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RESEARCH ARTICLE

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STUDY OF FRACTURE BEHAVIOUR OF COMPOSITE LAMINATE WITH CENTRAL CIRCULAR CRACK EXPOSED TO THERMO-MECHANICAL LOADING WITH TEMPERATURE RISE

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ABSTRACT

There is an increased usage of advanced composite structures due to several inherent benefits that they offer in comparison with the monolithic materials. But the application of these materials is being limited by the fact that the knowledge about the crack propagation and strength behaviour under application of loads and environmental conditions is not extensive. So, undertaking research in this direction is still very much important. In this paper, a circular crack which is present in the middle of a composite laminate was modelled and then subjected to temperature loading and combined (temperature + pressure) loading conditions where the temperature is considered to be rising and the pressure remains constant to study the fracture behaviour. The fracture behaviour of the composite laminate is studied using the strain energy release rate (SERR) value calculated using Virtual Crack Closure Technique (VCCT). The effect of temperature rise, fiber angle and the combined Thermo-Mechanical loading conditions on the SERR value in the 3 different modes of fracture with a circular crack located in the middle of the composite laminate is studied and the influence of these parameters are discussed in this paper.

KEYWORDS

Strain Energy Release Rate (SERR), Circular Edge Crack, Virtual Crack Closure Technique (VCCT), Thermo-mechanical Loading, Fracture behaviour, Finite Element Analysis (FEA)

1. INTRODUCTION

Due to the characteristics such as light weight, higher stiffness to weight ratio, high strength to weight ratios, the usage of advanced composites as a structural material has increased multiple folds in the 20th century. This is the main factor that has sparked interest in number of researchers for predicting their behavioural characteristics of these composite laminated materials. Fracture failures occur in composite laminates more often than anticipated. The ability to predict the facture behaviour of the laminate under different loading conditions is critical to avoid catastrophic failure of the composite materials. A lot of understanding is required on the crack propagation in different modes and mixed modes due to the application of the temperature loading and combined loading especially when the temperature is rising as these two conditions are most often endured by the composite laminates in operation in addition other factors.

Researchers have tried to predict the fracture behaviour of different functionally graded materials, composite laminates. The authors considered an edge crack in a multi-layered FGM stressed under the transient thermal loading [1]. The material was assumed to be thermally non-homogenous material and they calculated thermal stress intensity factors (TSIF) of TiC/SiC FGM for various volume fractions. It had been noted that TSIF could be reduced or increased with respect to the FGM strip used Tic, SiC respectively. The researchers developed 2D elements for both steady state and transient problems; which were explicitly used for modelling laminated plates and cylindrical shells, that reduces the order of shape function [2]. These elements have been verified with the help of different thermal lamination theories. The researcher presented a 2-D global higher order deformation theory for thermal buckling analysis of angle-ply laminated composite and sandwich plates [3]. He used the virtual energy method to derive the governing equations which takes the shear and normal stresses into consideration. The variation the displacement continuity functions for the 3-D layer wise theory and global higher order theories applied for thermal buckling of the angle ply and sandwich panels were explained. The researcher used 2-D fractal elements in analysing the cracks on thermo-elastic problems [4]. Transformation functions were analytically established to check thermal stress intensity factor with respect to thermal loading. The researchers through experimental investigation exposed the specimen for continuous 1-D thermal shocks, so to find out how the growth of crack develops and the method to analyse for predicting accurate results, they developed a two-stage crack growth model which also includes the effect of environment on the crack growth where the model was just true for carbon steel at below operating temperatures of creep range [5]. The two stages of model correspond to the high strain fatigue region and linear elastic fracture mechanics respectively. The researcher considered an interfacial crack with a contact zone with thermal problem as a Dirichlet-Riemann boundary value problem and solved it. They derived analytical formulations to determine the real contact zone length [6]. They found that the real contact zone length and its corresponding stress intensity factors depend on normal shear loading and heat flux. The researchers assumed linear elasticity for mechanical loading which imposed the thermal stresses where strain energy rates were calculated at delamination front [7]. They concluded that the anisotropy and heterogeneity nature of the composite forges to be a cause for mixed mode of interlinear fracture at delamination front. The researchers [8] analytically modelled the crack shape for a thermal cyclic loading induced with a thermal gradient in the specimen's thickness using stress intensity factors, weight functions and Paris law. The influence of thermal gradient on crack propagation were understood by comparing their analytical solution with FEM and experimental results. The researchers first analytically derived the steady state solution to thermo-elastic problem and later use weighted function method to know the stress intensity factors to determine from where semi elliptical crack initiates [9]. The researchers discussed the manufacturing defects that caused interlaminar elliptical delamination's to forego crack growth influenced by ply angle and thermo-elastic loading [10]. The authors describe about the energy consumed in the crack growth and about the material damage [11]. They used infrared cameras to study the crack growth by analysing thermal images by calculating the energy flux, crack growth which can be studied. The researcher studied a crack line subjected to thermo-mechanical loading in an infinite plate [12]. To facilitate solution for the problem, complex function method was integrated with thermo-elastic theory. Only mode I stress intensity factor was found to be effective and the heat flux along the vertical direction to the crack line has no effect on the thermal stress intensity factor. So, strain energy density factor theory has been effectively used to calculate applied failure stresses. It is noted that the direction of the heat flow has an influence on the crack growth whether it may be positive or negative. Many other references regarding the composite materials, facture and FEM analysis of composite material as have been referenced from [13-28].

