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Characterization and Analysis of Z Pinned Bi directional CFC using Minitab 17

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Abstract

This paper is to evaluate the performance of Z-pinned carbon fiber under tensile and flexural strength. Finite element package ANYSIS 14.5 used for determining structural analysis of laminates.The through-thickness reinforcement of composites with thin metallic or fibrous pins aids in suppressing delamination, improving impact damage tolerance and increasing joint strength. Z-pins are applied to the composite part during its manufacture. Pins are embedded within sheet/cloth of carbon fiber by the method of pinning process. The insertion die and the jig are used for pinning before curing. In this manner, large numbers of pins can be inserted quickly and easily. The pinned composite is then cured using conventional processes. The effect of pinning on the flexural properties, fatigue endurance and failure mechanisms of carbon/epoxy laminates. The pins did not affect the flexural modulus of the laminate. The use of z-pins is currently limited to several high performance composite structures, most notably Formula One racing cars and Super hornet F-18 fighter aircraft, although the technology has potential applications in a diverse variety of aerospace and non-aerospace composite structures. The aim is to investigate the mechanical properties and the effect of z-pin reinforcement on the tensile and flexural properties of laminates through FEA.

Key words: CFC, Resins, Z-pinned, FEA, Tensile, Flexural.

Introduction

The composite is a combination of two or more materials combine on a macroscopic scale to give superior properties than original materials include strength, fatigue life, stiffness, temperature dependent behavior, corrosion resistance, thermal insulation, wear resistance, thermal conductivity, attractiveness, acoustical insulation and weight. The composites possesses high specific strength, high specific strain, low thermal coefficient of expansion, low weight, wear and corrosion resistance, etc. Composites find its application in aerospace, defence, automobiles, machine tool, marine, construction industry, chemical industry and biomedical equipment, etc. Composite materials are the most advanced and adaptable engineering materials. A composite is a heterogeneous material created by the synthetic assembly of two or more components constituting reinforcing matrix and a compatible matrix, in order to obtain specific characteristics and properties. The matrix may be metallic, ceramic or polymeric in origin. The matrix gives a composite its shape, surface appearance, environmental tolerance and overall durability while the fibrous reinforcement carries most of the structural loads, thus giving macroscopic stiffness and strength. It is the behaviour and the characteristics of the interface that generally control the properties of a composite. Development of advanced composite materials having superior mechanical properties opened new horizons in the engineering field. Advantages such as corrosion resistance, electrical insulation, reduction in tooling and assembly costs, low thermal expansion, higher stiffness and strength, fatigue resistance, such as greater stiffness at lower weight than metals, etc., have made polymer composites widely acceptable in structural applications. However, the disadvantages of composite materials cannot be ignored: their complex nature, designers' lack of experience, little knowledge of material databases and difficulty in manufacturing are barriers to large-scale use of composites. A structural composite is a material system consisting of two or more phases on a macroscopic scale, whose mechanical performance and properties are designed to be superior to those of the constituent materials acting independently. One of the phases is usually discontinuous, stiffer, and stronger and is called reinforcement, whereas the less stiff and weaker phase is continuous and is called matrix sometimes, because of chemical interactions or other processing effects, an additional phase, called inter phase, exists between the reinforcement and the matrix. The properties of a composite material depends on properties of the constituents, geometry, and distribution of the phases. Historically, the concept of fibrous reinforcement is very old. There are biblical references to straw-reinforced clay bricks in ancient Egypt. Iron rods were used to reinforce masonry in the nineteenth century, leading to the development of steel reinforced concrete temperature applications. Applications abound, including underground pipes and containers, boats, ground vehicles, aircraft and aerospace structures, automotive components, sports equipment, biomedical products, and many other products designed to have high mechanical performance and/or environmental stability coupled with low weight. For suppressing the delamination of Composites the process of Z pinning is used. It is a thru thickness reinforcement of composites with thin metallic or fibrous pins aids in suppressing delamination, improving impact damage tolerance and increasing joint strength. Z-pins are applied to the composite part during its manufacture. Pins are embedded within sheet/cloth of carbon fiber by the method of pinning process. The insertion die and the jig are used for pinning. Subsequently, it is compacted and the pins transferred into the part, which is usually an uncured prepreg. In this manner, large numbers of pins can be inserted quickly and easily. Finite element analysis (FEA) has been preferred and chosen method to analyze. To determine the structural analysis of z-pinned carbon fiber using the ANSYS14.5 software. Discontinuous or short-fiber composites contain short fibers or whiskers as the reinforcing phase. These short fibers, which can be fairly long compared with the diameter, can be either all oriented along one direction or randomly oriented. In the first instance the composite material tends to be markedly anisotropic or, more specifically, orthotropic, whereas in the second it can be regarded as quasi-isotropic. Continuous fiber composites are reinforced by long continuous fibers and are the most efficient from the point of view of stiffness and strength. The continuous fibers can be all parallel (unidirectional continuous fiber composite)can be oriented at right angles to each other (crossply or woven fabric continuous fiber composite),or can be oriented along several directions (multidirectional continuous fiber composite).

