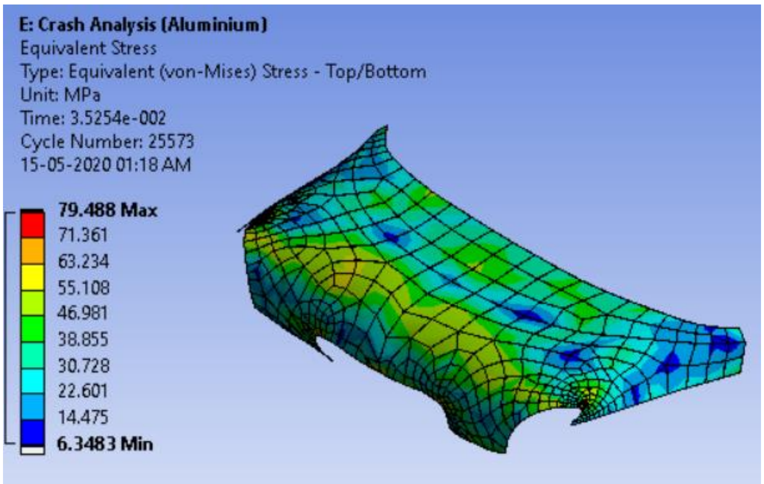


Figure 27: Stress produced in the hood by crash test (aluminium)

The maximum stress of 79.488 MPa was produced.

Case 2: Crash Analysis of hood (Carbon fibre material)

Under a test velocity of 17778mm/sec, the hood structure deformed. The stress and strain produced in the structure is represented below,

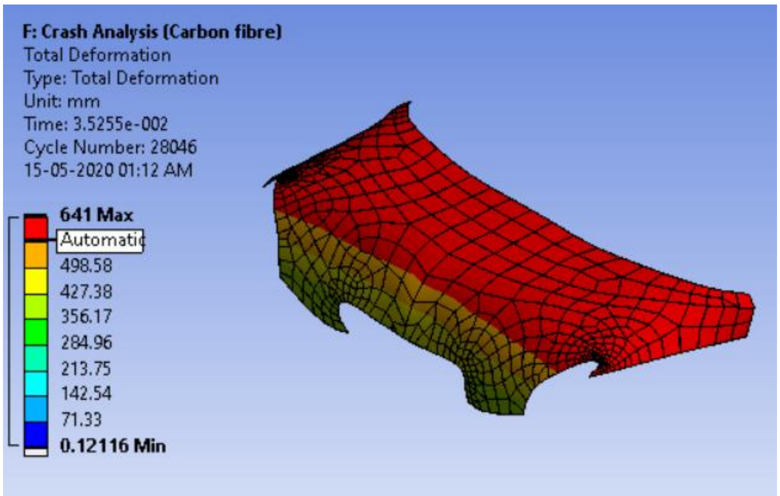


Figure 28:deformation produced in the hood by crash test(Carbon fibre)

The maximum deformation produced is 641 mm.

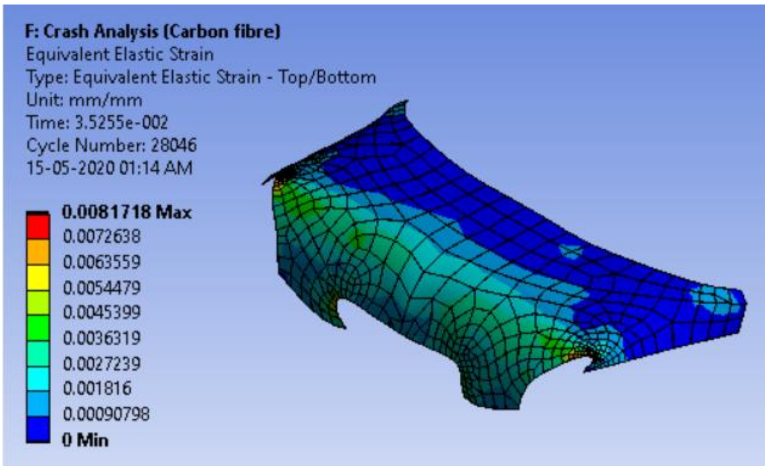


Figure 29: Strain produced in the hood by crash test (Carbon fibre)

The maximum strain produced is 0.0081718.

