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INVESTIGATION OF TENSILE STRENGTH OF NOTCHED FIBER-REINFORCED COMPOSITE SPECIMEN FOR VARIOUS LAYUP PATTERN

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ABSTRACT

For a variety of reasons, high-performance composite systems are often designed with different shapes and size discontinuities. Under different working loads, the areas near these notches become vital regions. The double-edge-notched Carbon fiber Specimen is investigated using a combination of analytical well as finite element (FE) simulation techniques to check the Tensile strength Stress concentration factor and delamination in this research study. In notched composites, the occurrence of subcritical damage has a considerable impact on the overall strength of the component. This experiment is a thorough investigation of three separate carbon fiber layups, which were examined in tension using a triangular, rectangular, and circular double-edge-notched specimen. Static analysis of carbon fiber plate having triangular and circular double-edge-notched specimen will be performed using ANSYS19 software. Comparative analysis will be done with FEA Experimental results using MCDM Techniques. Conclusion and future scope will be suggested.

KEYWORDS: *Composite; Carbon Fiber; Failure Mode; FEA; MCDM Techniques*

Article History

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INTRODUCTION

Fiber Reinforced Composites are a heavy-duty fiber composite created by wovencellular fiber molecules with the help of resins in the Fiber Reinforced Composites material matrix using a patented molecularrestructuring technique, resulting in a fabric with expected properties like strengths, ductility, and other respective properties. Unlike other composites, FRC is can be reutilizedmore than 20 times, allowing scrap composites to be again used repeatedly. Delamination, intraluminal matrix breaking, longitudinal matrix separation, matrix debonding, fiber fracturing,and fiber pull-out are all failure processes in FRC materials.

Many major industries, such as manufacturing, automotive, aerospace, oil and gas,defense, and shipping, can be seen a significant rise in various industrialpurposes of inventive FRPcomposite materials in recent years, driven by the need to overcome the shortcomings of traditional materials. However, a variety of technological and implementation challenges must be addressed before the use of FRP composites is widely adopted by some engineering organizations, such as Mechanical assemblies, civil structures, etc. This special issue aims to disseminate the latest up-to-date research and advancements in this fascinating area.Carbon fibers have a strong balance of Tensile strengths and Young's modulus, have a minor (slightly minus) CTE and are resistant to heat.

Figure 1 shows Tensile modulus is a common way to classify carbon fibers. Carbon fibers are classified into five types that are often utilized in composites: intermediate modulus, regular modulus, low modulus, ultra-high-modulus, and extreme modulus. Depending on the source, the precise cut-off for these forms vary, Low modulus fibers, on the other hand, have a tensile modulus of less than 30Msi, whereas ultra-high modulus fibers have a tensile modulus of more than 75Msi. Steel, by contrast, has a tensile modulus of 29Msi. Fiberglass is glass that has been spun into fibers, as the term implies. There are five types of fiberglass. Chemically resistant, A-glass (alkali glass) has weak electrical properties. Chemical resistance is a strong suit for C-glass (chemical glass). E-glass (electrical glass) is an excellent insulator that protects against water damage.

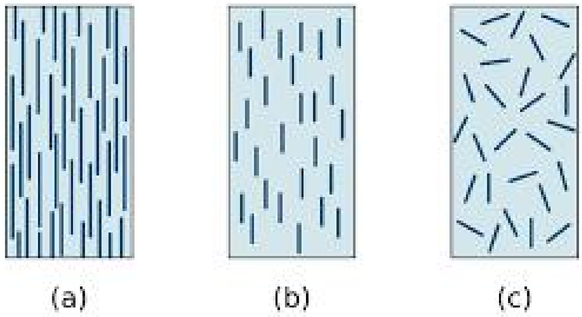

Figure 1: Fiber-Reinforced Composites Topology[12].

