Fiber Oriental Optimization on Glass Fiber Reinforced Polymer Composite in Multi Objective Perspective based on Computational Structural Analysis

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Abstract. Multi-perspective analyses on Glass Fiber Reinforced Polymer (GFRP) are a major concern of this work, in which bending and tensile loads focally applied. GFRPs are good composites, which have been developed to handle critical loads in an effectual manner with low price consumption. Instead of external research, this work focused to work on the optimization of the internal component of GFRPs. The component shortlisted for this research is reinforcement and its orientational angles. From the literature survey, 38 different orientational models are generated for the flexural tests, and 22 different orientational models are created for tensile tests. Three primary fibers are used for this optimization, which are E-Glass-UD, E-Glass-Wet, and S-Glass-UD. Commonly, Epoxy resin is used as a matrix for all the tests. The inputs of these computational simulations are External peak loads, which are estimated from experimental tests. The computational procedures are verified with Grid convergence test and analytical approach based validations. Finally, the structural analyses are computed and thereby models are optimized for both flexural and tensile loading conditions. Model 27 is reached the first position under flexural load and Model 1 is obtained the first position under tensile load based on low stiffness. In addition to that, Model 20 is also performed better than other models under flexural loads.

1. Introduction

The GFRP has become stable in building industry. Mostly composite materials are made of polymer reinforced with fibers. It consists of glass fiber and thermosetting resins. GFRP are used for both exterior and interior fixtures in variety of styles, shapes and textures. They are mostly used in roofs, signs, cupolas, porticos, facades, mouldings, entryways, sculpture, panels, planters, balustrade, columns, fountains and domes. GFRP has high strength to weight ratio also they are mostly recommended for durability, low maintenance, able to mould complex shapes, seamless constructions, resistance, light weight, and high strength. They are low weight of 1 to 2 kg per square foot means faster installation, less structural framing and lower shipping cost. Any form or shape can be moulded. They are unaffected by salts, most chemicals and acid rain. Due to its light weight and translucent nature, it is used as roofing material in various places. It also helps in allowing a partial light through it. It is even used as partitioning material between two spaces because of its cost efficiency. It can be easily shaped due to its elasticity. It is transparent to electrical field and radio frequencies. That’s why GFRP are widely used. It is a composite material made of polymer reinforced with fibers. They are used in aerospace and automobile construction industries and in marine application due to their high strength to weight ratio. They are flexible and also provide high resistant to chemical attacks. The rate of glass fibre is very low when compared to other polymers. There also transparent so used in
automobile and in constructions industries. It has high heat resistant and it resist up to 820-850°F. Major components of glass fibre are silica, limestone and waste glass. And some of the minor components are borax, magnesite, calcined alumina, feldspar etc. Glass fibers are both dimensionally stable and moisture resistant. As they are dimensionally stable it does not stink or stretch after exposing to high temperature or low temperature. And also do not absorb moisture and change their chemical property or physical property. There are types of glasses such as E-Glass and S-Glass. In this paper we are going to deal with E-Glass polymer [7 – 12].

The constituents of GFRP include high quality corrosion resistant vinyl ester resin that increases the lifespan of a concrete structure. As compared with the traditional reinforcement material GFRP rebar is ¼ the weight of steel with 2 times of tensile strength of steel. GFRP rebar is non-conductive to electricity and heat making it an ideal choice for facilities like power generation plants and scientific installation. Taking into account the long term benefits of GFRP rebar it is a cost effective product as compared with epoxy coated or stainless steel. It can be manufactured in custom lengths, bends and shapes. It is transparent to electric field and radio frequencies. A project reinforced with GFRP rebar is maintenance free, enabling builders to avoid rehabilitation cost. The application of GFRP concrete reinforcement is especially attractive when the intended concrete structure is susceptible to corrosion and other aggressive chemicals. It is also ideal to use GFRP rebar when electromagnetic transparency is a prime concern. GFRP can be used for broad range of new construction applications which include transportation infrastructure, rail LRT, runways, IT and research facilities, mining, tunnelling, building and waterside concrete structure such as retaining and sea walls [13 – 18].