Composite is one of highly used materials especially for high performance applications like airplanes, naval, defense…etc., In all of these cases many of the researchers have studied the propagation of cracks with either mechanical or thermal loadings but in real world these both combinedly will be having their effect on the fracture propagation in composite laminates. So, studying and understanding the influence of these loading condition on the expected SERR values is of utmost importance. The influence of fiber angle on the SERR values also has been studied with which let the designers design with different configurations of composite laminates.

2. FEA WORK

2.1 Problem Description

An angle ply composite laminate containing a circular hole & a virtual crack at its centre was considered. The Effect of temperature rise on the crack propagation present in the composite laminate with circular hole was studied in the first case. In the second case, an additional pressure load was applied in addition to the temperature loading and the effect of combined loading (temp rise + pressure) on the crack propagation was studied. From the results obtained through this work, conclusions were taken and presented in this paper.

2.2 Geometry

The geometry of the composite laminate was taken as 100 X 100 X 5 mm in length, width and thickness dimensions. The thickness of the laminate was divided into 4 laminas with a thickness of 1.25mm for each layer. A symmetric layup sequences of [θ, -θ, -θ, θ] was considered for modelling the fiber angles of the laminate with θ taking the values of 0^o,45^o,90^o in different configurations. A circular hole of 40mm diameter is placed at the centre of the composite laminate and a virtual circular crack of 0.22mm diameter was modelled at exact mid plane of the composite laminate. The geometry of the composite laminate is shown in the figure 1 and the geometry of the edge crack is shown in the figure 2. Different configurations used for the analysis are shown in the figure 3.

