Thermal Stress in Composite Structures Under Autoclave Conditions

Mr. Garapati Dora Babu[1], Mr. V.Satyanarayana[2], Mr. Y.Dhanasekhar[3]
[2]Assistant professor, Dept of Mechanical
[3]Associate professor, Dept of Mechanical
[1, 2, 3] Kakinada institute of technology and science, Divili

Abstract- *Thermo mechanical loading behavior of composite or nano composite laminated parts, particularly beams, plates and sandwiches have become on the verge of recent computational and analytical works.In our study importance is given to the thermal related stress induced in a composite structure due to temperature in autoclave. The study is carried out with three layer configurations and three materials (Epoxy Carbon Woven (395 GPa) Prepeg, Epoxy S-Glass UD, Nylon 6, glass fiber reinforced (PA6-GF)), the layer configurations are selected based on commercial available composite configurations, the observations made in this study are discussed.*

Keywords- Nylon 6, glass fibre reinforced, Epoxy Carbon Woven (395 GPa) Prepreg, PBT, glass fibre reinforced Using ANSYS software.

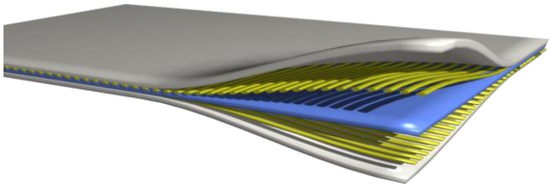
I. INTRODUCTION

A characteristic feature of human civilization is to move forward in the field of aerospace structures .this aspect is reflected in the continued urge to make a structure which is lighter, stronger, and stiffer and more damage tolerant. Progress towards this is closely associated with three broad aspects:

- Materials
- Processing Techniques
- Structural Concepts

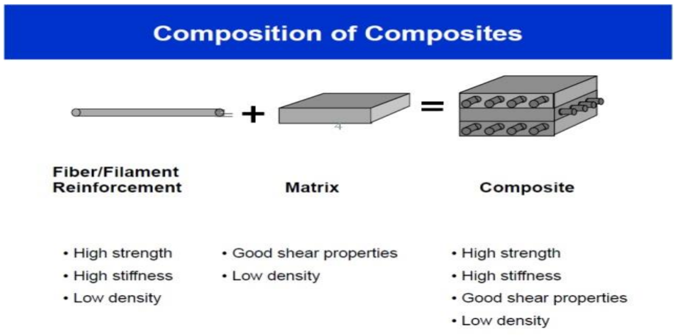
Materials are of basic importance in the development of any product .The term “material” is very common yet we fumble when we attempt to define it .A basic definition of the material is as follows.“A material is defined as a substance that is intended to be used for certain applications. There are a myriad of materials around us. They can be found in anything from buildings to spacecraft”.Materials can be generally divided into two classes .They are Crystalline and Non crystalline .The some of the examples of materials are metals, ceramics, and polymers and composites. These are four general classifications available for use in engineering applications. Most of the materials fall into one of these classes that are based on the atomic bonding forces of a particular material.They are metallic, ceramic, and polymeric. Additionally, different materials can be combined to create a composite material.

COMPOSITES: Composite materials are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components.



Composite

Definition: A Composite material can be defined as a material i.e made by combining of two or more constituents at a macroscopic level. The resulting material has the better properties than the individual constituents. The constituents are obtained from the previous three classes of materials. The constituents by themselves are not of much engineering utility, they are combined at macro level. They do not merge and do not chemically react. But when combined they form a unique material which properties are far better than those of the individual constituents. Thus the resultant composite material is highly efficient.



Composition of composites

CLASSIFICATION OF COMPOSITE MATERIALS:

Composites can be classified primarily into two ways .The first way to classify composite materials is by the type of matrix material.

- Polymeric matrix composites(PMCs)
- Metal matrix composites (MMCs)
- Ceramic matrix composites (CMSs)
- Carbon/carbon composites (CCCs)

The second type is based on the geometry and shapes of reinforcements and structural form of composites.

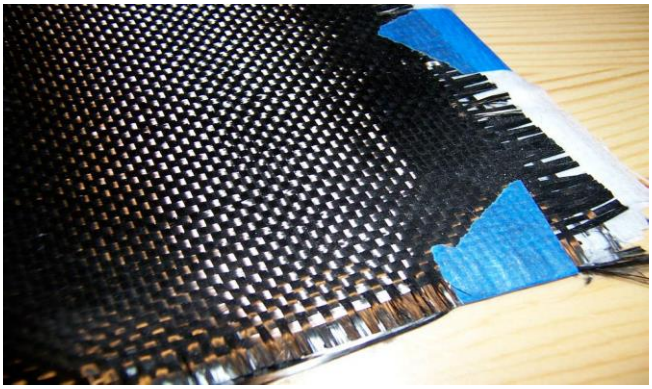
- Phased composites
- Particulate composites
- Short fibre composites
- Flake composites
- Unidirectional composites

Layered composites

- Laminated composites
- Sandwich composites

REINFORCEMENT:

The role of the reinforcement in a composite material is fundamentally to increase the of the neat resin system. All of the different fibers used in composites have different properties and so affect the properties of the composite in different ways.



Fiber Sheet

Fiber is a class of hair-like materials that are continuous filaments in discrete elongated similar to pieces of thread. They can be used as loading members of composite materials. Individual fibers or fiber bundles can only be used on their own in a few processes such as filament winding.

For most other applications, the fibres need to be arranged into some form of sheet, known as a fabric, to make handling possible. Different ways for assembling fibres into sheets and the variety of fibre orientations possible lead to there being many different types of fabrics, each of which has its own characteristics.

PROPERTIES OF REINFORCING FIBRES :

The four main factors that govern the fiber’s contribution are

1. The basic mechanical properties of the fiber itself.
2. The surface interaction of fiber and resin (the ‘interface’).
3. The amount of fiber in the composite (‘Fiber Volume Fraction’).
4. The orientation of the fibers in the composite

They can also be matted into sheets to make products such as paper or felt. Fibers are of two types: natural fibre which consists of animal and plant fibers, and man-made fiber which consists of synthetic fibers and regenerated fiber.

Reinforcement usually prevents crack propagation. Thin fibers can have very high strength, and provided they are mechanically well attached to the matrix and can improve the composite's overall properties.

Fibre-reinforced composite materials can be divided into two main categories normally referred to as short fibre-reinforced materials and continuous fibre-reinforced materials.

MATRIX:

The matrix is a phase or constituent that binds the fibers .The reinforcement by themselves are not useable as a product and matrix by binding gives shape to the product. In PMCs composite various resins are used as a matrix material .

Resins are available in different forms including liquid , flakes and granules etc, .During applications resins are used in the liquid form to impregnate the fibres and when cured cross-linking takes place and the liquid resin hardens and gives shapes to the product .We have different types of resins available based on the availability and use. The some of the resins are Natural resins, Synthetic resins etc.