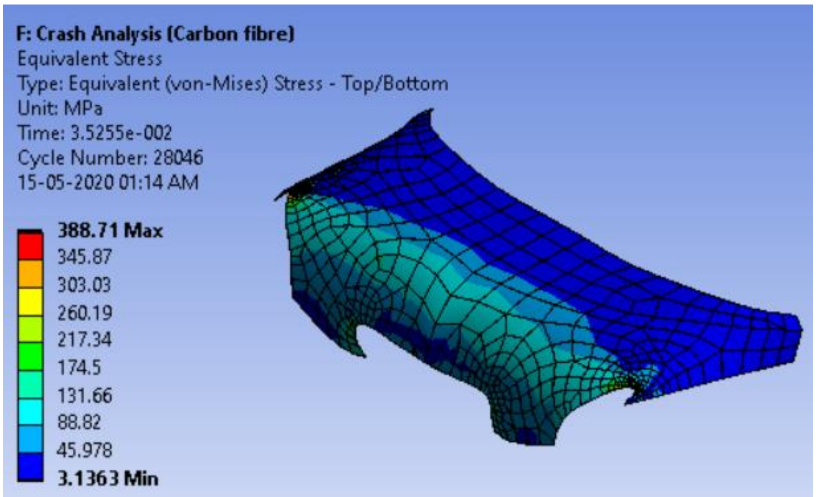


Figure 30: Stress produced in the hood by crash test (Carbon fibre)

The maximum stress of 388.71 MPa is produced.

Case 3: Crash Analysis of hood (Nano reinforced hybrid composite Material)

Under a test velocity of 17778 mm/sec, the hood structure deformed. The stress and strain produced in the structure is represented below,

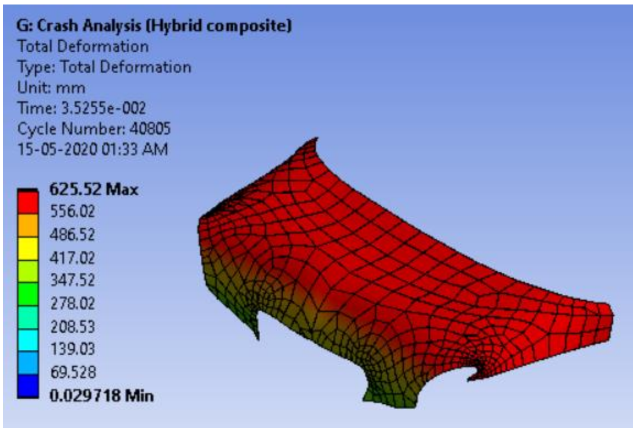


Figure 31: deformation produced in the hood by crash test(Nanoreinforced hybrid composite)

The maximum deformation produced is 625.52 mm.

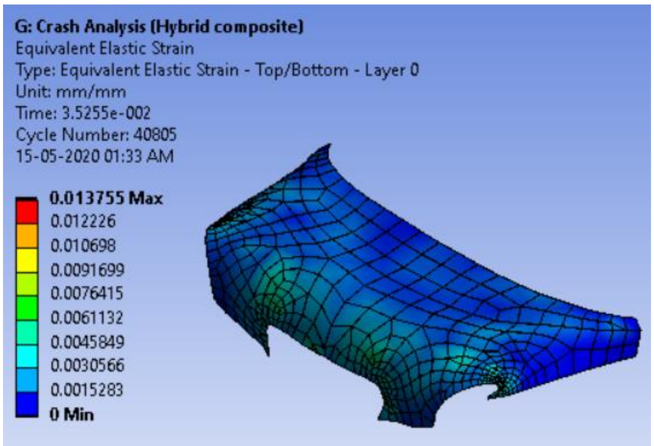


Figure 32: Strain produced in the hood by crash test (Nano reinforced hybrid composite)

The maximum strain of 0.013755 was produced.