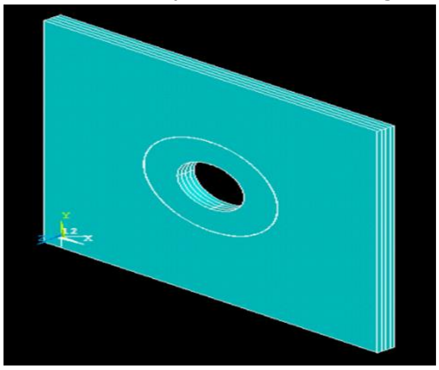

Figure 1: Geometry of the Composite Laminate

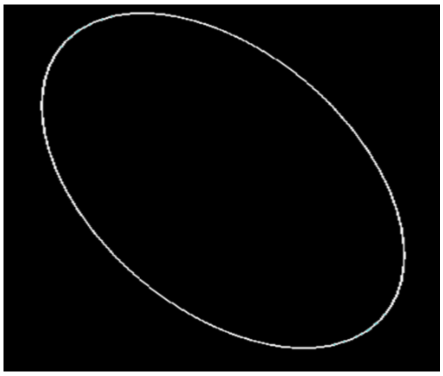

Figure 2: Geometry of the Virtual Crack

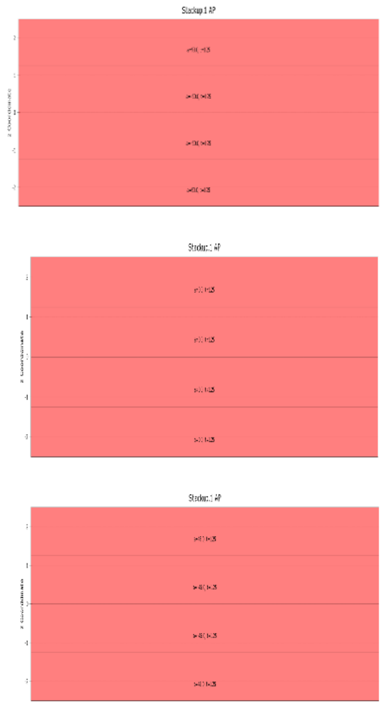

Figure 3: Different configurations of the Angle ply composite laminate

2.3 FE Model

The above-mentioned geometry was converted into finite element model using the process of meshing. For this purpose, the solid 20 node 186 elements, with suitable refinement and mesh settings was used. It is an element which is suitable for modelling of both homogeneous solids and also layered solids effectively. In our work the element was used to mesh a layered solid. Fig.4 shows the FEM element used for meshing the composite geometry.

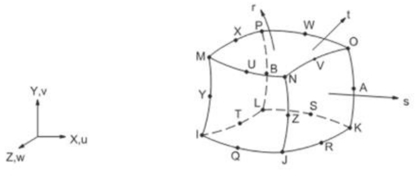

Figure 4: 20 Node 186 Solid Elements used for Meshing

2.4 Material Properties

AS_4 carbon fiber embedded inside the 3501-6 epoxy was the lamina material that was considered for the modelling the composite. The material properties are taken from the text book of I.M.Daniel& Ori ish [28]. Once the material properties of the lamina with 0^o fiber angle are taken from the reference, these properties of the lamina are used to find out the properties of the lamina with 45^o and 90^o using a simple MATLAB code. Table.1 shows the properties of the AS4/3501-6 Carbon/Epoxy lamina.

Table.1: Material Properties Taken for FEA

As4/3501-6 Epoxy carbon Composite Properties								
E_{11}(Gpa)	E_{22}(Gpa)	E_{33}(Gpa)	G_{12}(Gpa)	G_{23}(Gpa)	G_{13}(Gpa)	ν_{12}	ν_{23}	ν_{13}
147	10.3	10.3	7.0	3.48	7.0	0.27	0.51	0.27

$\alpha 1$ (10^{-6}/°C)	$\alpha 2 = \alpha 3$ (10^{-6}/°C)
-0.9	27

2.5 Boundary& Loading conditions

Simply supported boundary conditions are placed at the four edges of the lamina using the displacement constraints in the Ansys Software. In the first case where, pure thermal loading is considered, different temperatures starting from 30 °C to 180 °C with a step size of 50 °C are applied on the composite laminate. In the second case where, combined loading was considered, a pressure load of 5 MPa is applied to the top face of the laminate in the downward direction in addition to the earlier stated thermal loading. Fig.5 represents the boundary and the loading conditions considered for the present work.

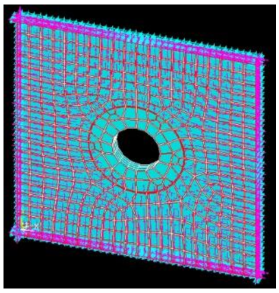

Figure 5: Boundary Conditions applied for the composite laminate

2.6 Validation of FE Model

Validation of the FE model was conducted using the results taken from V.V. Venu Madhav et al. [13]. Different crack lengths are taken and the SERR values obtained from our FE model are validated against the reference. Table.2 shows the results obtained from validating the FE model. From the results obtained from the table.2, it can be stated that the percentage of error between the FEM values and the reference values is very low. From this we can say that our FEM model has been verified.

Table 2: SERR due to Pressure load for different values of Virtual Crack

Virtual Crack Length (mm)	Present SERR (KJ/m^2)	Reference SERR (KJ/m^2)	% of Error
5	12.64	12.35	2.35
3	11.36	11.22	1.22
2	10.81	10.64	1.64
1	10.16	10.05	1.05
0.5	10.23	9.94	2.94

3. RESULTS AND DISCUSSION

3.1 Effect of Pure Thermal Loading

The variation on the SERR values for different fracture modes for the circular hole & crack that is located at the middle of the composite laminate due to the application of the temperature loading for different fiber angles of the composite are shown in the fig. 6,7,8.