2. Literature Survey

This paper investigated about GFRP, which was used in many industries for its good flexural behaviour. The flexural strength is essential to know about the structural properties. GFRP has been mostly used for high strength to weight ratio, easy availability, cost effectiveness and stiffness. It is used in application like space, aircraft, automotive, marine and sports goods. Nowadays, the three point test was mostly used in fiber reinforced composites in order for characterization of flexural strength. By three points bending test, deflection of specimen and flexural strength has been determined. Finally, the specimen is validated by ANSYS 14.5 software only after the three point bending test. In analysis, the orientation is based on [0/90, + or - 45, + or – 45, 0/90]. Its dimension is 280*170 mm. In three point test, ASTM D790 is followed. Finally, the structural strength is obtained by ratio of 3*load*length to 2*width*(thickness) ². Then it is followed by finite element analysis and then results were obtained. The analysis shows that it has 290 MPa of flexural strength [experimental] and 272 MPa of flexural strength [numerical]. Then by comparison of experimental and numerical results, there was almost 10% error. It may mostly had been happen due to manufacturing defects [1].

In this paper, it says about the environment friendly materials mostly used as an alternative for the existing material .Nowadays ,natural fibers has miniature in density and high economic impact when compared to GFRP. The strength is not equal to glass fibers and this paper says about the tensile characteristics on hybrid composites by intruding glass fibers and unidirectional banana in epoxy mixture. The loading values on fiber are found to be higher for resin transfer moulding while it is compared with compression moulding (CM). The difference is obtained due to finite element analysis (FEA) in ANSYS. In this process, Hardener HY951 and epoxy resin LY556 for unidirectional banana and GFRP and also the tensile test is obtained. The composite is obtained by resin and hardener in the ratio of 10:1. The dimension is 300mm*300mm*4mm. For testing, the specimen is prepared by ASTM D3039. Finally, for various specimens UGF and UB/GF, the tensile test values were determined. In ANSYS, the nodal vector force [F] is obtained by product of stiffness matrix [K] and nodal displacement vector (q). The procedure is followed as geometry, element type, material properties, mesh definition, boundary conditions, analysis and post processing. In results, the tensile properties are 57.88 KN for UGF and for UB/GF is 38.88 kN. The average ultimate strength of UB/GF is 296.7 MPa and UGF is 498.9 MPa. The stress of UB/GF is 295.38 MPa and UGF is 567.7 MPa. Finally, both the glass fiber and unidirectional fibers are fabricated. As a result, UGF has ultimate tensile strength and the load displacement was around 10.8 to 11 mm. Natural fibers can be enhanced
for tensile strength, when it was chemically treated. In order to make the tensile property equal to glass
fiber, the natural fiber was treated with chemicals [2].

This paper says about the development of composites that are made up of natural fibers that
are mostly used in applications such as automotive, marine, aircraft and aerospace due to its properties
like high specific strength, non-abrasives, bio-degradability, renewable and low cost. Many
researchers work on a suitable material as the replacement for glass fiber and finally they got jute, it
appears to be more favourable for high strength, low cost, good insulating, high aspect ratio and low
thermal conductivity. For experiments, the resin used is polyester resin fb-333 and hardener used is
catalyst methyl ethyl ketone peroxide [MEKP]. For tensile strength, it is prepared based on ASTM
D3039 with the dimensions 250*25*3mm. The test takes place in UTM machine. For flexural
strength, it is made based on ASTM D790 and with dimension127*12.7*3 mm. For impact strength,
ASTM D256 standard is followed and executed by Charpy impact test. As a result, 100% of glass
composite has high tensile strength. In flexural testing, glass composite has high flexural strength
when compared to other materials. In finite element analysis, glass fiber has tensile strength of 271.78
MPa and flexural strength of 380.09 MPa. For impact testing, glass composite showed high absorbed
energy. Comparing all the papers, it has been found that glass composite has high tensile, flexural and
impact strength. Therefore, glass fiber was better than natural fibers [3].