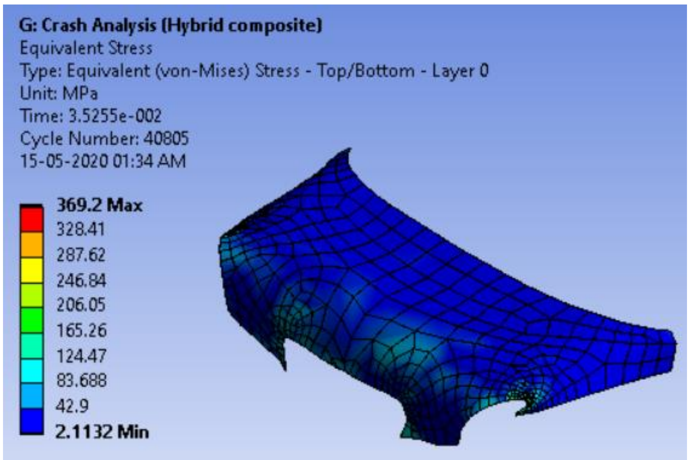


Figure 33: Stress produced in the hood by crash test (Nano reinforced hybrid composite)

Maximum stress produced is 369.2 MPa.

4. Results and Discussion

- In this research, the properties of nanofillers were analysed and a nano reinforced polymer composite is modelled using representative volume element (RVE). Initially, the polymer matrix Epoxy resin material is infused with the carbon nanotubes and their change in material property is obtained.
- The model is developed with different volume fraction, such as 0.3% and 0.5%, the square-shaped body is considered for the modelling.

Table 4: RVE modelling results of Epoxy infused with 0.3 and 0.5 % CNT

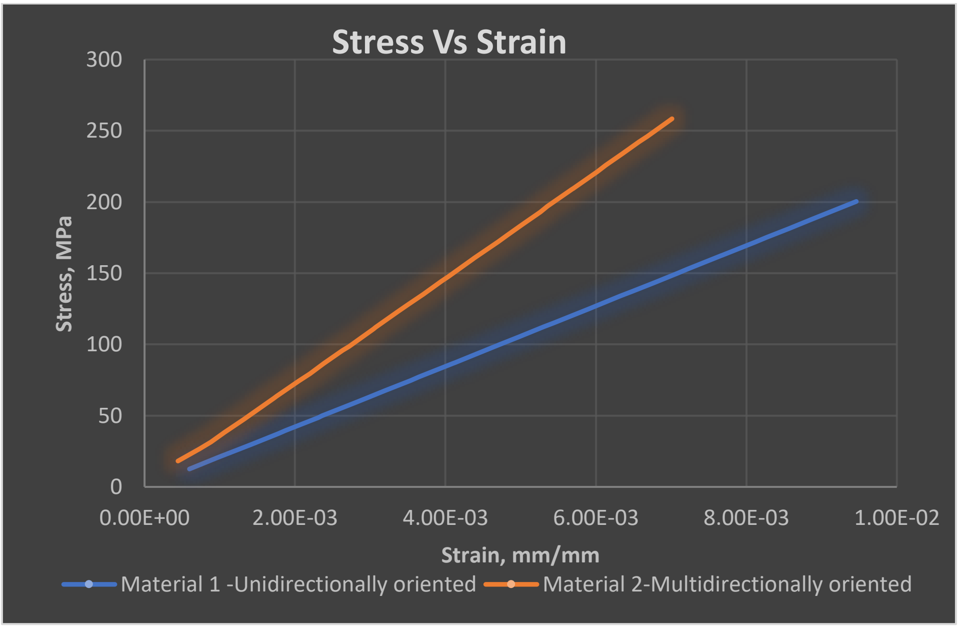
Properties	Epoxy with 0.5% CNT	Epoxy with 0.3% CNT	
E1	8508.3	8255	MPa
E2	8702	7660.7	MPa
E3	8691.1	7447.5	MPa
G12	3211	2951.5	MPa
G23	3270.6	3067.8	MPa
G31	3463.1	3006	MPa
nu12	0.29952	0.30372	
nu13	0.32172	0.32716	
nu23	0.30039	0.34669	
Density	1550.4	1500.9	Kg m^{-3}