Resin

The main functions of the matrix are to Bind the fibres together and place them in desired place. Resin also translates load from one to another through shear and it also protects from the environmental conditions such as temperature, humidity and imports some special properties to the composite material. Transfers stiffness and strength and shear stiffness and shear strength depends on the matrix material.Some of the commonly used resins are epoxy , polyester etc.

The use of composite material is growing day by day, it is due to the various advantages the composites offer over a traditional metallic components. There are many advantages of composites, together with lighter weight, improved fatigue life, the ability to tailor the layup for optimum strength and stiffness, resistance to corrosion, and with beneficial in design practice, assembly costs is reduce due to less fasteners and detail parts.

The many other advantages of composites are following:

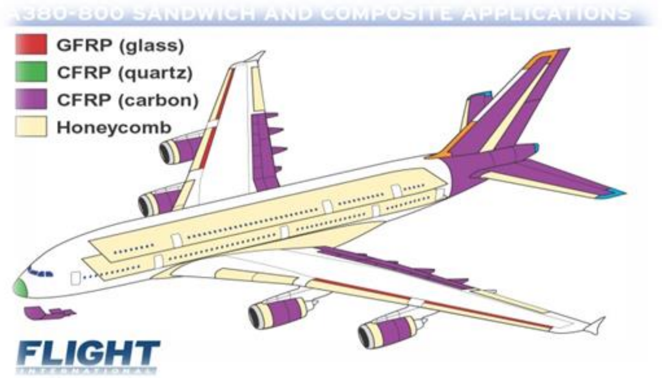
- High tensile strength and stiffness
- High specific strength and specific modulus
- High fatigue strength
- Inherent material damping and good impact properties
- Tailor able properties
- Design flexibility
- Less corrosion
- Simple manufacturing techniques
- Near net shape part and lower part count
- Cost effective product development

Benefits of composites are well recognized today, and use of composite materials in different industrial sectors is steadily growing. Industrial sectors that use composites can be listed as

- Aerospace applications
- Civil Engineering applications
- Electronics applications
- Marine and other applications

It is important to note that each sector has its own characteristics in their functional requirement, demand of goods , and many other parameters.

Depending upon the particular need of a sector , composite materials , their design and manufacturing processes are exploited suitably.



A380 Composite application

PROCESSING TECHNIQUES:

There are different types of processing available to manufacture the composite materials based on the type of the matrix and reinforcement.The basic steps involved in the processing techniques are as follows:

- We have to necessarily impregent the fibres.
- Arrange the fibres in the required direction.
- The materials are consolidated.
- Solidification process is carried out, later it is cured at certain temperature.

The processing techniques are broadly classified on

- Open Moulding - Wet layup
- Closed Moulding - Compression moulding
- Continues Moulding - Filament winding ,Hoop winding, Tape winding

Techniques of manufacturing a polymer matrix composite include Filament Winding used generally for making pipes and tanks to handle chemicals, Auto Clave Forming used to make complex shapes and flat panels for structures where low void content and high quantity are important ,and Resin Transfer Molding is used extensively in the automotive industry where short production runs are necessary.

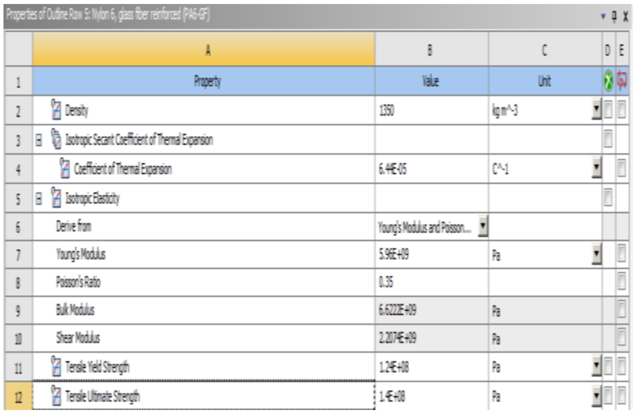
Auto clave forming manufacturing method is used with composites available as prepregs. Resin transfer moulding is also called as liquid molding.

ANSYS: ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyse by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations. ANSYS is the standard FEA teaching tool within the Mechanical Engineering Department at many colleges.

Material properties

1.Nylon 6, glass fibre reinforced (PA6-GF)

Polyamide/nylon 6 (PA6) + 30% glass fiber

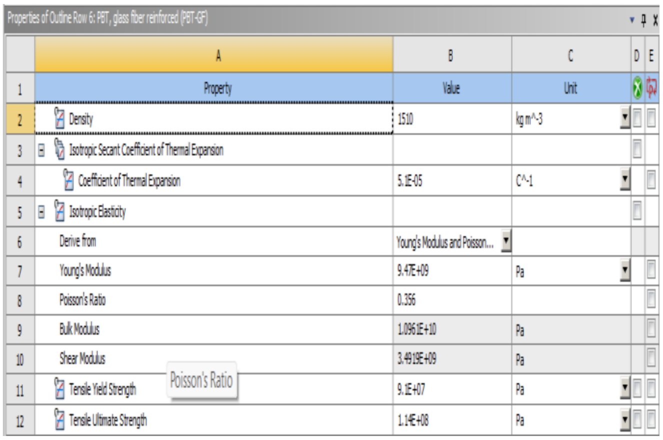


Properties of Outline Row 5: Nylon 6, glass fiber reinforced (PA6-GF)

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1350	kg m^-3	☐	☐
3	Isotropic Secant Coefficient of Thermal Expansion			☐	
4	Coefficient of Thermal Expansion	6.4E-05	C^-1		☐
5	Isotropic Elasticity			☐	
6	Derive from	Young's Modulus and Poisson...			
7	Young's Modulus	5.96E+09	Pa		☐
8	Poisson's Ratio	0.35			☐
9	Bulk Modulus	6.6222E+09	Pa		☐
10	Shear Modulus	2.2074E+09	Pa		☐
11	Tensile Yield Strength	1.24E+08	Pa	☐	☐
12	Tensile Ultimate Strength	1.4E+08	Pa	☐	☐

PBT, glass fibre reinforced (PBT-GF)

Polybutylene terephthalate (PBT) + 30% glass fiber

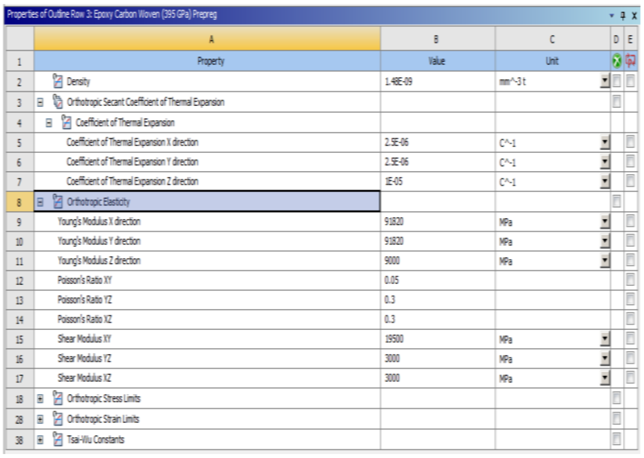


Properties of Outline Row 6: PBT, glass fiber reinforced (PBT-GF)