The main purpose of this literature is to numerically analyse the mechanical behaviour of the
both flux/epoxy composite material and E-glass/flax/epoxy hybrid composite material. Here the FEA
was used for simulation. Three kinds of beams made of eight flax/epoxy layers; a sandwich beam
having two glass/epoxy layers as bottom shell, four flax/epoxy layers as core and two layers of
glass/epoxy as top shell; a beam made of four flax/epoxy layers and four glass/epoxy layers
alternatively. The theoretical results and experimental results like force-displacement c

equivalent modulus of elasticity Ex were compared. Regarding Ex, it was found that the greater values
of errors are 6.11% and 5.58% and this corresponds to E-Glass/Flax/Epoxy hybrid composite in weft
direction and warp direction of the fabric, respectively. The equivalent modulus of elasticity of this
proposed hybrid composite is Ex = 5046.92 MPa which is greater than flax/epoxy composite, which
can be used in manufacturing innovative products in automotive industry or civil engineering [4]. This
literature dealt about the evaluation of the release rate of strain energy of glass fibre/ epoxy
composites. Glass fibre reinforcement with epoxy-based polymer composite with different ply angles
and later which is sandwiched between two steel plates are made and designed to ASTM standard
d5528. The experimental model of study is chosen and the fracture test was conducted on a testing
machine to know about the crack length and strain energy. The experiment showed a great result for
(0°,-45°, 45°, 0°) orientation as strain energy release rate is more which indicates the crack growth is
less for this orientation because of high fracture toughness [5].

Composite materials are currently most widely used in aircraft and aerospace applications due
to their attractive properties like high strength to weight ratio and stiffness to weight ratio. In the study
of finite element analysis of fibre glass uni-directional E-type was analysed in the framework of
ABAQUS finite element commercial software. The simulation was run twice, for ply-1 with an angle
of 45degree, ply-2 with an angle of -45 degree and ply-3 with angle of 90 degree. Second simulation
the orientation angle is 0 degree for all the plies. Both simulation and experimental analysis are made.
The composite plate is made of 6 layer of uni-direction E-glass and each layer has and thickness of
0.25 mm. The dimension of the specimen is 250 mm* 25mm*1.5 mm. one side of the specimen is
fixed and the other side of the specimen concentrated force and 20 kN of magnitude of load is applied.
In experimental the tensile test was undertaken using material test system machine. The maximum
stress obtained from experimental result is 0.23 and the maximum stress obtained from analysis
method is 0.46 [6].

3. Computational Structural Analysis – Methodology

3.1. Computational Model

The real-time model is simply known as physical model, which has been constructed through
various modelling tools. If the physical model is simple in nature, then the solver tools itself have the
facility to construct the physical model. Whereas the physical model is complicated in geometrical nature, the solver tools have the facility to adopt the models via export option. More commonly, the physical model has been given the fundamental platform to execute the computational simulation therefore the fundamental platform is represented as computational model. Generally, the simple computational model has been created in an easiest way but this comprehensive investigation deals the construction of GFRP based simple computational model. Thus the extra care has been given in the construction, which is attachment of reinforcement and enclosure of Epoxy matrix in the computational models. ANSYS ACP is the computational tool is used for the construction of GFRP’s computational model. In which, the rosette (fiber angle) creation, orientational setup, ply creation and solid model generation are the major flairs used to represent the composite computational model as reliable as to original hand-layup based GFRP composite specimen. Apart from these inputs, the common structure for the base analysis is looks like dog bone shape, which is used in this work for tensile test, whereas the flexural test specimen is looks like the rectangular shape [19- 21].

3.2. Discretization
Discretization is the practice of conversion of physical model into finite element model, in which this conversion mainly intended to upgrade the physical model. The upgraded cum modified physical model has the capability to capture the reaction of applied external actionable loads. Computationally, the upgraded model is called as finite element model, which has been comprised of nodes and elements. Both of the tests analyzed in this work are used three dimensional structural elements to capture the complete physical models. Therefore each and every node has the capacity to predict the six deformation relevant structural outputs. With the help of conventional relationships, the other structural outcomes such as stresses, strains, etc., are been estimated through known displacements. The facility used for both of the tests is fine structural proximity, which has the capacity to form uniform brick elements. Apart from the mandatory needs, this paper also executed one of the predominant computational sensitivity tests, which is grid convergence test. Through this grid convergence test, the optimized mesh and its components (nodes and elements) are attained, which have the power to provide reliable outcomes. Generally, the grid convergence test has been comprised of various mesh cases versus and its compositional elements. This work, totally five mesh cases are formed and imposed into the computational simulations. Finally, Case-2 [Fine proximity] is shortlisted as best mesh structure to provide trustworthy outcomes with logical compositional elements of grids [22 – 26].