Methodology

Z-pins are thin, rigid rods for through-the-thickness reinforcement of pre-preg laminates. Individual pins are cut from a long pultruded length of cured T300 / bismaleimide (BMI) rod stock which is twisted during the pultrusion process to give it a near circular cross-section. Two z-pin diameters are available, 0.28mm and 0.51 mm. Both of these diameters are available in a range of areal densities from 0.5% to 4%; the array of z-pins is almost always square.

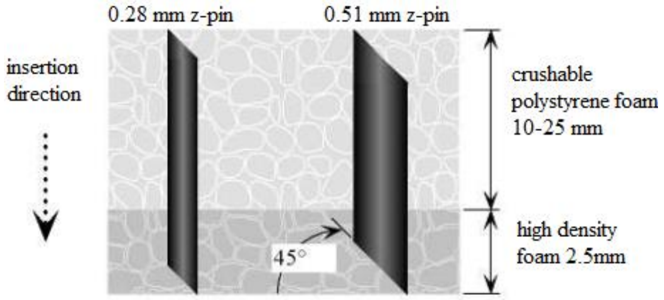

Fig.1. Schematic of z-pin

Z-pins are being used increasingly to enhance the delamination toughness and impact damage tolerance of composite air craft structures. An important consideration in the design of z pinned structures is the knock down to the in plane mechanical properties of the composites materials due to pins. Experimental property data which reveals that large improvements to the delamination toughness of carbon epoxy composite gained with z-pins also results in un avoidable reduction to the in-plane tension, compression, bending, interlaminar shear fatigue properties. Data shows increasing the volume fraction of z-pins in carbon –epoxy to raise the delamination resistance causes a corresponding deterioration to the in-plane properties and this is a key consideration in the design of z-pinned structures for damage tolerance.Z-pin Insertion Methods There are two methods for inserting z-pins into prepreg-based laminates: This method uses the overpressure inside an autoclave to compress the foam carrier and thereby drive the z-pins into the underlying prepreg stack, which is soften at the high curing temperature. While simpler than the UAZ process, the co-cure method is not commonly used because of the difficulty in fully inserting the z-pins all the way through thick prepreg performs. The other method for the insertion of z-pins is the co-cure process ultrasonic insertion and co-cure insertion. The manual process involves a skilled operator holding the ultrasonic horn whereas the automated process involves the horn being held within a gantry and controlled using a numerical operating system. The automated process reduces the likelihood of human error during the z pinning process and often results in higher quality laminates produced within a shorter time. Z-pinning can be customised by changing the material, diameter, spatial density, angle and pattern of the pins. The material and diameter are controlled during the z-pin fabrication process whereas the other parameters are determined by how the z-pins are arranged within the foam carrier. Composite z-pins (precured unidirectional carbon fiber/bismalemide rods) are the most widely used because of their high stiffness and strength and good compatibility with the host composite material (which is usually carbon fiber/epoxy) the diameter of z-pins is typically in the range of 0.1 to 1 mm. The aerial density (or volume content) is controlled by the diameter and spacing between z-pins, and density values in the range of 0.5% to 4% are the most commonly used. The typical length of z-pins is about 12 mm, and the tip is chamfered in order to assist the insertion.