- The elastic modulus increased when the weight percentage of the nanoparticles increased. And this shows the influence of nanoparticle on a matrix increases the elasticity of the material. And thus the material will hold higher stability compared to the pure epoxy material
- Followed by that the matrix produced is considered to be used as the matrix material for the fibre reinforcement. Since the research is based on modelling material for the automotive structure, commonly used FRP composites such as CFRP and GFRP is considered.
- The matrix produced Epoxy with 0.5% CNT is used for the fibre reinforcement and they were modelled with multiple configurations. The obtained results of those are tabulated below in

Table 5: RVE modelling results of fabric infused with matrices

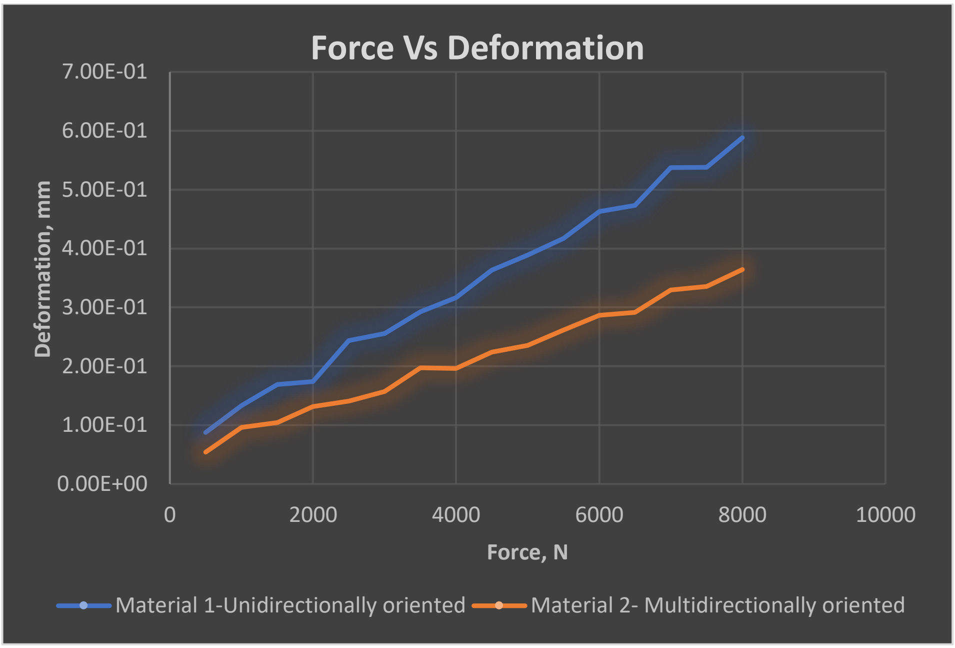
Properties	CF/EPOXY	GF/EPOXY	CF/EPOXY with 0.5 % CNT	GF/EPOXY with 0.5 % CNT	
E1	1.17E+05	38405	1.1917E+05	40676	MPa
E2	10001	10167	13101	17781	MPa
E3	10001	10167	13099	17778	MPa
G12	4185.3	3749.4	4956.7	7082.8	MPa
G23	3428.4	3587.7	4773.6	6834.1	MPa
G31	4185.3	3749.4	4956.7	7082.8	MPa
nu12	0.25098	0.27723	0.24925	0.25904	
nu13	0.25112	0.27752	0.25406	0.26071	
nu23	0.45487	0.42576	0.42812	0.36331	
Density	1480	1880	1650	2050.5	Kg m^{-3}

- The influence of the nanoparticles by which the values of the elastic constants were increased. Which shows the elasticity increases when the nanoparticles infused with the polymer composite. And the density also changes based on the weight percentage of particle infused.
- The hybrid composite is modelled in Ansys ACP considering the laminate orientations and two different orientation by which Material 1 and 2 were modelled. These materials are with the orientation of ($CF_0/GF_0/CF_0/GF_0$) and ($CF_0/GF_{90}/CF_0/GF_{90}$).
- This structural analysis is performed for the developed material under tensile and flexural loading. Stress-strain graph was generated and the deformation occurred on the material by force were also plotted.