LITERATURE REVIEW

Venkat Aitharaju, SatvirAashat, Hamid Kia Arun Kumar Satya Narayana, Philip Bogart [1] "Progressive Damage Modeling of Notched Composites". Non-crimp fiber-reinforced composites are gaining popularity for primary and secondary structural weight savings in high-performance automotive applications.One of the most difficult difficulties in integrating these composites is a lack of knowledge of damage progression under a broad range of loading conditions for general configurations. To that end, GM and NASA researchers are designing new harm models to reliably assess the progressive breakdown of these composites.The evolved progressive failure analysis model was used in this study to study damage development in center-notched and open-hole stress specimens for different laminate schemes. The findings of a thorough investigation into the impact of element size on research outcome are discussed.Computational models based on stress intensity factors (SIF) have been used to estimate crack growth and, eventually, the failure load of composites. Rice used the J-integral approach to quantify the SIF of a composite with cracks to estimate crack growth by computing stress and strain at several internal points around the crack.This technique, on the other hand, is extremely computationally costly.

Mohamad Fotouhi, MeisamJalalvand, and Michael R. Wisnom [2] "Notch insensitive orientation-dispersed pseudo-ductile thin-ply carbon/glass hybrid laminates". The use of traditional composite laminates is limited by notch sensitivity, free edge delamination, and brittle failure. In a previous report, we successfully designed pseudo-ductile hybrid composites with no free-edge delamination using a hybrid layup concept with the various materials blocked together but with scattered orientations.This study introduces a comprehensive selection of engineered and specified orientation-dispersed pseudo-ductile thin-ply hybrid composites to combat notch sensitivity, another important limiting factor in typical composite laminates. Three various thin-ply carbon/glass hybrid configurations were subjected to unnotched, open-hole, and sharply notched stress checks.The investigated laminates demonstrated effective pseudo-ductile un-notched activity with improved notch-insensitivity and suppression of free-edge delamination, which was previously identified as an unacceptable harm mode in hybrids with plies with the same inclination blocked together. The pseudo-ductile damage mechanisms cause subcritical damage in the laminates, resulting in notch insensitivity.

This research introduces a detailed collection of engineered and defined orientation-dispersed pseudo-ductile thin-ply glass/carbon hybrid composites to address some of the drawbacks of traditional laminated composites' notched conduct and free edge delamination. The following conclusions have been reached: Free edge delamination was effectively suppressed in both un-notched and notched configurations, demonstrating the superiority of the orientation-dispersed principle over previously investigated orientation-blocked hybrids.Subcritical pseudo-ductile damage mechanisms, such as scattered delamination and fragmentations, were used to achieve efficient pseudo-ductile un-notched action with notch-insensitivity.

A. Khechai, A. Tati, B. Guerra, A. Guettala, P.M. Mohite [5] “Strength degradation and stress analysis of composite plates with circular, square and rectangular notches using digital image correlation”. For a variety of reasons, high-performance composite systems are often designed with different shape and size discontinuities. Under varying working loads, the zones near these notches become critical.In the current research, the stress concentration factor (SCF), failure mechanism, delamination, and tensile strength deterioration of aluminum and E-glass laminated plates was investigated using a mixture of theoretical, experimental, and computational experiments using finite element (FE) simulation techniques. To assess the fracture mechanisms and Stress Concentration Factor In the first part of the current work, a series of tensile tests on laminates with various fiber orientation angles and specimens with various notch diameter/width (D/W) ratios were designed and tested for unnotched/notched specimens.

Tensile strength degradation and the final failure mechanism that occurs after final failure are influenced by hole type, open notch size, fiber orientation angle, and stress distribution. The Stress Concentration Factor and the harmed zone rise as the notch size is increased, while the notched capacity decreases.

Stephen R. Hallett And Michael R. Wisnom [8] “Experimental Investigation of Progressive Damage and the Effect of Layup in Notched Tensile Tests” In notched composites, the occurrence of subcritical damage has a considerable impact on the ultimate failure mode and weight. This paper examines four separate E-glass/913 layups that were examined using a double-edge-notched specimen primed in strain. Three different in-plane dimensions are tested for each layup. The findings are described in terms of failure mode, weight, and the creation of subcritical injury.