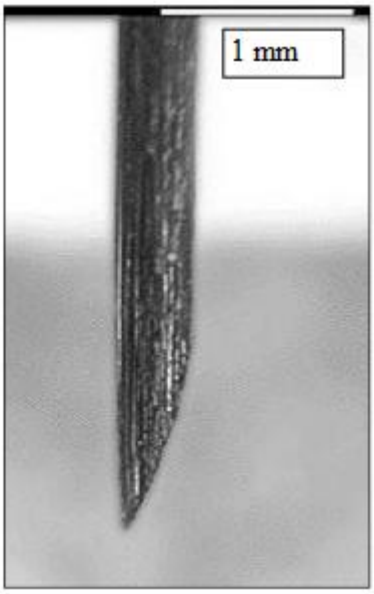

Fig.2. Photograph showing chamfered tip of z-pin

Pin angle is the orientation of the z-pins after they have been embedded into the composite. Usually the objective is to have z-pins embedded orthogonally within the composite to maximize the through-thickness stiffness and delamination toughness. The z-pinning process can have major influence on the mechanical properties and strengthening mechanics of composite materials. Various methods are used to manufacture z-pinned laminates; Z-Pins are made from extruded metal wire of fibrous composite produced by pulling a continuous fiber tow through a resin bath and then pultruding it through a circular die. The metal wire or composite strand is then cut to length and inserted into the foam carrier. The z-pins are arranged in a square pattern inside the foam carrier. The foam is used to ensure an even spacing between the z-pins and to provide them with lateral support during insertion. The foam carrier does not form part of the final composite product, and is discarded after the z-pins have been inserted. Z-Pins are driven from the foam carrier into the prepreg using an ultrasonically actuated tool that can be operated in a manual hand-held mode by a trained operator or controlled using an automated system. The ultrasonic horn generates high frequency compressive waves that are transmitted into the foam carrier, which collapses under the pressure that drives the z-pins into the prepreg. The stress waves also cause moderate heating of the prepreg that softens the resin matrix which eases insertion of the pins. Z-Pins are inserted carrier several times until all the pins have penetrated the prepreg stack .The compressed foam carrier and any excess length of z-pin protruding the prepreg is shaved off using a blade to ensure a smooth surface finish.

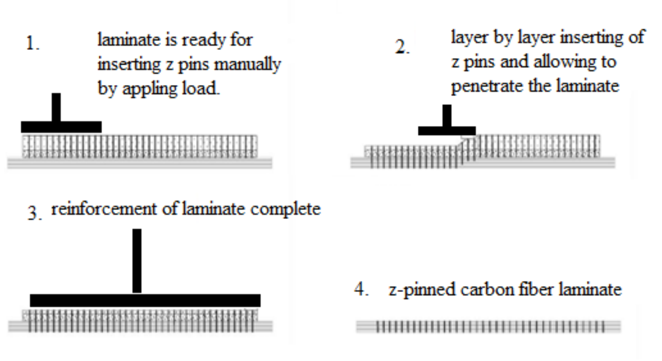

Fig.3. Major stages (numbered 1to 4) in the insertion of z-pins into uncured laminate

Experimental Setup

The laminates were made using a carbon/epoxy (LY556) prepreg tape supplied by Araldite®. The epoxy matrix is a high cure temperature, non-toughened resin. The specimens contained twenty plies of tape stacked in a unidirectional or quasi-isotropic pattern. Prior to curing, the laminates were debulked by vacuum bagging and then z-pinned using pultruded carbon/bismaleimide The z-pins were 2 mm long, and their tips were chamfered to an angle of 45° to ease their insertion into the prepreg stack. The laminates were reinforced with thin (0.28 mm) diameter z-pins to volume contents of 0.5%, 2.0% and 4.0%. These specimens were used to investigate the effect of z-pin content on tensile properties and fatigue performance. In addition, the unidirectional laminate was reinforced to a volume content of 2.0% using thin (0.28 mm) or thick (0.51 mm) diameter z-pins to study the effect of pin size on the mechanical performance. The entire gauge region of the tensile coupon specimens was z-pinned, with the z-pins aligned in parallel rows along the specimen. The spacing between the axial rows of small diameter z-pins was 3.5, 1.75 and 1.2 mm for the volume contents of 0.5%, 2.0% and 4.0%, respectively. The row spacing for the large diameter z-pins was 3.2 mm, thus maintaining the volume content of 2.0%. After z-pinning, the laminates were consolidated and cured in an autoclave at an overpressure of 500kPa and temperature of 115°C for one hour and then 750kPa and 180°C for two hours. The average fiber volume fraction of the laminates was nominally 62%. For reference unidirectional and quasi-isotropic laminates were manufactured using the same curing process.

Materials used

Carbon fiber mat ,Z-pins,Epoxy resin LY556,Hardener HY2424,Wax.First we prepared a rectangular frame of 250mmx25mm with a height of 25mm then a carbon fiber mat sheet with same dimension prepared. Fiber mat also prepared with respective dimension. Wax is applied to frame and as well as to carbon fiber mat sheet. Then carbon fiber mat sheet is placed in the frame and epoxy resin LY 556 is mixed with hardener HY 2424 with required proportions. Have to apply the adhesive to the fiber mat is placed over it and again adhesive is applied with help of brushes. When the adhesive applied properly place another layer of carbon fiber over

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before one and apply adhesive. Similarly we can do this whenever there is need for more layers. This increases the thickness of the composite material. Then z-pins are placed over the laminate before curing the laminate. Keep small load to avoid voids in the composite material. After the soaking period we get the composite material. While preparing the material need to wear gloves to avoid skin infections or any allergies. The preparation steps are shown in below figures.