Graph 1: Stress-strain relation under tensile loading

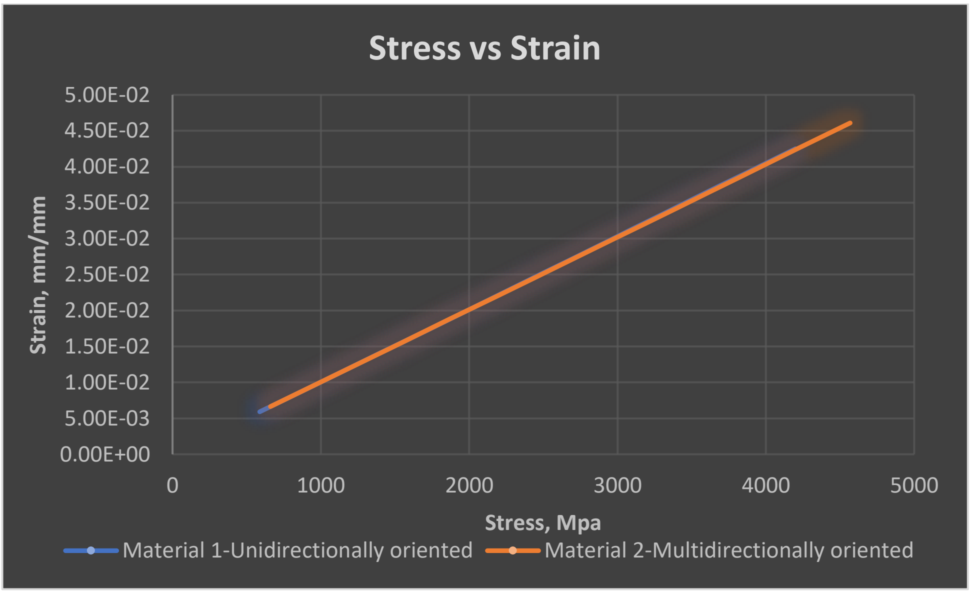
– The stress-strain relationship shows that the stress produced in Material 1 is comparatively lower than the Material 2. But the strain value is opposite. But from the result, it is clear that the elasticity of the material 2 is better under loading conditions.



Graph 2:Force-Deformation relation under tensile loading

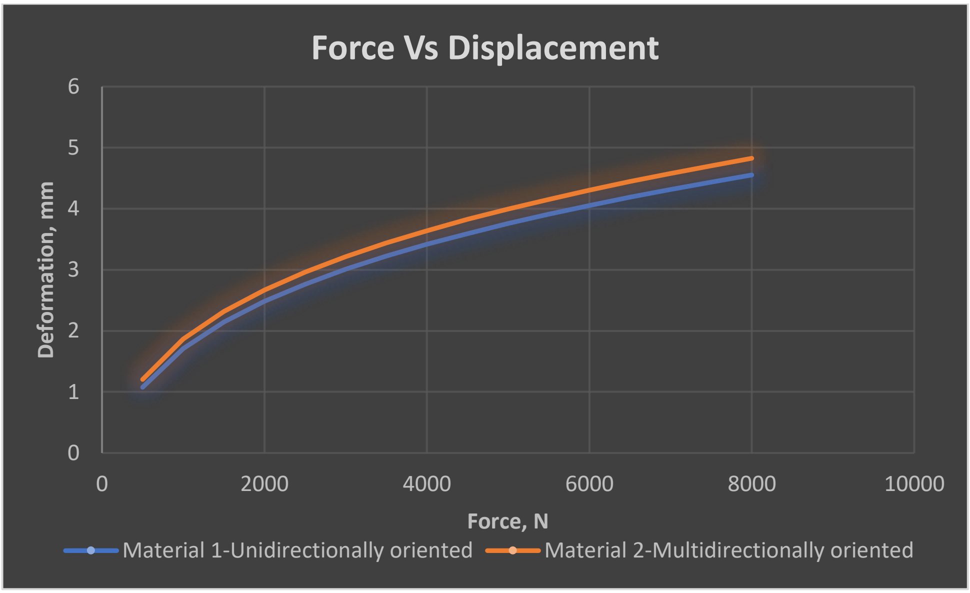
– The represented graph shows that material 2 provides a minimum deformation under tensile loading.