3.3. Boundary Conditions
The FEA computation has been initiated with the support of major boundary conditions such as displacement values extracted from supports, load inputs extracted from external impacts, etc. In Flexural test, both the ends are arrested under simply supports, which are been attained through zero displacement facility. At the mid of the flexural test specimen, the peak concentrated load is applied through the help of external force facility in the computational tools. In Tensile test, the fixed support is associated at one of the edges of tensile test specimen. The peak tensile load is applied at the other edge of the test specimen. Both of the external loads were estimated through the supports of conventional experimental tests. The peak loads for tests were 537.0981 N was obtained under flexural test and 72700 N was obtained under tensile test from conventional experimental tests.

4. FEA based Optimization under Flexural Load
As per the abovementioned external load, the relative structural analyses are carried out for all the 38 models. In this optimization the outcomes of total deformation, equivalent elastic strain, strain energy, equivalent stress, normal stress, and shear stress are contributed as selection parameters. The optimization of suitable reinforcement’s angle is obtained based on generation of less reaction occurred inside the model’s structure with respect to applied peak flexural load. The comprehensive results are revealed through graphical plots, in which the lower margin is picked as best performer from all the graphical images [Figures 7 to 12, and 14 to 19].
4.1. Computational Model – Flexural Test

From the literature [3] the design parameters are obtained to execute flexural test, in which the ASTM D790 has been majorly supported a lot. The different orientational angles with respect to its model numbers are listed in Table 1. All of these 38 physical models are acted as computational models and thereby the structural simulations are carried out.

| Model No. | Orientational Angles       | Model No. | Orientational Angles       |
|-----------|-----------------------------|-----------|-----------------------------|
| Model – 1 | 0-15-30-15-0-0-15-30-15-0  | Model – 20| 90-0-75-0-90-0-75-0-90-0   |
| Model – 2 | 15-0-30-0-15-15-0-30-0-15  | Model – 21| 0-45-90-45-0-0-45-90-45-0  |
| Model – 3 | 30-15-0-15-30-15-0-15-30  | Model – 22| 45-0-90-45-45-0-45-90-0-45 |
| Model – 4 | 30-0-15-0-30-0-15-0-30    | Model – 23| 45-90-0-90-45-90-0-90-45   |
| Model – 5 | 0-30-45-30-0-30-45-30-0   | Model – 24| 90-45-0-45-90-90-45-90-90  |
| Model – 6 | 30-0-45-0-30-30-0-45-0-30  | Model – 25| 90-0-45-90-90-45-90-90-0   |
| Model – 7 | 45-30-0-30-45-45-30-0-30-45| Model – 26| 0-90-45-90-45-90-45-90-45  |
| Model – 8 | 45-0-30-0-45-45-0-30-0-45  | Model – 27| 0-0-0-0-0-0-0-0-0-0-0-0-0-0   |
| Model – 9 | 0-45-60-45-0-0-45-60-45-0  | Model – 28| 15-15-15-15-15-15-15-15-15-15 |
| Model – 10| 45-0-60-0-45-45-0-60-0-45  | Model – 29| 30-30-30-30-30-30-30-30-30-30 |
| Model – 11| 60-45-0-45-60-45-0-45-60-0| Model – 30| 45-45-45-45-45-45-45-45-45-45-45-45 |
| Model – 12| 60-0-45-0-60-0-45-0-45-60  | Model – 31| 60-60-60-60-60-60-60-60-60-60 |
| Model – 13| 0-60-75-60-0-0-60-75-60-0 | Model – 32| 75-75-75-75-75-75-75-75-75-75 |
| Model – 14| 60-0-75-0-60-60-0-75-0-60  | Model – 33| 90-90-90-90-90-90-90-90-90-90 |
| Model – 15| 75-60-0-60-75-75-60-0-75-75 | Model – 34| 15-30-0-30-15-15-30-30-15-15 |
| Model – 16| 75-0-60-75-75-0-60-0-75-75 | Model – 35| 30-45-0-45-30-30-45-0-45-30-30 |
| Model – 17| 75-90-75-0-75-90-75-90-75-90 | Model – 36| 45-60-0-60-45-60-60-60-60-60 |
| Model – 18| 75-90-0-75-75-0-90-75-0-75-90 | Model – 37| 60-75-0-75-60-75-0-75-60-75-60 |
| Model – 19| 90-75-0-75-90-75-0-75-75-0-75-90 | Model – 38| 75-90-0-90-90-75-75-90-0-90-75-90 |