Fig.4. Preparation of Composite specimens

Fig.5.Preparation of Composite specimen for tensile and flexural testing.

Tensile Specimen according to ASTM standards D3039/D3039M Z-pinned carbon fiber laminate is prepared. It has enlarged ends or shoulders for gripping. The important part of the specimen is the gage section. The cross-sectional area of the gage section is reduced relative to that of the remainder of the specimen so that deformation and failure will be localized in this region. The gage length is the region over which measurements are made and is centered within the reduced section. The distances between the ends of the gage section and the shoulders should be great enough so that the larger ends do not constrain deformation within the gage section, and the gage length should be great relative to its diameter. Otherwise, the stress state will be more complex than simple tension. The end may be screwed into a threaded grip, or it may be pinned; butt ends may be used, or the grip section may be held between wedges. There are still other methods. The most important concern in the selection of a gripping method is to ensure that the specimen can be held at the maximum load without slippage or failure in the grip section. Bending should be minimized the diameter.

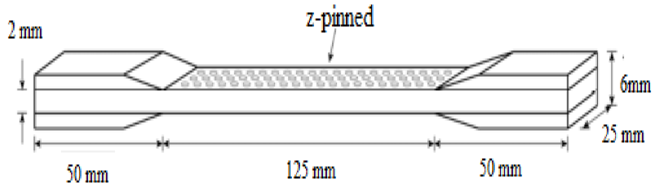

Fig.6. Dimensions for tensile test specimen

The Flexural test measures the force required to bend a beam under 3 point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of a material's stiffness when flexed. Since the physical properties of many materials (especially thermoplastics) can vary depending ambient temperature it is sometimes appropriate to test material at temperature that simulate the intended end user environment. In engineering mechanics, bending (also known as flexure) characterizes the behavior of a slender structural element subjected to an external load applied perpendicular to an axis of the element. When the length is considerably larger than the width and the thickness, the element is called a beam. Simple beam bending is often analyzed with the Euler-Bernoulli beam equation. The classic formula for determining the bending stress in a member is

$$\sigma = \frac{My}{Ixx}$$

Where:

σ is the bending stress
M the moment about the neutral axis
Y the perpendicular distance to the neutral axis
Ixx the area moment of inertia about the neutral axis x

Fig .7. Three point flexural testing machine

Fig.8. Z-pinned carbon fiber laminates before performing tensile and bending test

Fig. 9. Z-pinned carbon fiber laminates after performing tensile and bending test

Results and discussions

TABLE.1. Tensile test results for different types of z-pin reinforcement.

Z-Pin Volume Content (%)	Z-Pin Diameter (mm)	Specimen Thickness (mm)	Tensile strength (N/mm^2)
0.25	0.5	2	518.6
0.5	0.5	2	547.6
2.0	0.5	4	602.8
4.0	0.5	4	639.8

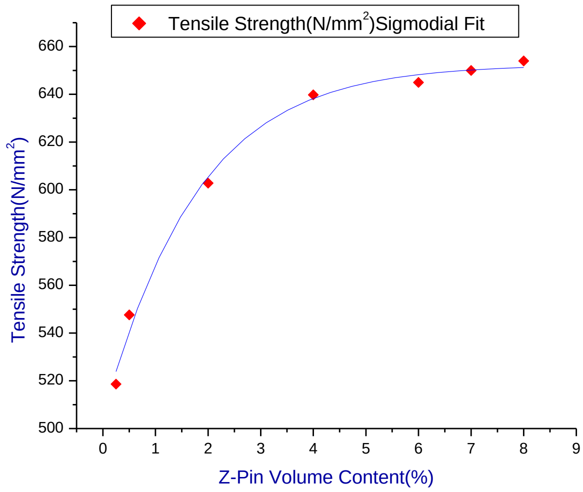

Fig 10 : Tensile strength sigmodial fit

TABLE .2. Flexural strength test results for different types of z-pin reinforcement.