Finally, failures caused by notches in composite materials are diverse and vary depending on the layup and specimen scale. Not only do the failure pressures differ, but the failure modes still differ significantly.The failure stresses could not be fully characterized by the computational methods used here, which were dependent on fracture mechanics or the average stress criteria.Until reliable forecasts can be reliably made over a variety of sizes, layups, and materials, more sophisticated models that account for various risk modes and subcritical damage must be created. The test results reported here show proof of various failure modes in the specimens and provide a substantial body of data for the correlation of analytical and computational models for failure prediction.

R. Venkata Rao,Vimal J. Savsani, 2012 “Mechanical Design Optimization Using Advanced Optimization Techniques” Making choices in the face of several, normally competing factors is referred to as multiple criterion decision making (MCDM). Depending on whether the problem is a selection problem or a design problem, MCDM problems can be divided into two categories: multiple attribute decision making (MADM) and multiple objective decision making (MODM).

MADM techniques, but in the other hand, are usually isolated, only with a few preset options. MADM is a method for solving problems require selecting between a limited range of options. An MADM approach defines how data sets can be analyzed in taking a decision.

PROBLEM STATEMENT

1st Problem

The use of advanced fibrous composites in automotive structural areas will reduce vehicle weight, resulting in increased fuel economy and lower emissions. Failure mechanisms and damage evolution of composite materials, on the other hand, face serious challenges to correct load-carrying capability prediction and are one of the key obstacles to large-scale use of composite materials in vehicles.

2nd Problem

Fiber pull-out and breakage or kinking, matrix splitting, fiber/matrix interface shear breakdown, and delamination between the layers are all failure modes for the composites. The design of packing, lay-up, and geometric conditions of a composite has a big impact on the form of failure.

3rd Problem

In the case of an automotive assembly consisting of composite components, it is impossible to prevent the appearance of holes or cutouts, which contain stress concentrations that can dramatically decrease strength. As a result, one of the architecture drivers for composite structures in load-bearing areas is notched capacity. Experiments, analytical methods, and statistical numerical methods were used by many researchers to investigate the power of notched composites.

OBJECTIVE

- To study advanced composite material to minimize the weight.
- To study major barriers in the implementation of composite materials in automobiles like failure mechanisms & damage evolution.
- To investigate the result of load on stress, displacement and Strain carbon fiber plate having triangular and circular double-edge-notched specimen through finite element analysis.
- To get the good strength of our test specimen we will find the optimum sizes of notches and holes by using optimization techniques.
- To study failure mode effect analysis in composites.
- To study notch strengths to reduce stress concentration consequences.
- Comparative analysis between FEA Experimental results and Validation with MADM Techniques.

DESIGN

Here I have designed & drafted the 3D CAD model using CATIA R19 Software to use this model for my experimental study. The size of all specimens is kept the same to get comparative results between them. The outer sides of the specimen are 200X25 having 5mm thickness. The Notch of Different sizes is designed having different shapes like Triangular, Circular, and Rectangular.

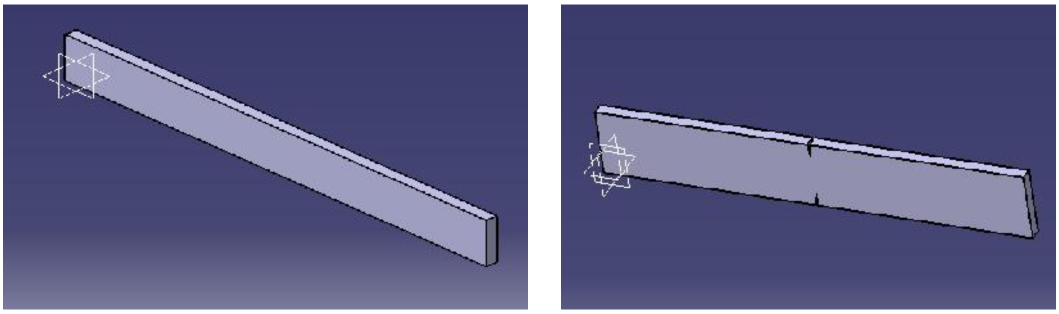

Figure 2: CAD Model of Regular Specimen & Triangular Notched Specimen.