4.2. Flexural Test Results

The best flexural test results are revealed in Figures 1 to 6, in which Figure 1 is corresponds for total deformation of Model-27, Figure 2 is corresponds for normal stress variations of Model-33, Figure 3 is corresponds for shear stress variations of Model-27, Figure 4 is corresponds for equivalent stress variations of Model-18, Figure 5 is corresponds for equivalent elastic strain of Model-27, and Figure 6 is corresponds for strain energy variations of Model-4. As said before, the low reacted case is picked as good one, which means that the low reacted case is more stiffer than other cases so that is why the same case are picked good performers from Figures 7 to 12 and Figures 14 to 19.

Figure 1. Total deformation – M-27

Figure 2. Normal Stress – M-33
4.3. Bending Test – Comparative Results

Aside from the best outcomes, the representations of comprehensive report of entire test models are unavoidable one because which provides the judgment about the best model. In this purpose, the comprehensive variations are revealed in Figures 7 to 12, wherein the Figure 7 is contained the results of total deformations, the Figure 8 is contained the results of Strain Energy, the Figure 9 is revealed the results of Equivalent stress, Figure 10 is contained the results of equivalent elastic strain, the Figure 11 is revealed the outcome of Shear Stress and the Figure 12 is revealed the structural outcomes of Normal stress.
Figure 8. Comprehensive analysis of Strain Energy of Epoxy-E-Glass-UD

Figure 9. Comprehensive analysis of Equivalent Stress of Epoxy-E-Glass-UD

Figure 10. Comprehensive analysis of Equivalent Elastic Strain of Epoxy-E-Glass-UD
5. FEA based Optimization under Tensile Load

As per the abovementioned external load, the relative structural analyses are carried out for all the 22 models. Based on the previous experience, one of the useful modification is incorporated in this optimization, which is the test specimen is symmetric about all of its axis so instead of full model, the half of the model is involved in this computation, that is why the thickness of the layer is reduced from 10 to 5. In this optimization the outcomes of total deformation, and strain energy are contributed as selection aspects. The optimization of suitable reinforcement’s angle is obtained based on generation of less reaction occurred inside the model’s structure with respect to applied same tensile load. In addition to the fiber orientational angle’s optimization, the suitable material to withstand tensile load under the family of Glass Fiber Reinforced Polymer (GFRP) composite is also executed.

5.1. Tensile Test – Computational Model

From the literature [3] the design parameters are obtained to execute tensile test, in which the ASTM D3039 has been majorly supported a lot. The different orientational angles with respect to its model numbers are listed in Table 2. All of these 22 physical models are acted as computational models and thereby the structural simulations are carried out under same tensile force.
Table 2. Comprehensive Details of Computational Models for Tensile Test