Z-Pin Volume Content (%)	Z-Pin Diameter (mm)	Specimen Thickness (mm)	Flexural strength (N/mm^2
0.25	0.5	2	577.6
0.5	0.5	2	606.6
2.0	0.5	4	648.8
4.0	0.5	4	659.6

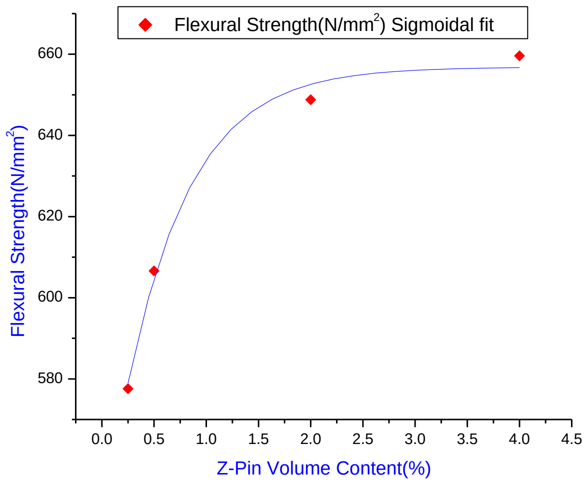

Fig .11.Flexural strength sigmodial fit

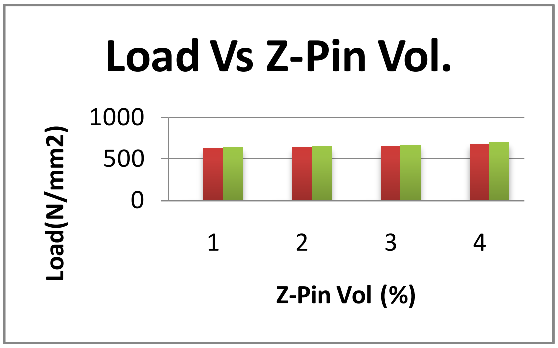

Fig.12. Comparison of experimental results of tensile and flexural strength

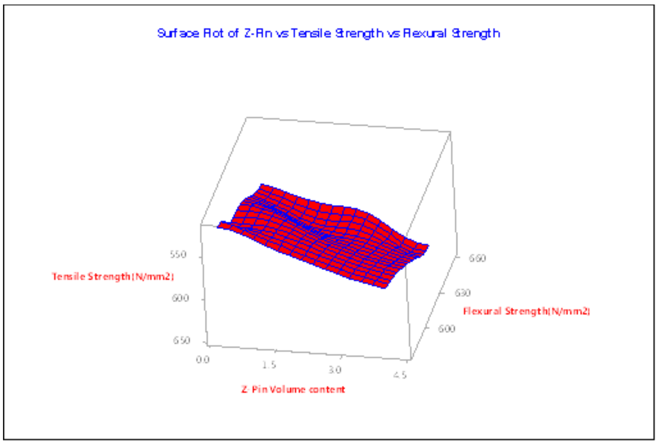

Fig.13. Surface plot of tensile and flexural strength SEM Results

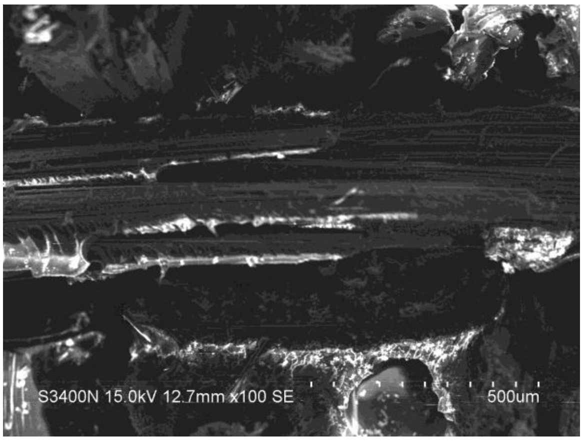

Fig.14. SEM microscopic view of carbon fiber

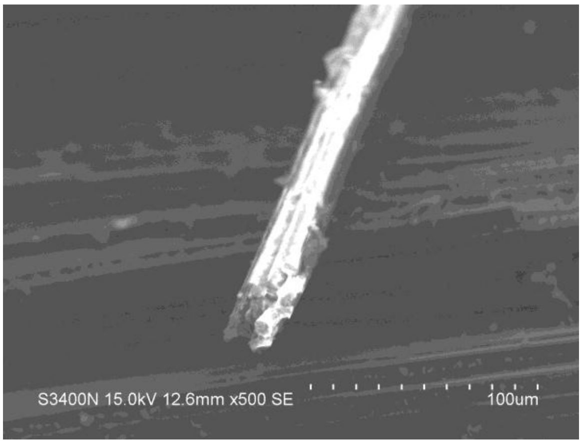

Fig.15. SEM microscopic view of z pinned carbon fiber

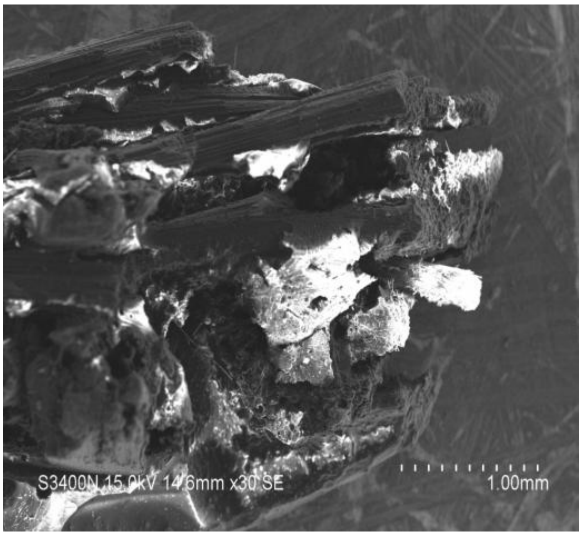

Fig.16. Z pinned carbon fiber layers from SEM

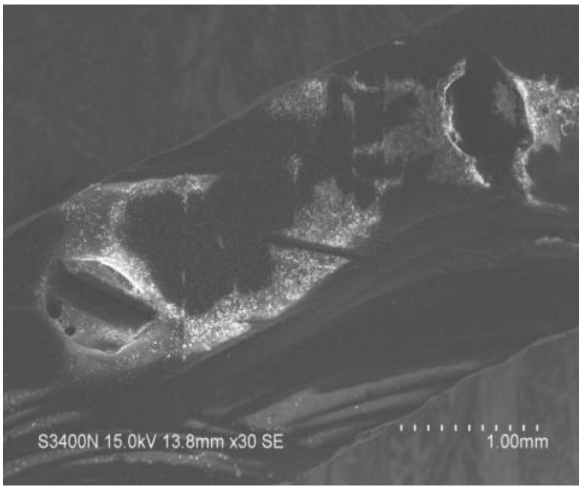

Fig.17.Penetration of z-pins into carbon fiber laminates

Finite Element Analysis

Then it is imported into Ansys then load applied to that and by solving the problem we get all the required data for each element. In this analysis model is designed in SOLID WORKS13.0.

Fig.18. Solid model for analysis

Tensile test (FEA)