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1510	kg m^-3	☐	☐
3	Isotropic Secant Coefficient of Thermal Expansion			☐	
4	Coefficient of Thermal Expansion	5.1E-05	C^-1		☐
5	Isotropic Elasticity			☐	
6	Derive from	Young's Modulus and Poisson...			
7	Young's Modulus	9.47E+09	Pa		☐
8	Poisson's Ratio	0.356			☐
9	Bulk Modulus	1.0961E+10	Pa		☐
10	Shear Modulus	3.4919E+09	Pa		☐
11	Tensile Yield Strength	9.1E+07	Pa	☐	☐
12	Tensile Ultimate Strength	1.14E+08	Pa	☐	☐

Epoxy Carbon Woven (395 GPa) Prepreg

Epoxy + 30% Carbon Woven fiber

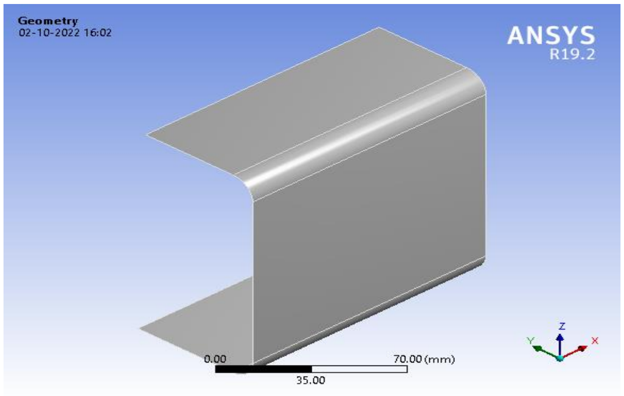


Properties of Outline Row 3: Epoxy Carbon Woven (395 GPa) Prepreg

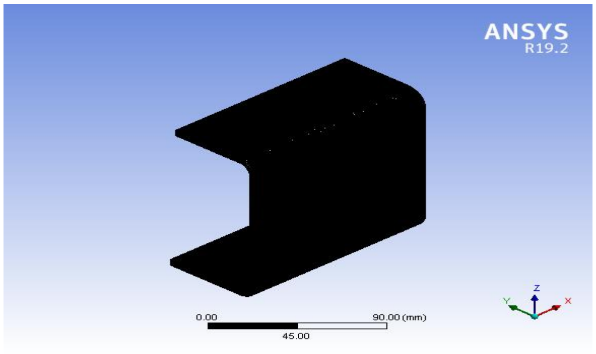
	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1.48E-09	mm^-3 t	☐	☐
3	Orthotropic Secant Coefficient of Thermal Expansion			☐	
4	Coefficient of Thermal Expansion				
5	Coefficient of Thermal Expansion X direction	2.5E-06	C^-1		☐
6	Coefficient of Thermal Expansion Y direction	2.5E-06	C^-1		☐
7	Coefficient of Thermal Expansion Z direction	1E-05	C^-1		☐
8	Orthotropic Elasticity			☐	
9	Young's Modulus X direction	91820	MPa		☐
10	Young's Modulus Y direction	91820	MPa		☐
11	Young's Modulus Z direction	9000	MPa		☐
12	Poisson's Ratio XY	0.05			☐
13	Poisson's Ratio YZ	0.3			☐
14	Poisson's Ratio XZ	0.3			☐
15	Shear Modulus XY	19500	MPa		☐
16	Shear Modulus YZ	3000	MPa		☐
17	Shear Modulus XZ	3000	MPa		☐
18	Orthotropic Stress Limits			☐	
28	Orthotropic Strain Limits			☐	
38	Tsai-Wu Constants			☐	

Boundary conditions

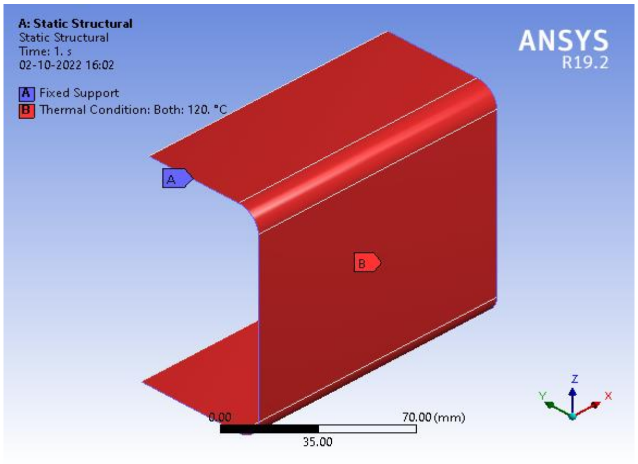
Geometry



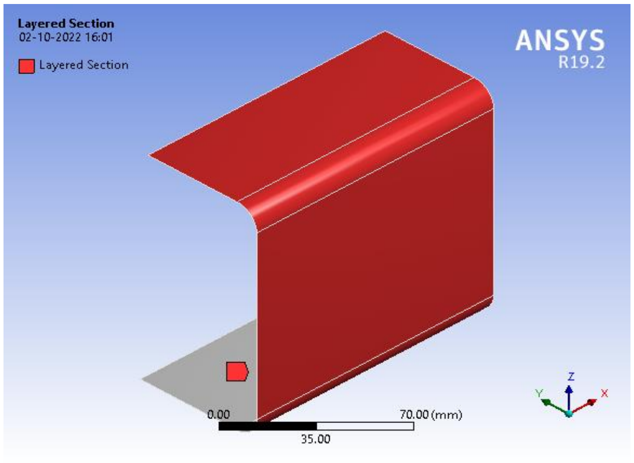
Meshed model



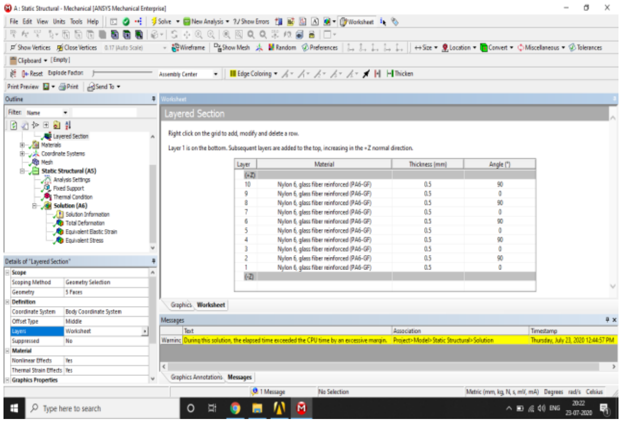
Fixed supports and Thermal condition



Layered section



Layer configuration 1


A : Static Structural - Mechanical [ANSYS Mechanical Enterprise]

Layered Section

Right click on the grid to add, modify and delete a row.

Layer 1 is on the bottom. Subsequent layers are added to the top, increasing in the +Z normal direction.

Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
10	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	90
9	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
8	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	90
7	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
6	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	90
5	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
4	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	90
3	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
2	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	90
1	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
(-Z)			

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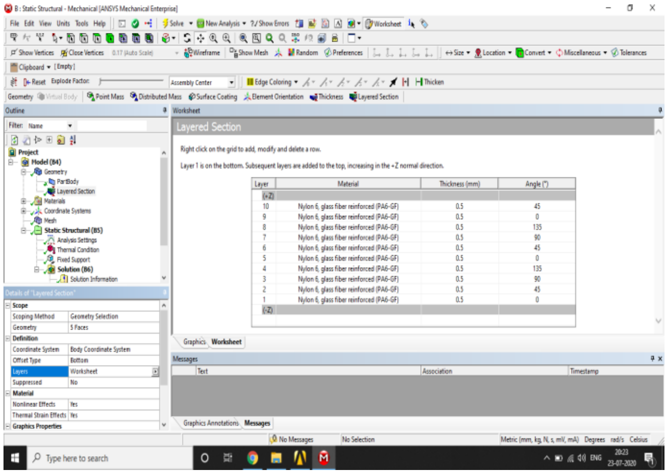
Layer configuration 2


B : Static Structural - Mechanical [ANSYS Mechanical Enterprise]

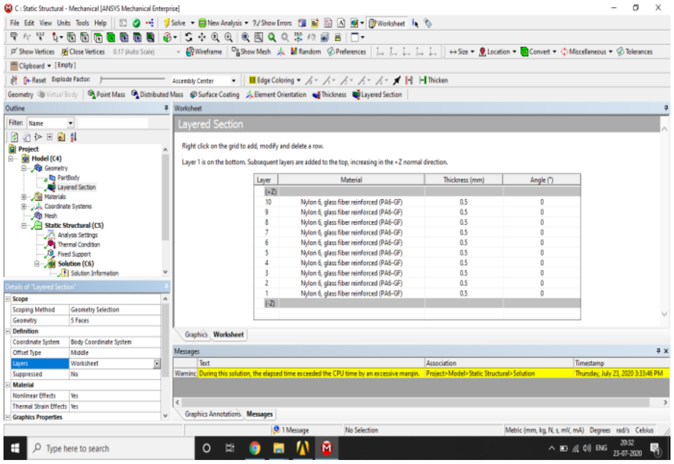
Layered Section

Right click on the grid to add, modify and delete a row.

Layer 1 is on the bottom. Subsequent layers are added to the top, increasing in the +Z normal direction.

Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
10	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	45
9	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
8	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	135
7	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	90
6	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	45
5	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
4	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	135
3	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	90
2	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	45
1	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
(-Z)			

Layer configuration 3


C : Static Structural - Mechanical [ANSYS Mechanical Enterprise]

Layered Section

Right click on the grid to add, modify and delete a row.

Layer 1 is on the bottom. Subsequent layers are added to the top, increasing in the +Z normal direction.

Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
10	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
9	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
8	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
7	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
6	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
5	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
4	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
3	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
2	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
1	Nylon 6, glass fiber reinforced (PA6-GF)	0.5	0
(-Z)			

	Text	Association	Timestamp
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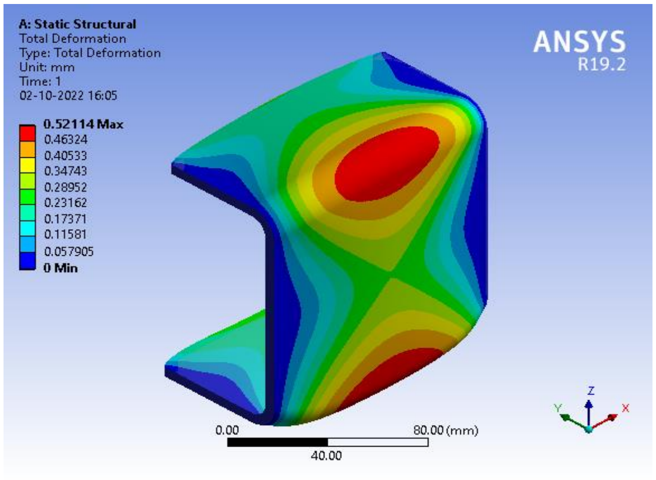
THERMAL STRESS AT AUTOCLAVE TEMPERATURE EPOXY CARBON WOVEN (395 GPA) PREPEG

TABLE -1

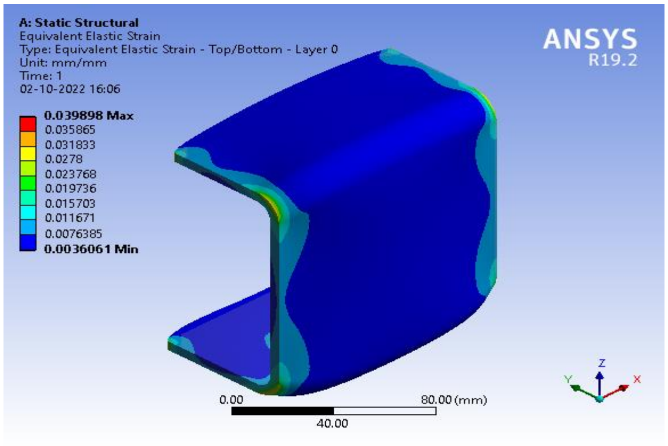
thermal stress at autoclave temperature	Total Deformation			Equivalent Elastic Strain			Equivalent (von-Mises) Stress		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
cross play	0	0.52114	0.24224	3.61E-03	3.99E-02	7.13E-03	21.492	237.79	42.503
45o	0	0.51942	0.26572	4.13E-03	2.12E-02	7.35E-03	24.52	119.8	43.285
unidirectional	0	0.52114	0.24193	3.61E-03	3.99E-02	7.13E-03	21.492	237.79	42.494

CROSS PLAY

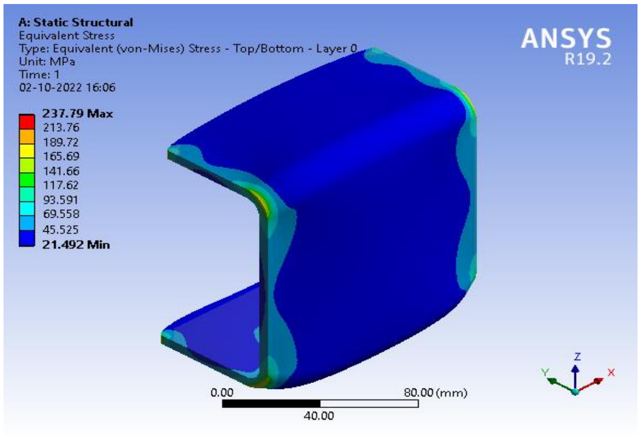
DIRECTIONAL DEFORMATION (MM)



EQUIVALENT ELASTIC STRAIN (MM/MM)