| Model | Orientational Angle | Model | Orientational Angle |
|-------|---------------------|-------|---------------------|
| M-1   | 0-0-0-0-0           | M-12  | 0-45-0-45-0         |
| M-2   | 10-10-10-10-10     | M-13  | 0-30-0-30-0         |
| M-3   | 20-20-20-20-20     | M-14  | 30-45-30-45-30      |
| M-4   | 30-30-30-30-30     | M-15  | 0-60-0-60-0         |
| M-5   | 40-40-40-40-40     | M-16  | 0-75-0-75-0         |
| M-6   | 50-50-50-50-50     | M-17  | 0-90-0-90-0         |
| M-7   | 60-60-60-60-60     | M-18  | 75-90-75-90-75      |
| M-8   | 70-70-70-70-70     | M-19  | 60-75-60-75-60      |
| M-9   | 80-80-80-80-80     | M-20  | 45-75-45-75-45      |
| M-10  | 90-90-90-90-90     | M-21  | 45-60-45-60-45      |
| M-11  | 45-45-45-45-45     | M-22  | 75-75-75-75-75      |

The tensile test results for best material are revealed in Figure 13, which is belongs for Epoxy-S-Glass-UD based composite.

5.2. Tensile Test – Model – 1 Results

Figure 13. Structural Outcomes of Epoxy-S-Glass-UD

5.3. Tensile Test – Comparative Results

The representations about the all-inclusive structural variations are mandatory one, which provides the common platform to initiate the judgment. With this consideration, the comprehensive variations are revealed in Figures 14 to 19, wherein the Figure 14 and 15 are revealed the total deformation and strain energy results of Epoxy-S-Glass-UD composite, the Figure 16 and 17 are revealed the total deformation and strain energy results of Epoxy-E-Glass-Wet, finally the Figure 18 and 19 are revealed the total deformation and strain energy variations of Epoxy-E-Glass-UD.

Figure 14. Comprehensive analysis of Total Deformation of Epoxy-S-Glass-UD
Figure 15. Comprehensive analysis of Strain Energy of Epoxy-S-Glass-UD

Figure 16. Comprehensive analysis of Total Deformation of Epoxy-E-Glass-Wet

Figure 17. Comprehensive analysis of Strain Energy of Epoxy-E-Glass-Wet
6. Conclusions

The multi perspective analyses on Glass Fiber Reinforced Polymer are computed under tensile and bending loads. The total counts of 22 different tensile test models are analyzed for three different GFRP materials and thereby the suitable orientational angle with respect to its GFRP material is shortlisted. The Epoxy-S-Glass-UD based composite performed better than other two GFRP composites by this means it can be used in the tensile load based real-time applications. The Model-1 and its orientational angle is reacted very lower level than other 21 tensile test models therefore Model-1 is optimized model under Tensile load. After tensile test, the 38 flexural test models are simulated under the peak flexural load through ANSYS Structural tool. The E-Glass-UD is used as reinforcement element and Epoxy resin is used as adhesive element for all of the 38 models, wherein the computational setups are created with the help of ANSYS Composite Pre-Post Processor Tool. The Model-27 is picked as best performer and its corresponding angles are proposed as best reinforcement angles for bending test based real time applications. In addition to this Model-27, the Model-20 is also performed better to withstand peak bending load based applications. Thus Model-27 and Model-20 are better to withstand any kind of magnitude of flexural loads.
References

[1] Kalyan Kumar Singh, Akshay Kumar Singh and Sunil Kumar Chaudhary, Experimental and Finite Element Analysis of Flexural Strength of Glass Fiber Reinforced Polymer Composite Laminate, Journal of Material Science and Mechanical Engineering , e-ISSN: 2393-9109, Volume 3, Issue 2., pp. 50-53, 2016.

[2] A Shadrach Jeyasekaran, K Palani Kumar and S Rajarajan, Numerical and experimental analysis on tensile properties of banana and glass fibers reinforced epoxy composite, Sadhana, 41, 11, pp. 1 –11, 2016, DOI 10.1007/s12046-016-0554-z.

[3] Ashik K P, Ramesh S. Sharma and Subhash Patil, Evaluation of tensile, flexural and impact strength of natural and glass fiber reinforced hybrid composites, Renewable Bioresources, Volume 5, Article 1, pp. 1–7, 2017, doi: 10.7243/2052-6237-5-1

[4] Camelia Cerbu, Marius Botis, Numerical modelling of the flux/glass/epoxy hybrid composite materials in bending, Procedia Engineering, 181, pp. 308 – 315, 2017, doi: 10.1016/j.proeng.2017.02.394

[5] K. Kiran Kumar, D. Srikanth Rao, N. Gopikrishna, Evaluation Of Strain Energy Release Rate of Epoxy Glass Fibre Laminate, International Education & Research Journal, Volume 3, Issue 1, pp. 44 - 46, 2017.