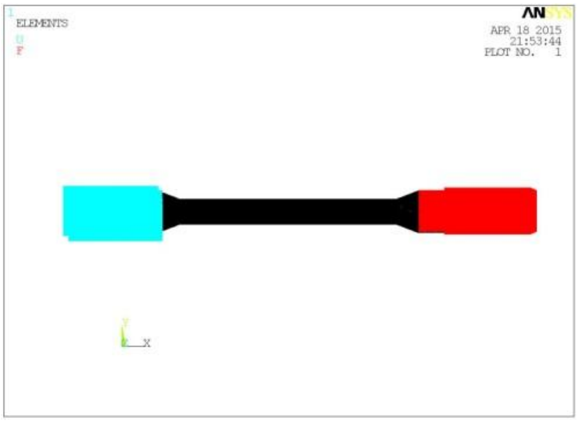

Fig.19.Boundary condition of Tensile test from practical application

Fig.20. Deformed shape diagram of z-pinned carbon fiber

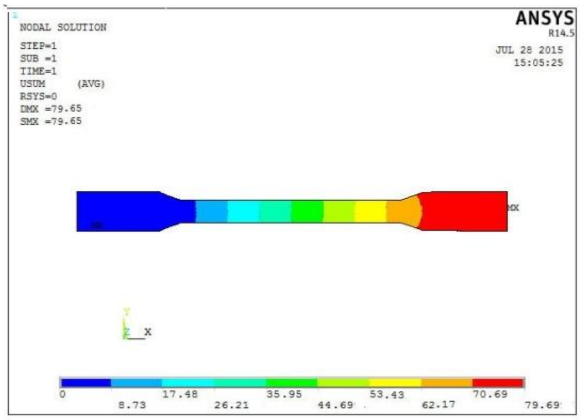

Fig. 21.Vector sum deformation of z-pinned carbon fiber

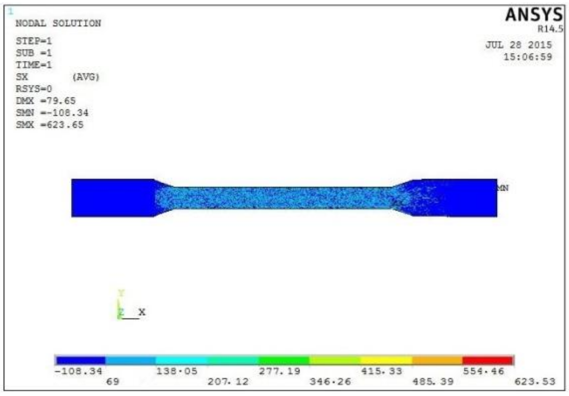

Fig. 22.Stress in x direction for z-pinned carbon fiber

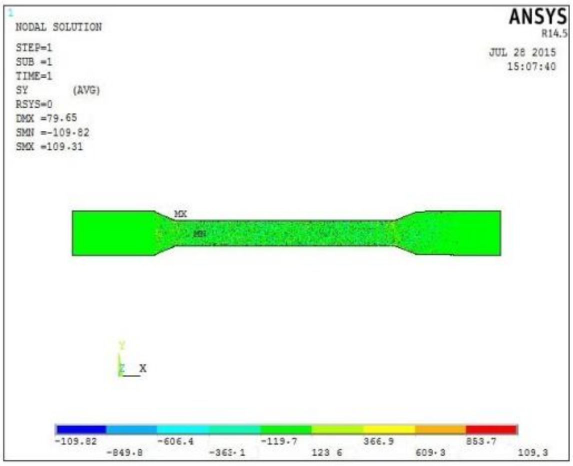

Fig.23.Stress in y-direction for z-pinned carbon fiber

Flexural test (FEA)