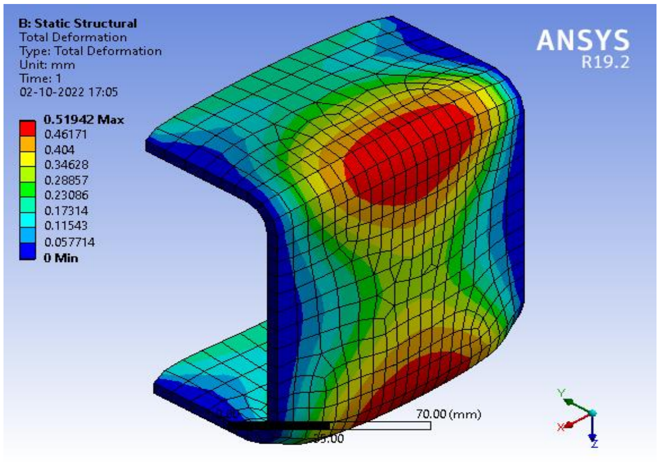


EQUIVALENT STRESS (MPA)

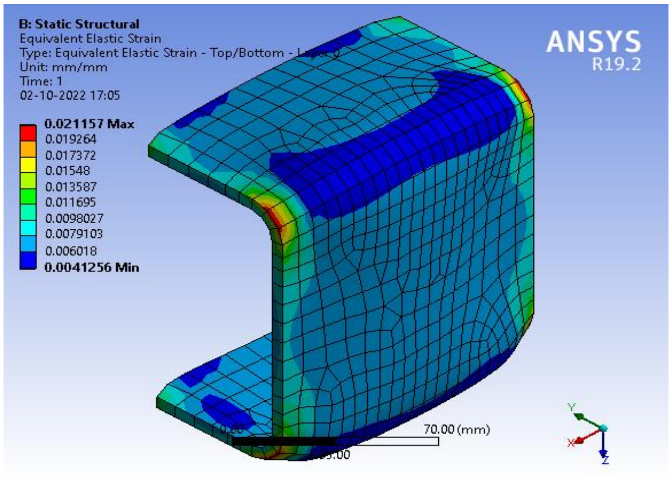


45^{O}

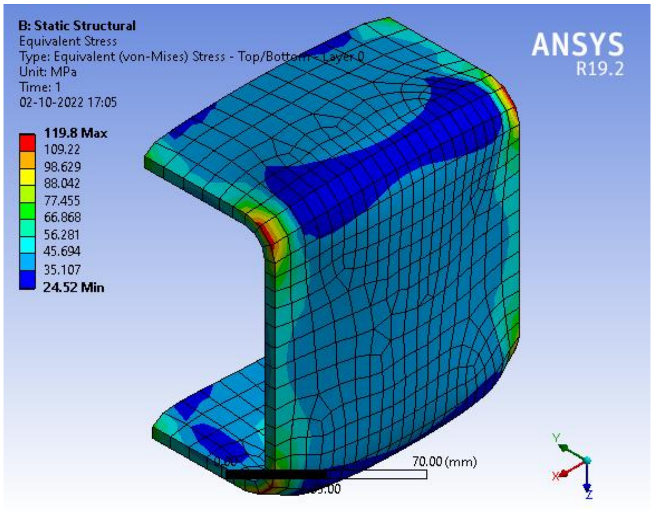
DIRECTIONAL DEFORMATION (MM)



EQUIVALENT ELASTIC STRAIN (MM/MM)

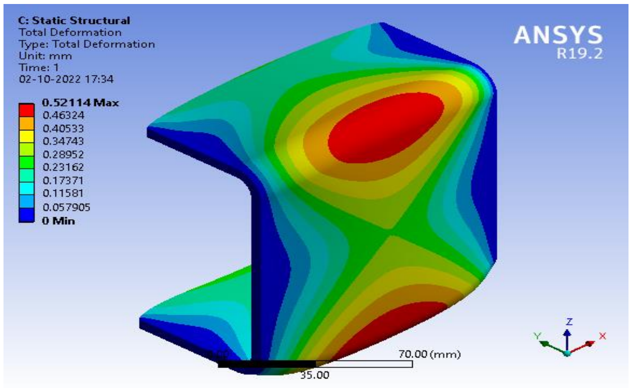


EQUIVALENT STRESS (MPA)

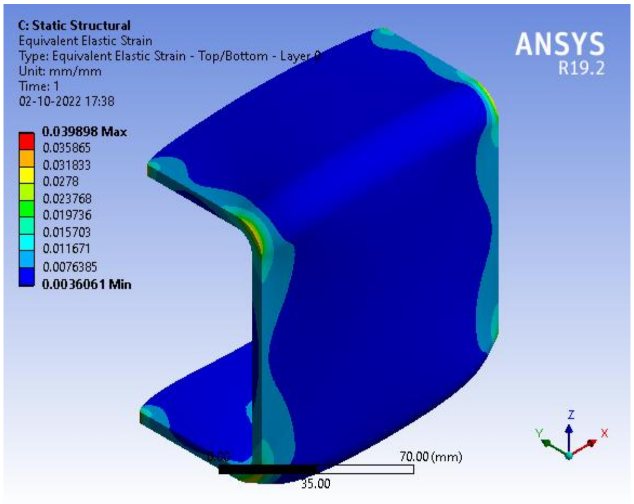


UNIDIRECTIONAL

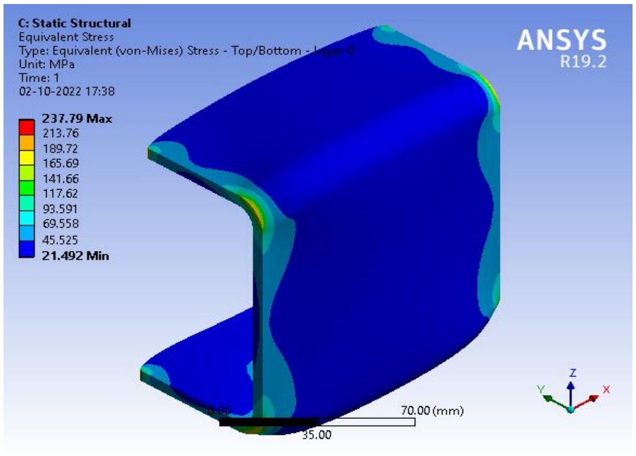
DIRECTIONAL DEFORMATION (MM)



EQUIVALENT ELASTIC STRAIN (MM/MM)



EQUIVALENT STRESS (MPA)



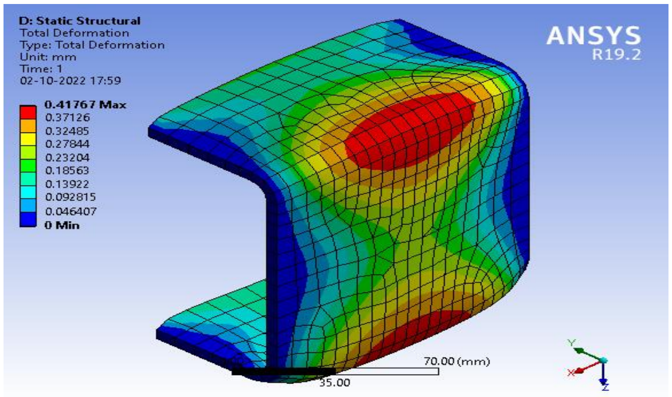
THERMAL STRESS AT AUTOCLAVE TEMPERATURE, EPOXY S-GLASS UD,