ANALYSIS

The finite element method (FEM) is a numerical solution method for engineering and mathematical physics problems. The easiest way to understand FEM is to look at how it's used in practice, which is called finite element analysis (FEA). FEA is a statistical instrument used in engineering to perform engineering research. It entails the use of mesh generation techniques to break down a large problem into smaller components, as well as the use of FEM-coded software programs.

What is ANSYS ACP?

Ansys Composite Prep Post (ACP), a technique for modeling composite layups and failure analysis. For tacit and explicit structural and thermal, and also fluids, simulations, you can create layered composite models. Composite materials are made up of two or more layers, each with its own set of properties. These fabrics have become the industry standard for light and solid goods. Composites provide enough complexity to allow for the production of items with complicated designs, such as boat hulls and surfboards.

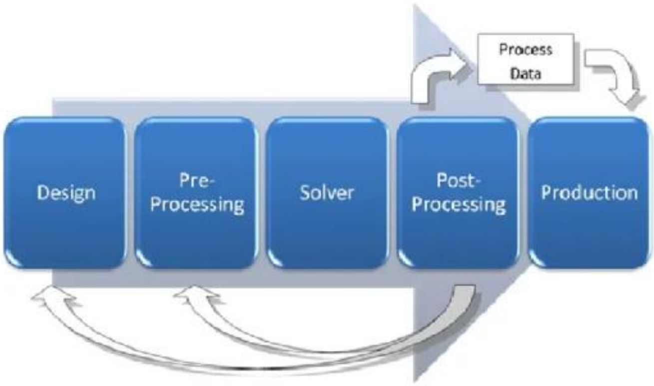

Figure 3: FEA Flowchart.

Stacks of Angle Combinations

In the Automotive industry, we know now a day car comes in various complex designs and every design is having sharp corners different kind of shapes and various type of holes and notches.Currently, we make all this with different materials like MS, Aluminum, Different types of alloys to meet this requirement. But as we know Fuel efficiency is becoming a huge challenge in our latest cars. To get maximum efficiency of fuel they need to reduce the weight of the vehicle without losing the strength and considering all safety aspects.

Somehow some automotive companies are started using a composite material in combination with some kind of fibrous materials but they are struggling with using the right combination of layers of fiber to get optimum strength in all direction to withstand new design trends, strength requirements, less weight of the structure, optimum fuel efficiency and maximum safety. With the understanding of the whole problem, I have come to one conclusion that if we consider the only automotive industry, several cars have different designs and each design has a different type of Notches, holes, etc. For this study, I have chosen three types of notches that are often used in the industry...

I created several Stacks of Various combinations of Angles of Layup Patterns as our objective is to check the strength of Composite fiber in different operating conditions. With these types of Notches and Different Angle stacks, I have created several numbers of test specimens to analyze them in ANSYS software. There is a total of 24 Samples are Analyzed in ANSYS software for Different Layup Patterns of Angle Stacks & With Different types of Notches.

Table 1: Stacks of Angles between Layers

Stack	1	2	3	4	5	6
Angle Set	0	0	0	0	0	45
	45	30	90	45	30	-45
	0	0	0	90	90	90
	-45	-30	90	-45	-30	45
	0	0	0	0	0	-45

Now As we have all the perquisites for the analysis with ANSYS ACP, so I have carried out the analysis as follows. We can see the dashboard below for the analysis.