[6] M. Nurhaniza, M.K.A. Ariffin, Aidy Ali, F. Mustapha and A. W. Noraini, Finite Element Analysis Of Composite Material For Aerospace Applications, IOP Conf. Series: Materials Science and Engineering, 11, 012010, pp. 1-7, 2010, doi:10.1088/1757-899X/11/1/012010.

[7] Udhaya Prakash R, Raj Kumar G, Vijayanandh R, Senthil Kumar M, Ram Ganesh T, Structural analysis of aircraft fuselage splice joint, IOP Conference series: Materials Science and Engineering Journal, ISSN 1757-899X, Vol.149, No. 1, 012127, pp. 1-8, 2016, https://doi.org/10.1088/1757-899X/149/1/012127

[8] G Raj Kumar, R Vijayanandh, M Senthil Kumar, S Sathish Kumar, Experimental Testing and Numerical Simulation on Natural Composite for Aerospace Applications, AIP Conf. Proc., 1953, 090045-1–090045-5, 2017, https://doi.org/10.1063/1.5032892.

[9] Raj Kumar G, et al., Conceptual design and structural analysis of integrated composite Micro Aerial Vehicle, Journal of Advanced Research in Dynamical and Control Systems, Vol. 9, Sp–14, pp 857 – 881, 2017.

[10] Vijayanandh R, Naveen Kumar K, Senthil Kumar M, Raj Kumar G, Naveen Kumar R, Ahilla Bharathy L, Material Optimization of High Speed Micro Aerial Vehicle using FSI Simulation, Procedia Computer Science, ISSN 1877-0509, Volume Number 133, pp 2-9, 2018, https://doi.org/10.1016/j.procs.2018.07.002

[11] Rajagurunathan. M, Raj Kumar. G, Vijayanandh. R, Vishnu. V, Rakesh Kumar. C & Mohamed Bak. K, The Design Optimization of the Circular Piezoelectric Bimorph Actuators Using FEA, International Journal of Mechanical and Production Engineering Research and Development, ISSN(E): 2249-8001, Vol. 8, Sp. Issue 7, pp. 410-422, 2018.

[12] Raj Kumar. G, Senthil Kumar. M, Vijayanandh. R, K. Raja Sekar, Mohamed Bak. K & Varun. S, The Mechanical Characterization Of Carbon Fiber Reinforced Epoxy with Carbon Nanotubes, International Journal of Mechanical and Production Engineering Research and Development, ISSN:2249-8001,Vol. 9, Sp. Issue 1, pp. 243-255, 2019.

[13] Vijayanandh R., M. Senthil Kumar, M. Naveen Kumar. G, Raj Kumar. R, Naveen Kumar, Design Optimization of Advanced Multi-rotor Unmanned Aircraft System Using FSI, Lecture Notes in Mechanical Engineering, eBook ISBN - 978-981-13-2718-6, Chapter number 28, pp. 299-310, 2019, DOI 10.1007/978-981-13-2718-6.

[14] Vijayanandh R et al., Numerical Study on Structural Health Monitoring for Unmanned Aerial Vehicle, Journal of Advanced Research in Dynamical and Control Systems, Vol. 9. Sp issue. 6, pp. 1937 – 1958, 2017.

[15] Senthil Kumar. M, Vijayanandh. R & Gopi. B, Numerical Investigation on Vibration Reduction in Helicopter Main Rotor Using Air Blown Blades, International Journal of Mechanical and Production Engineering Research and Development, ISSN (E): 2249-8001, Vol. 8, Sp. Issue 7, pp. 152-164, 2018.
[16] Raj Kumar. G, Vijayanandh. R, Mohammad Bak. K, Shyam Chander. R & Arawinth. R, Experimental Testing On Mechanical Properties Effect of Aluminum Foam, International Journal of Mechanical and Production Engineering Research and Development, ISSN (E): 2249-8001, Vol. 8, Spl. Issue 7, pp. 1047-1059, 2018.