TABLE -2

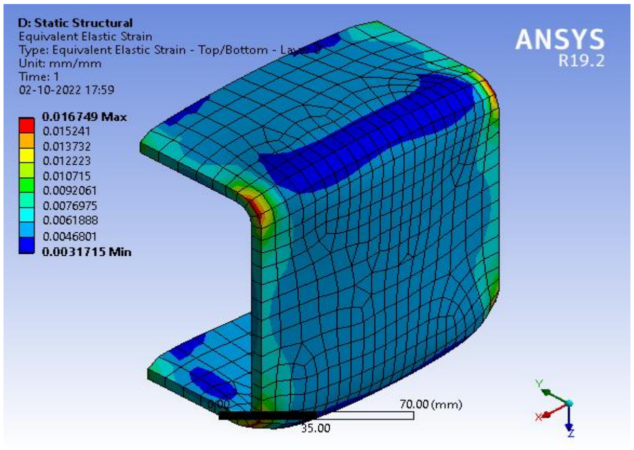
thermal stress at autoclave	Total Deformation			Equivalent Elastic Strain			Equivalent (von-Mises) Stress		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
cross play	0	0.41767	0.20873	3.17E-03	1.67E-02	5.85E-03	29.954	150.32	54.754
45o	0	0.4254	0.21079	3.19E-03	1.92E-02	6.52E-03	26.525	108.15	48.673
unidirectional	0	0.41767	0.20873	3.17E-03	1.67E-02	5.85E-03	29.954	150.32	54.754

CROSS PLAY

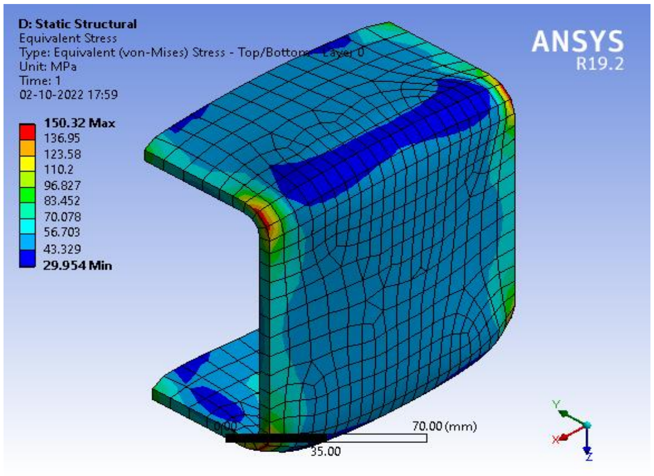
DIRECTIONAL DEFORMATION (MM)



EQUIVALENT ELASTIC STRAIN (MM/MM)

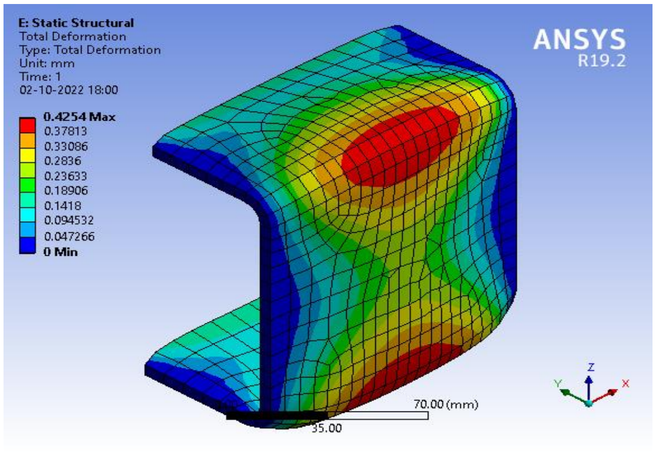


EQUIVALENT STRESS (MPA)

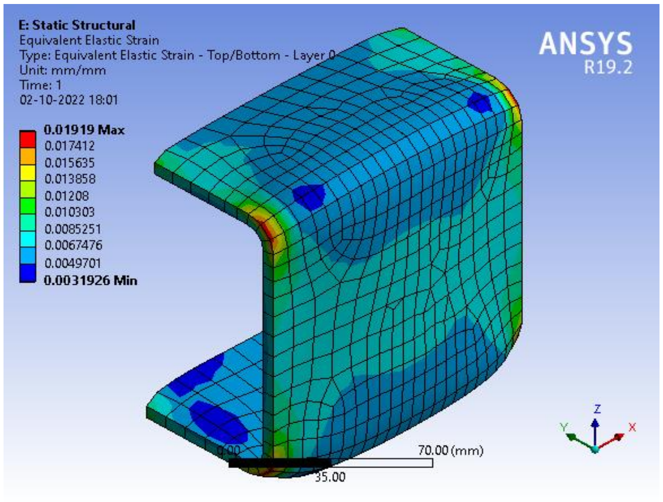


45^{O}

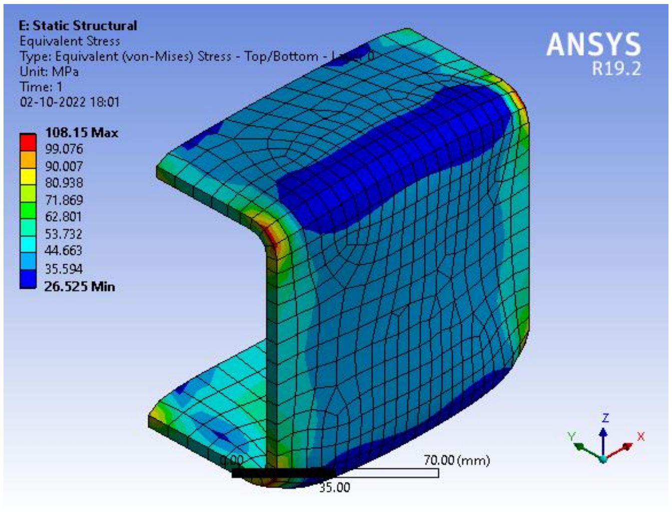
DIRECTIONAL DEFORMATION (MM)



EQUIVALENT ELASTIC STRAIN (MM/MM)