– Followed by that the flexural loading condition is considered and as in the previous case, the Stress-strain and force-deformation graph are plotted.



Graph 3: Stress-strain relation under Flexural loading

– Under flexural loading, both the material shows almost similar relation. The stress and strain relation produced has only minor changes. But considering elastic modulus the Material 2 has the higher elasticity.



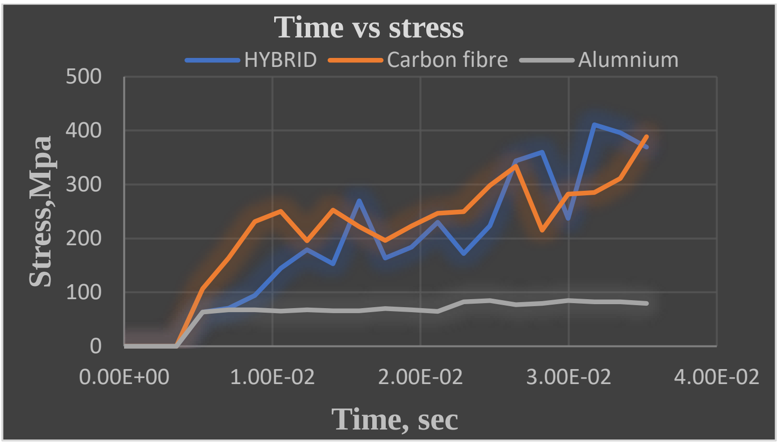
Graph 4: Force-Deformation relation under flexural loading

- The force-deformation graph shows the representation of deformation produced under the load conditions.
- From the testing performed it can be concluded that the hybrid nano reinforced polymer composite with the orientation of $CF_0/GF_{90}/CF_0/GF_{90}$ shows better performance compared to the unidirectional oriented hybrid composite material.
- As the research indicates, the developed material is investigated for its application as an automotive part. The hood is considered for the investigation of the developed material.
- The crash test is performed on the rigid concrete wall at a standard velocity of 17778 mm/sec using three different material (aluminium, carbon fibre and nano reinforced hybrid composite). The stress, strain and deformation obtained from the initial condition. The results were tabulated below,

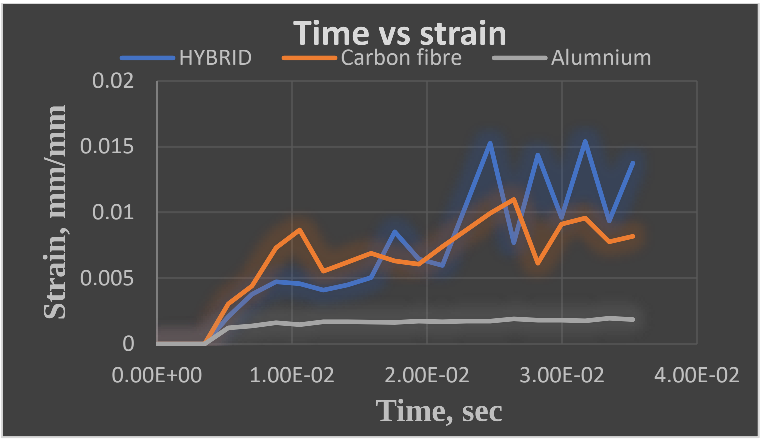
Table 6: Solution obtained from the crash analysis