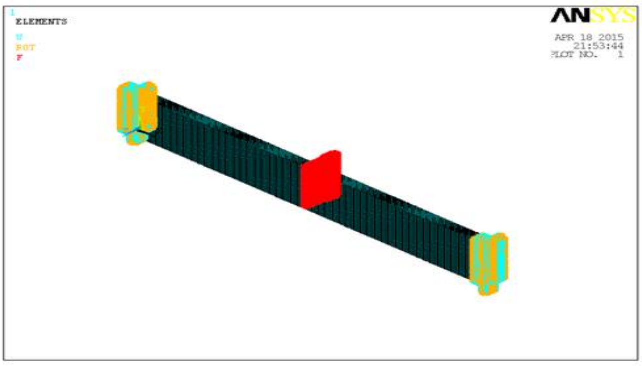

Fig. 24. Boundary condition of bending test from practical application

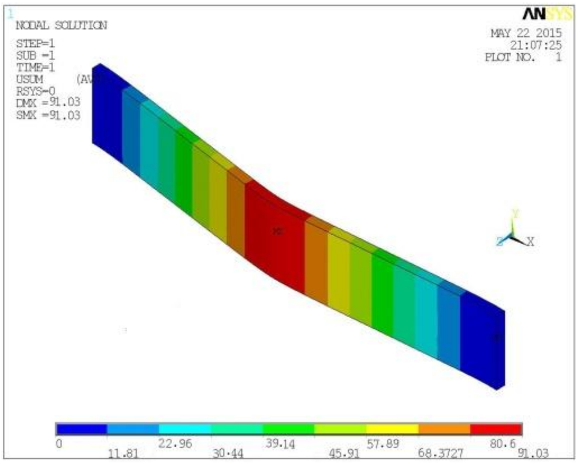

Fig.25.Vector sum Deformation

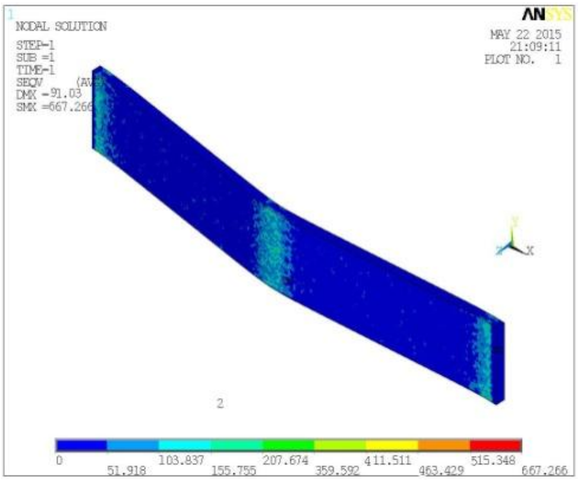

Fig. 26. Von mises stress of z-pinned carbon fiber

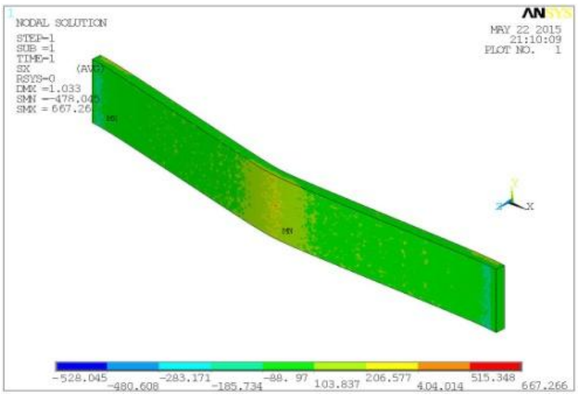

Fig. 27. Stress in x direction of z-pinned carbon fiber

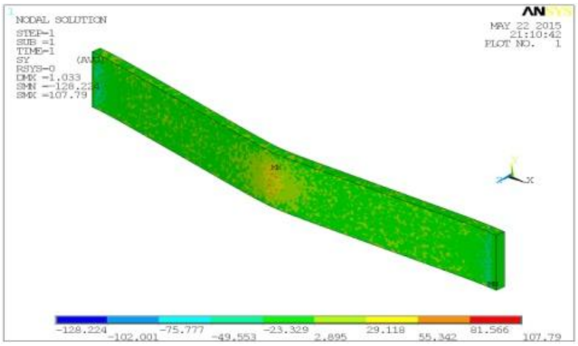

Fig.28.Stress in y direction of z-pinned carbon fiber

TABLE.3. Comparison of experimental results with analysis results

Z-Pin Volume Content (%)	Experimental results		ANSYS results	
	Tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Tensile strength (N/mm^2)	Flexural strength (N/mm^2)
0.25	518.6	577.6	623.27	632.26
0.50	547.6	606.6	638.39	645.41
2.0	602.8	648.8	653.64	667.26
4.0	639.8	659.6	676.12	692.12

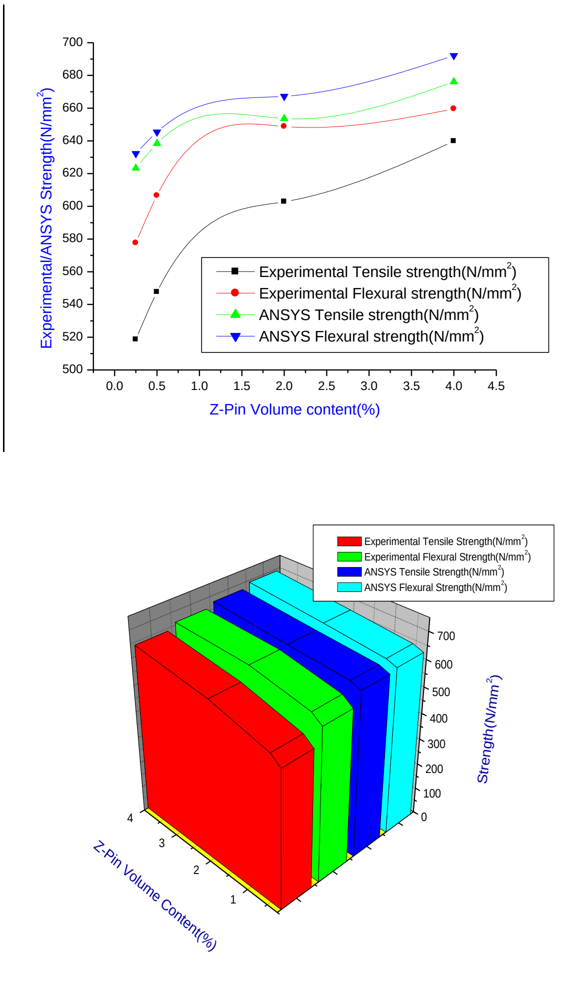

Fig.29. Comparison of experimental with analysis results

Conclusion

Applying Z-Pinning concept we have significant benefits such as improved delamination resistance, damage tolerance, through- thickness stiffness and joint strength increases. The effect of z-pin volume content and diameter on the tensile and flexural properties of bidirectional carbon/epoxy laminates was determined. The through thickness reinforcement of z-pin carbon composite material improves delamination resistance and impact damage tolerance. The finite element analysis results are compatible with experimental results. The tensile strength was degraded more than Young's modulus by z-pinning. The changes are less than 5% which is good for structures which require modulus retention. The change in strength with increasing z-pin volume content was caused by a change in failure mode.

Acknowledgement

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