[17] K. Naveen Kumar, R. Vijayanandh, G. Raj Kumar, B. Sanjeev, Hariharan Balachander and S. Guru Prasad, Comparative Approaches for Fatigue Life Estimation of Aluminium Alloy for Aerospace Applications, Int. J. Vehicle Structures & Systems, 10(4), 282-286, ISSN: 0975-3540, doi: 10.4273/ijvss.10.4.11

[18] K. Venkatesan, S. Geetha, R. Vijayanandh, G. Raj Kumar, P. Jagadeeshwaran, and R. Raj Kumar, Advanced structural analysis of various composite materials with carbon nano-tubes for property enhancement, AIP Conference Proceedings 2270, 030005 (2020), pp. 030005-1 to 030005-6, https://doi.org/10.1063/5.0019367

[19] P. Mirrudula, P. Kaviya Priya, M. Malavika, G. Raj Kumar, R. Vijayanandh, and M. Senthil Kumar, Comparative structural analysis of the sandwich composite using advanced numerical simulation, AIP Conference Proceedings, 2270, pp. 040005-1 to 040005-5, 2020, https://doi.org/10.1063/5.0019370

[20] S. Indira Prasanth, K. Kesavan, P. Kiran, M. Sivaguru, R. Sudharsan, and R. Vijayanandh, Advanced structural analysis on E-glass fiber reinforced with polymer for enhancing the mechanical properties by optimizing the orientation of fiber, AIP Conference Proceedings 2270, pp. 040006-1 to 040006-5, 2020, https://doi.org/10.1063/5.0019378

[21] S. Bhagavathyappan, M. Balamurugan, M. Rajamanickam, R. Vijayanandh, G. Raj Kumar, and M. Senthil Kumar, Comparative computational impact analysis of multi-layer composite materials, AIP Conference Proceedings, 2270, pp. 040007-1 to 040007-5, 2020, https://doi.org/10.1063/5.0019380

[22] Vijayanandh R, Venkatesan K, Ramesh M, Raj Kumar G, Senthil Kumar M, Optimization of Orientation Of Carbon Fiber Reinforced Polymer Based On Structural Analysis, International Journal of Scientific & Technology Research, ISSN 2277-8616, Volume 8 - Issue 11, November 2019.

[23] Raj Kumar G, Balasubramaniyam S, Senthil Kumar M, Vijayanandh R, Raj Kumar R, Varun S, Crash Analysis on the Automotive Vehicle Bumper, International Journal of Engineering and Advanced Technology, Vol. 8, Issue. 6S3, pp. 1602 - 1607, 2019, DOI: 10.35940/ijeat.F1296.0986S319.

[24] Naveen Kumar K, Vijayanandh R, Bruce Ralphin Rose J, Swathi V, Narmatha R, Research on Structural behavior of Composite Materials on different Cantilever Structures using FSI, International Journal of Engineering and Advanced Technology, Vol. 8, Issue 63, pp: 1075 - 1086, 2019, DOI: 10.35940/ijeat.F1178.0986S319.

[25] K. Mohamed Bak, Raj Kumar G, Ramasamy N and Vijayanandh R, Experimental and Numerical Studies on the Mechanical Characterization of Epdm/S-Sbr Nano Clay Composites, IOP Conference Series: Materials Science and Engineering, 912, 052016, 2020, pp. 1-11, doi:10.1088/1757-899X/912/5/052016

[26] Ramesh M, Vijayanandh R, Raj Kumar G, Vijayakumar Mathaiyan, P Jagadeeshwaran, Senthil Kumar M, Comparative Structural Analysis of Various Composite Materials based Unmanned Aerial Vehicle’s Propeller by using Advanced Methodologies, IOP Conf. Series: Materials Science and Engineering, 1017, 012032, 1-10, 2021, doi:10.1088/1757-899X/1017/1/012032

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