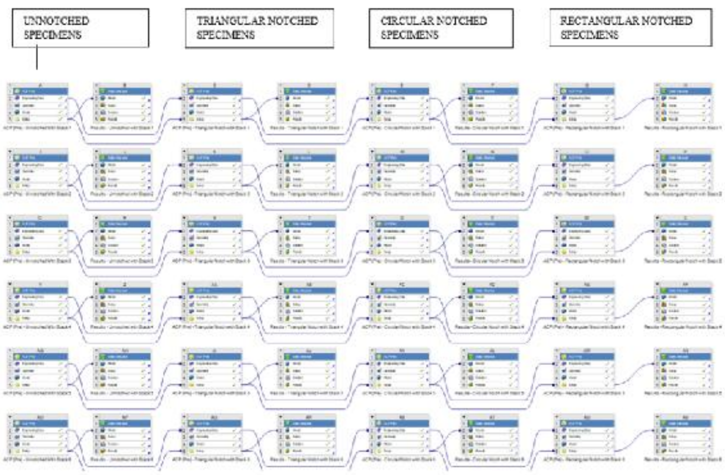

Figure 4: Analysis Dashboard of ANSYS Software.

Materials for Analysis

For the Analysis we are taking the Carbon fiber sheets with Epoxy resin for Bonding the Different layup Patterns, we are using Carbon fiber Prepreg (Epoxy Carbon UD Prepreg) which having 395Gpa Tensile strength. Let us know in detail about this material.

What is Carbon Fiber Prepreg?

Carbon fiber is made up of a long chain of carbon atoms that have been bonded together. The fibers are rigid, light, and sturdy, and they're used in a lot of ways to make high-quality building materials. Pre-preg composite fibers are "pre-impregnated" with a polymer matrix substance, such as epoxy or phenolic, or perhaps thermoplastic products. Since the fibers sometimes assume the form of a weave, the matrix is used to tie them together and to other components during production. I chose the Epoxy carbon Uni-Directional Prepreg with a tensile strength of 395Gpa for this analysis.

Mesh

ANSYS is a computer simulation program. Meshing is a high-performance, general-purpose, intelligent, and automatic product. It generates the best mesh for precise and effective multiphasic solutions. A mesh that is well suited for a particular study can be created for all parts in a model with a single mouse click. For the advanced user who wants to fine-tune the mesh, full control over the options used to create it is possible.

As we saw the specimen of standard size is designed and the regular and triangular notch is generated to understand the composite layer stress distribution. It is observed that in ANSYS layer by layer stress distribution is easily visualized, Now I created the layup patterns Differently to simulate the practical operating conditions.

Now as we have all the perquisites for the analysis with ANSYS ACP, so I have carried out the analysis as follows. We can see the Deformation result for the Triangular Notched specimen with angle stack 1, similarly, analysis is carried out for other specimens with Different angle stack.

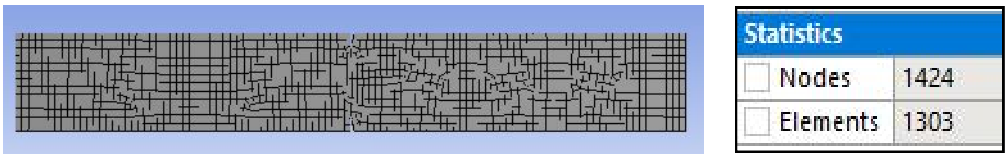

Figure 5: The Mashing of Triangular Notched Specimen.

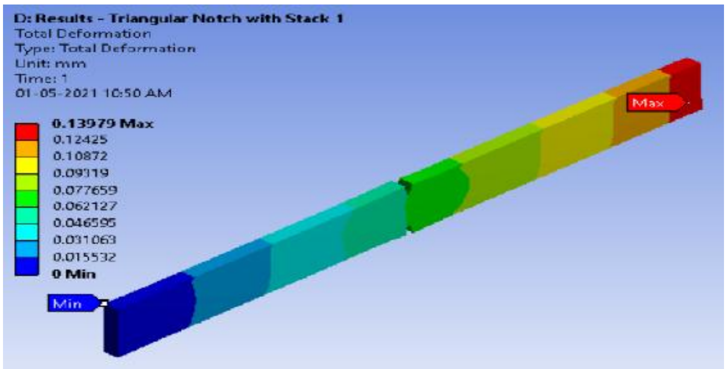

Figure 6: Deformation Result of Triangular Notched Specimen.