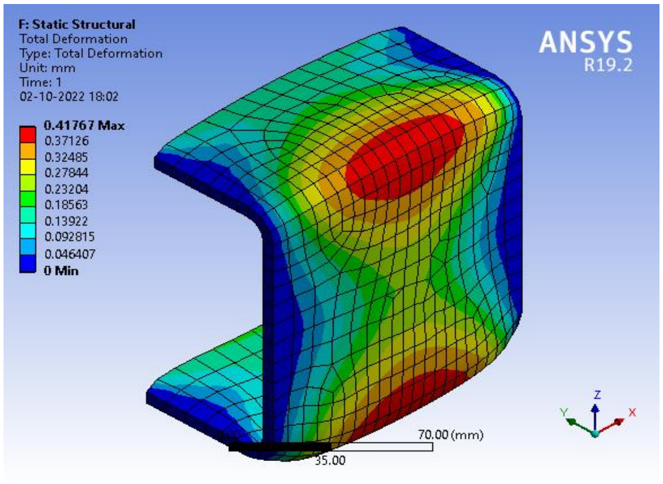


EQUIVALENT STRESS (MPA)

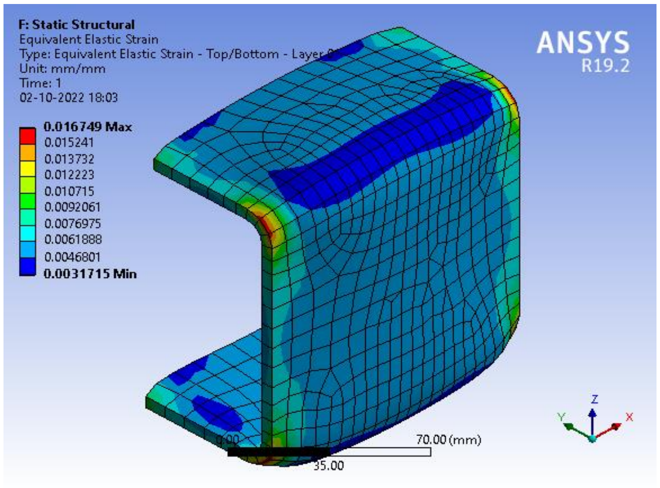


UNIDIRECTIONAL

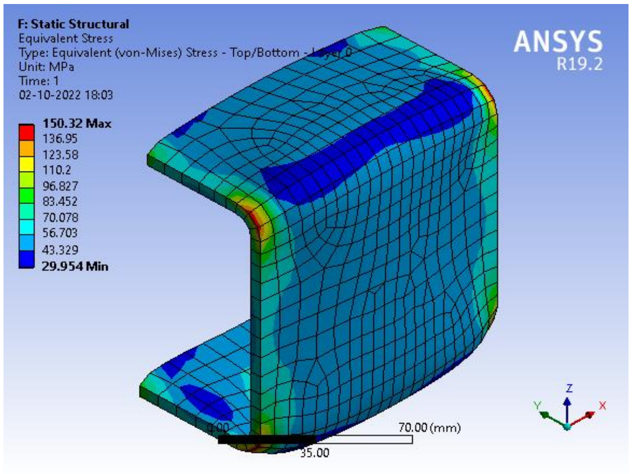
DIRECTIONAL DEFORMATION (MM)



EQUIVALENT ELASTIC STRAIN (MM/MM)



EQUIVALENT STRESS (MPA)



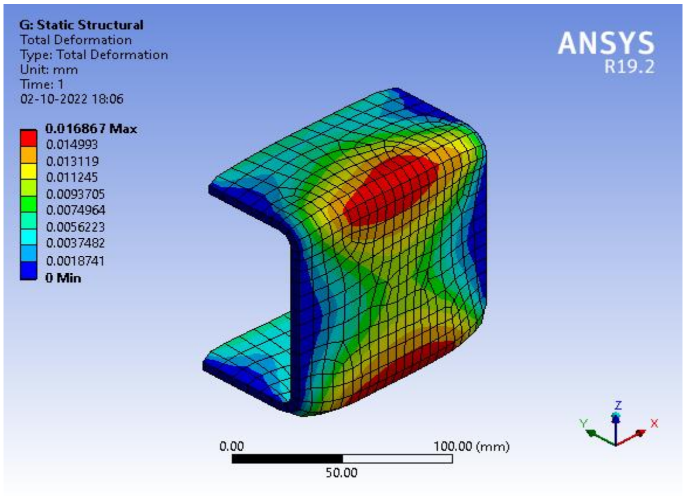
THERMAL STRESS AT AUTOCLAVE TEMPERATURE NYLON 6, GLASS FIBER REINFORCED (PA6-GF)

TABLE-3

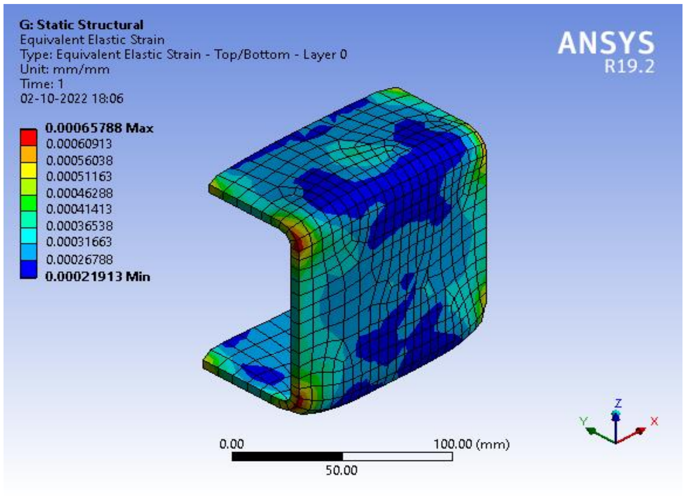
thermal stress at autoclave	Total Deformation			Equivalent Elastic Strain			Equivalent (von-Mises) Stress		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
cross play	0	1.69E-02	8.67E-03	2.19E-04	6.58E-04	3.18E-04	14.21	38.883	21.858
45o	0	1.84E-02	8.96E-03	2.00E-04	6.79E-04	3.16E-04	9.9714	44.03	20.159
unidirectional	0	1.55E-02	7.42E-03	2.08E-04	1.28E-03	3.03E-04	16.132	81.391	22.408

CROSS PLAY

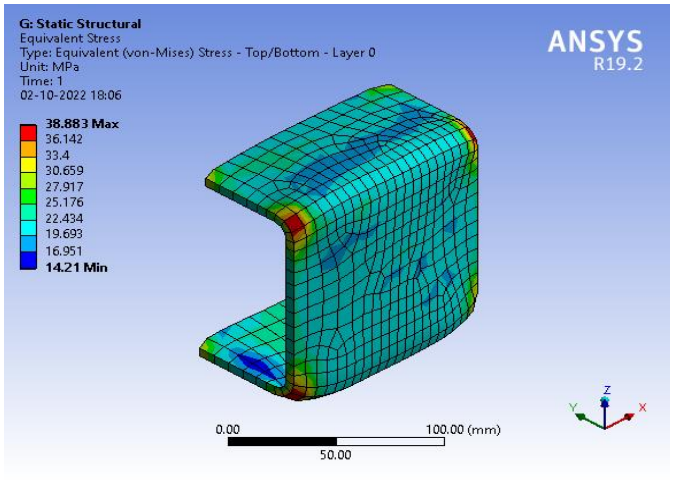
DIRECTIONAL DEFORMATION (MM)