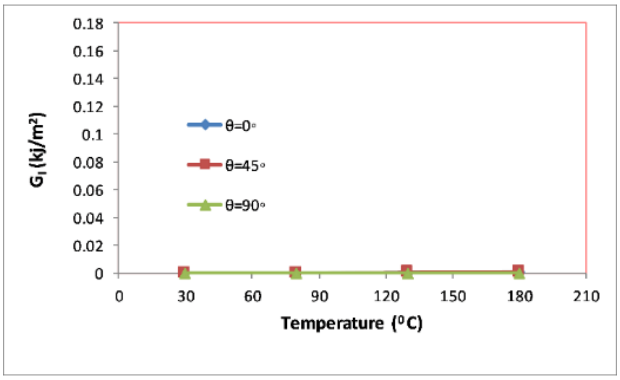

Figure 6: SERR vs Temperature for different fiber angles for Fracture Mode-I

From the figure 6, it can be observed that as the temperature is increasing, there is no evident change that is observed in the SERR value. This trend is observed in the case of all the angle ply composite laminates with the different fiber angles. Even as the fiber angle is increasing the SERR value remains unchanged. So, there is no evident effect either in temperature rise or the fiber angles on SERR value in fracture mode -I (G_I), for the laminate with the circular hole and crack at the middle of the laminate subjected to temperature (rise) loading.

From the figure 7, it can be observed that as the temperature is increasing, the SERR value is also increases. This trend is observed in the case of all the angle ply composite laminates with the different fiber angles. Then as the fiber angle in the lamina is increasing the SERR value has decreased. At lower temperatures, the effect of fiber angle on the SERR value of the laminate was minimal. But as the temperatures have increased, the SERR rate is decreasing with the increase in the fiber angle. The most profound effect of the fiber angle on the SERR value found at higher temperatures, when the laminate is subjected to thermal loading So, there is an increased effect of either temperature rise or the fiber angles on SERR value in fracture mode -2 (G_{II}), for the laminate with the circular hole & crack at the middle of the laminate is subjected to temperature (rise) loading.

From the figure 8, it can be observed that as the temperature is increasing, there is very minimal change that is observed in the SERR value. This trend is observed in the case of all the angle ply composite laminates with the different fiber angles. At lower temperatures the effect of fiber angle on the SERR value of the laminate is minimal. But as the temperatures have increased the SERR rate is decreasing with the increase in the fiber angle.

The most profound effect of the fiber angle on the SERR value is found at higher temperatures, when the laminate is subjected to thermal loading. So, there is an increased effect of either temperature rise or the fiber angles on SERR value in fracture mode -3 (G_{III}), for the laminate with the circular hole & crack at the middle of the laminate subjected to temperature (rise) loading.