ANALYSIS RESULTS

Table 2: FEA Results of Different Notched Specimens

Fiber Reinforced Polymer					Tensile Load Applied: 10000 N
Sr. No	**Stack**	**Notch Type**	**Notch Size**	**Deformation (mm)**	**Equivalent Stresses (Mpa)**
1	1	Triangular	1X5	0.13979	373.93
2	2	Triangular	1X5	0.12661	326.53
3	3	Triangular	1X5	0.14717	451.27
4	4	Triangular	1X5	0.18012	205.06
5	5	Triangular	1X5	0.15358	218.57
6	6	Triangular	1X5	0.54466	529.56
Sr. No	**Stack**	**Notch Type**	**Notch Size**	**Deformation (mm)**	**Equivalent Stresses (Mpa)**
1	1	Circular	5	0.13476	458.5
2	2	Circular	5	0.12179	406.34
3	3	Circular	5	0.13967	520.29

Table 2 Contd.,

4	4	Circular	5	0.17512	119.2
5	5	Circular	5	0.14914	80.306
6	6	Circular	5	0.53727	529.42
Sr. No	**Stack**	**Notch Type**	**Notch Size**	**Deformation (mm)**	**Equivalent Stresses (Mpa)**
1	1	Rectangular	2.5X5	0.13544	318.58
2	2	Rectangular	2.5X5	0.1224	287.12
3	3	Rectangular	2.5X5	0.1405	367.14
4	4	Rectangular	2.5X5	0.1759	115.15
5	5	Rectangular	2.5X5	0.1498	87.457
6	6	Rectangular	2.5X5	0.5392	529.42

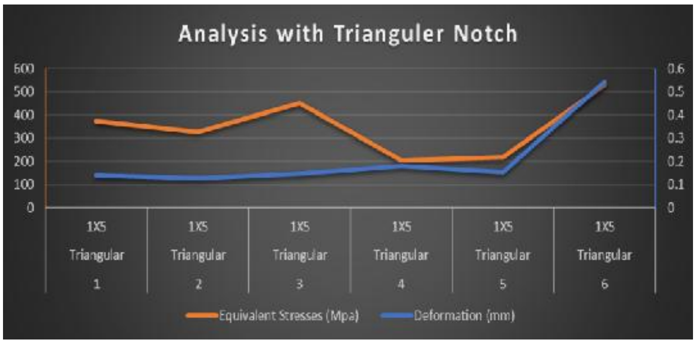

Figure 7: Analysis Result of Triangular Notched Specimen.

OPTIMIZATION OF OBTAINED RESULTS

As I got all the Analysis results but we need to optimize the All results to get the optimum result. We have 6 stacks of Different angles and each stack is giving different values of Equivalents stresses and Deformation results, but Based on these results we cannot get the Solution I want.

To get an Optimum solution of getting a set of angles to get minimum Deformation & Equivalent stresses at a Particular type of Notch, we can Obtain these results using Multiple Optimization Techniques but MCDM (Multi-Criteria Decision Making) Method is well known for solving such type of problems.

Making choices in the face of various, often overlapping factors is referred to as multi-criterion decision making (MCDM). The issues with MCDM can be divided into two categories:

- Multiple Attribute Decision Making (MADM)
- Multiple Objective Decision Making (MODM)

The decision variable values in MODM methods are calculated in a constant or integer space, with an infinitive or a large number of options, the best of which should satisfy the decision maker's constraints and priority preferences. MADM strategies, on the other hand, are usually isolated, with just a few preset options. We have a range of predefined parameters such as Notch Type, Angle Stacks, Load, and so on.

For Such type of Data, MADM Technique is preferred. MADM method specifies how to attribute information is to be processed to arrive at a choice. Here I have chosen three MADM techniques as follows.