EQUIVALENT ELASTIC STRAIN (MM/MM)

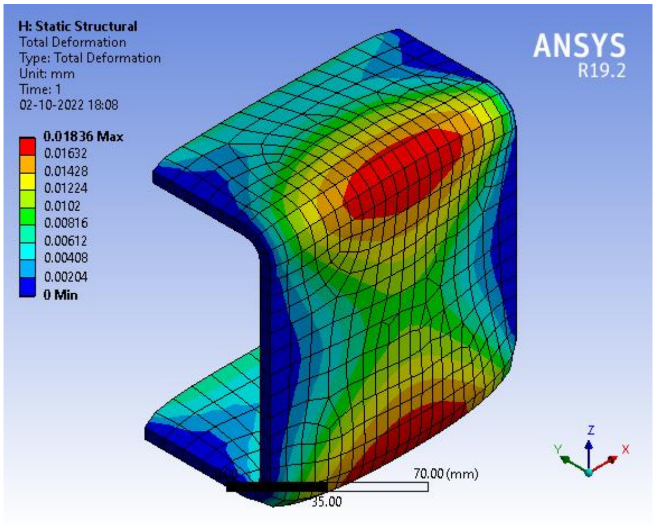


EQUIVALENT STRESS (MPA)

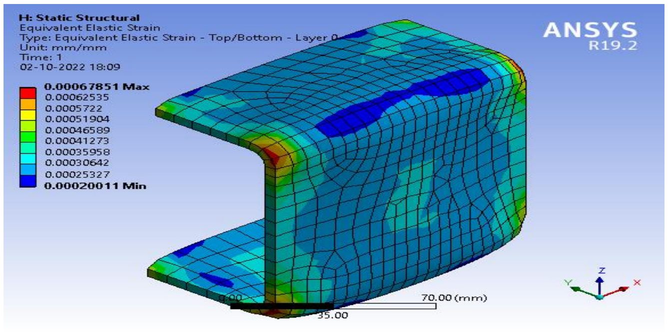


45^{O}

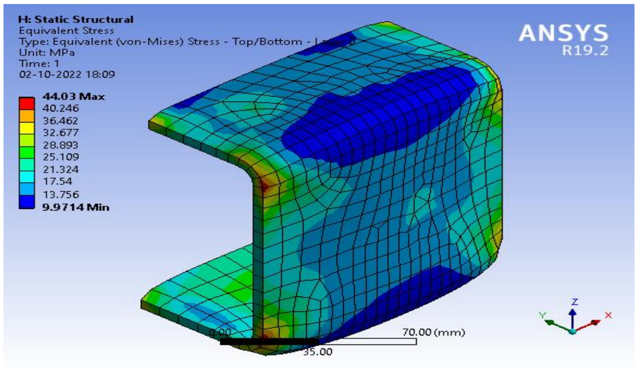
DIRECTIONAL DEFORMATION (MM)



EQUIVALENT ELASTIC STRAIN (MM/MM)

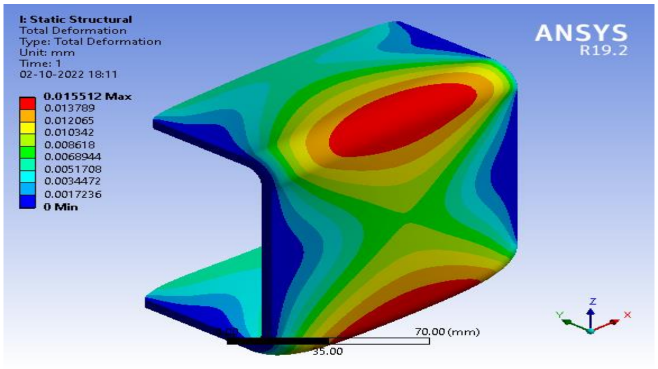


EQUIVALENT STRESS (MPA)

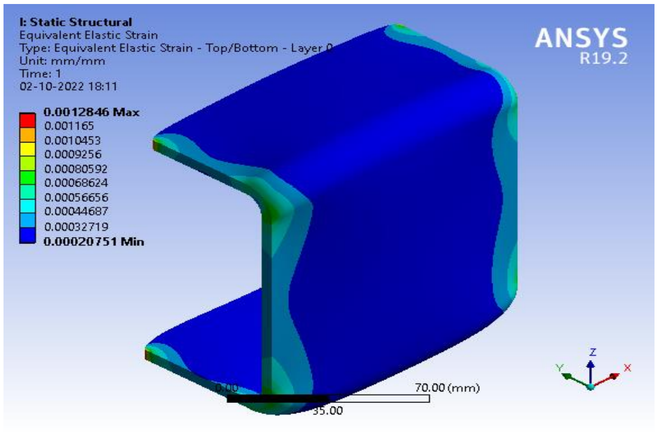


UNIDIRECTIONAL

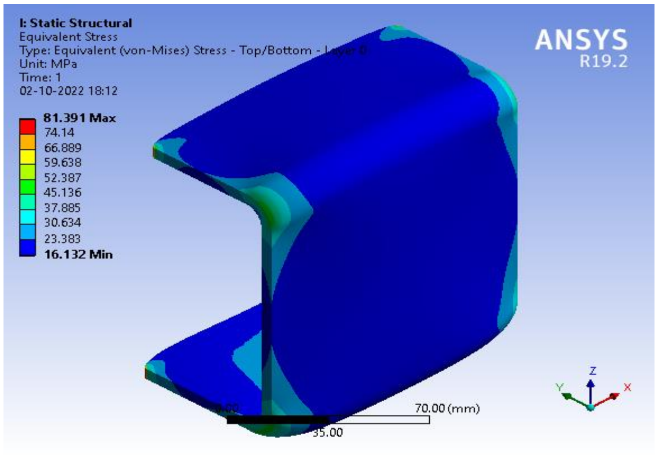
DIRECTIONAL DEFORMATION (MM)



EQUIVALENT ELASTIC STRAIN (MM/MM)



EQUIVALENT STRESS (MPA)



II. CONCLUSION

In our study importance is given to the thermal related stress induced in a composite structure due to temperature in autoclave. The study is carried out with three layer configurations and three materials (Epoxy Carbon Woven (395 GPa) Prepeg, pollster S-Glass UD, Nylon 6, glass fiber reinforced (PA6-GF)), the layer configurations are selected based on commercial available composite configurations, the observations made in this study are listed below

Composites with laminates oriented at 45o have more deformations than other composites
Tough the deformations are very less due to low thermal expansion coefficient stress are significant
The stress generation in different specimens didn't follow any specific patron but there is no much variation
Displacement is mainly observed in the middle section and further rise in temperature may result in buckling as per our observations As the ends are described as fixed the stress are more prominent here.

III. FUTURE SCOPE

In this work complete work is carried out using ANSYS simulation Thermal stress are evident and varies with ply orientation, this work can be extended by experimental testing of composite specimens with different ply orientations subjected to thermal stress.

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