	Aluminium	Carbon fibre	Nano reinforced hybrid composite
Deformation, mm	617.1	641	625.52
Stress, MPa	79.488	388.71	369.2
Strain, mm/mm	0.001855	0.0081718	0.013755

- The above results show at a time of 0.035 sec the crash rate occurred in all three materials varies following its material property. In this analysis, the wrought aluminium form is considered which is commonly used in automobiles. It shows reduced deformation compared to the composite materials.



Graph 5: time-stress graph for crash analysis



Graph 6: time-stress graph for crash analysis

- The time-stress and time-strain graph represent the stress and strain produced in the material during collision concerning the time.
- From the graph, the stress and strain variation of the material during a collision concerning the time can be known. The aluminium material in wich the stress and strain produced is comparatively low compared to the composite material analysed.
- But comparing the hybrid composite with the conventional composite, both the deformation and stress produced during a collision are low. Which shows that the nano reinforced hybrid composite shows similar stiffness behaviour comparing to the conventional composite.
- The weight of the hood was analysed and they were charted below,

Material	Carbon fibre	Aluminium	Nano reinforced Hybrid composite
Weight	8.6244	14.879	10.19

- For the developed model, the weight reduction has been achieved, as the result indicates the hybrid material also have a reduced weight compared to the other materials.

Conclusion

In this research, the hybrid nano reinforced polymer composite is developed based on different laminate orientations and the developed material is tested under mechanical loading conditions and the best-performed material by which a hood model is developed and it was analysed with crashing conditions and compared with the existing material used as automotive part. the conclusions made in the research are listed below,

1. The polymer matrix is developed in Ansys material designer in which two different volume fraction of carbon nanotubes were reinforced from which change in engineering constants are noticed. In which, the value of elastic modulus along all the direction is increased to a percentage of 3.06 %.
2. Considering the improved properties of the nano reinforced matrix material, the fibre reinforcement is performed with the nano reinforced polymer matrix. The carbon fibre and glass fibre fabric materials were used, in this process, the fabrics were modelled with the pure matrix material and the nano reinforced matrix material to compare the change in engineering constant values, the nano reinforced carbon fibre material shows 1.85% increase in elastic modulus and the nano reinforced glass fibre shows 5.91 % increase in elastic modulus along the longitudinal direction and the other properties were also better.
3. The structural analysis is performed with the developed hybrid nano reinforced polymer composites to analyse the stiffness behaviour of the material under tensile and flexural loading under a maximum load of 8000 N, under tensile loading, the unidirectionally oriented material shows Young‘s modulus of 2.12×10^4 MPa and the multi-directionally oriented material in which Young‘s modulus of 3.69×10^4 MPa is obtained and under flexural loading Young‘s modulus of unidirectionally oriented material is 9.88×10^4 MPa and for the multidirectional oriented material is 9.91×10^4 MPa is obtained. In both testing condition, the multi-directionally oriented material shows a high young’s modulus. From the results obtained it shows that the multi-directionally oriented material shows better stiffness than the unidirectionally oriented material.
4. The material developed is utilised in an automotive structure, an automotive hood is modelled and the application of the material in the hood is analysed by performing crash analysis,
5. The developed material is analysed in an automotive hood comparing with the existing material such as aluminium and carbon fibre. The crash analysis is performed under a standard velocity of 64 km/hour with an end time of 0.035 sec. the analysis shows that the aluminium shows better stiffness compared to the composite materials. But comparing the nano reinforced hybrid composite with the existing composite materials, both show almost similar stiffness behaviour and also around 31 % of weight reduction has been achieved in nano reinforced composite comparing to the aluminium material. The nano reinforcement in polymer composites shows adequate results and in future, it may be utilised as an automotive part.

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