Simple Additive Weighting (SAW)

This method, also known as the weighted sum method (Fishburn, 1967), is the most basic and widely used MADM method. Each attribute is assigned a weight, and the total weight must equal 1.

Any feature of each option is evaluated. The equation calculates an alternative's cumulative or combined output score. [10]

$$P_i = \sum_{j=1}^{M} w_j \, (m_{ij})_{normal}$$

The final weights are calculated by dividing the total number of points by one.

We can see with SAW Method we got optimum Angle stack number 5 which gives Optimum Results; we will check these Results by using more 2 methods.

Table 3: Performance Scores of the Triangular Notched Specimen Using the Saw Method

		Rank
Stack 1	0.7271	4
Stack 2	0.8140	3
Stack 3	0.6574	5
Stack 4	0.8515	2
Stack 5	0.8813	1
Stack 6	0.3098	6

⇐ BEST STACK WITH MIN. DEFORMATION & STRESS

Weighted Product Method (WPM)

This method resembles SAW. The biggest distinction is that instead of combining, there is multiplication in the model (Miller and Starr, 1969). The equation calculates an alternative's cumulative or aggregate output ranking. [10]

$$P_i = \prod_{j=1}^{M} [(m_{ij})_{normal}]^{w_j}$$

The normalized values are determined using the SAW method as described. Each alternative's normalized value concerning an attribute. We have the ability to as you can see, using WPM, we were able to find the optimal Angle stack number 5, which yields the best results. We can verify these results using another tool.

Table 4: Performance Scores of the Triangular Notched Specimen Using the WPM Method

		Rank
Stack 1	0.7048	4
Stack 2	0.7925	3
Stack 3	0.6252	5
Stack 4	0.8384	2
Stack 5	0.8795	1
Stack 6	0.3000	6

⇐ BEST STACK WITH MIN. DEFORMATION & STRESS

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method

Hwang and Yoon invented the TOPSIS system (1981). According to this formula, the optimal option should have the shortest Euclidean distance from the ideal solution and the greater distance from the negative ideal solution.The optimum solution is a hypothetical solution in which all attribute values correspond to the highest attribute values in the database, while the pessimistic perfect solution is a hypothetical solution in which all attribute values correspond to the lowest attribute values in the database. TOPSIS thus produces a solution that is not only the nearest to the hypothetically ideal but also the furthest away from the purely hypothetical worst.[10]

$$R_{ij} = m_{ij} / [\sum_{j=1}^{M} m^2_{ij}]^{1/2}$$

Table 5: Performance Scores of the Triangular Notched Specimen Using the TOPSIS Method

		Pi +		Pi -	Rank
Stack 1	P1	0.7775	P1	0.2225	4
Stack 2	P2	0.8374	P2	0.1626	3
Stack 3	P3	0.6961	P3	0.3039	5
Stack 4	P4	0.8895	P4	0.1105	2
Stack 5	P5	0.9400	P5	0.0600	1
Stack 6	P6	0.0000	P6	1.0000	6

⇐ BEST STACK WITH MIN. DEFORMATION & STRESS

CONCLUSIONS

In the present research specimens of standard size are designed and with a regular and triangular notch, Circular Notched & Rectangular Notched Specimens are generated to understand the composite layer stress distribution.It is observed that in ANSYS layer by layer stress distribution is easily visualized compared.

By Using MADM Techniques the results we got from FEA we Validated and checked for Optimization, and it was observed that Angle Stack no 5 gives Optimum values of Deformation & Equivalent Stresses. Using the same MADM Methods Notch level Optimization is Done and it is Observed that the Circular type of Notch can give the best results if it Combined with Angle Stack 5.

Overall, it can be concluded that In this study we have Investigated the Tensile Strength of CRPF material having different Layup Pattern can give Better results when used at a specific set of angles and if it is used at any notch of Hole prone zone the Circular type of Notch can perform Better than any other type of Notches.

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