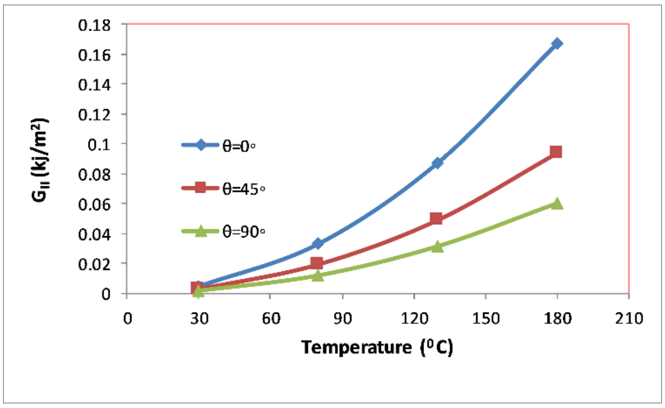

Figure 7: SERR vs Temperature for different fiber angles for Fracture Mode-II

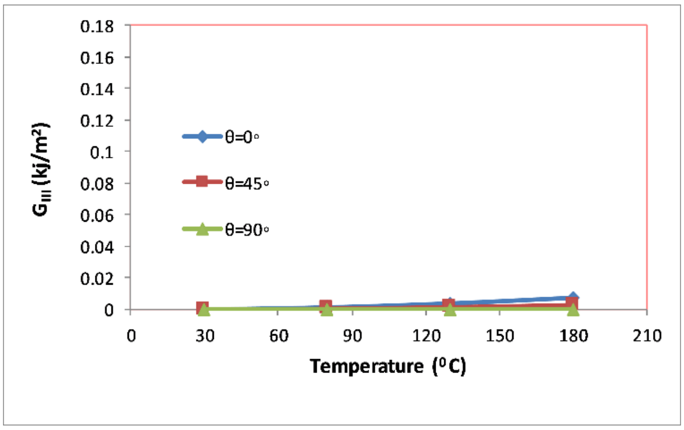

Figure 8: SERR vs Temperature for different fiber angles for Fracture Mode-III

The variation on the SERR values for different mixed fracture modes for the circular hole & crack that is located at the middle of the composite laminate due to the application of the temperature loading for different fiber angles of the composite are shown in the figure 9,10.11.

From the figure 9, it can be observed that as the temperature is increasing, there is no evident change that is observed in the SERR value. This trend is observed in the case of all the angle ply composite laminates with the different fiber angles. Even as the fiber angle is increasing the SERR value remaining unchanged. So, there is no evident effect of either temperature rise or the fiber angles on SERR value in mixed fracture mode -1 (G_I/G_T), for the laminate with the circular hole & crack at the middle of the laminate subjected to temperature (rise) loading.

From the figure10, it can be observed that as the temperature is increasing, there is no evident change that is observed in the SERR value. This trend was observed in the case of all the angle ply composite laminates with the different fiber angles. But as the fiber angle is increasing the SERR value is also increasing, but that change also minimal. So, there is no evident effect of temperature rise and a slight effect of the fiber angles on SERR value is observed in mixed fracture mode -II (G_{II}/G_T), for the laminate with the circular hole & crack at the middle of the laminate subjected to temperature (rise) loading.

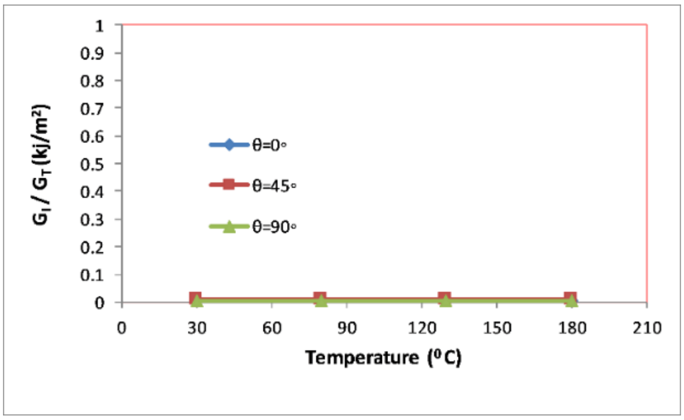

Figure 9: SERR vs Temperature for different fiber angles for mixed fracture Mode-I

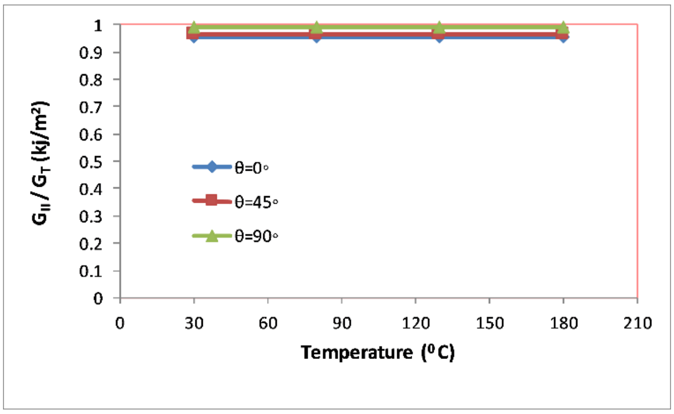

Figure 10: SERR vs Temperature for different fiber angles for mixed fracture Mode-II

From the figure 11, it can be observed that as the temperature is increasing, there is no evident change that is observed in the SERR value. This trend is observed in the case of all the angle ply composite laminates with the different fiber angles. But as the fiber angle is increasing the SERR value is decreasing, but that change also minimal. So, there is no evident effect of temperature rise and a slight effect of the fiber angles on SERR value is observed in mixed fracture mode -III (G_{III}/G_T), for the laminate with the circular hole & crack at the middle of the laminate subjected to temperature (rise) loading.

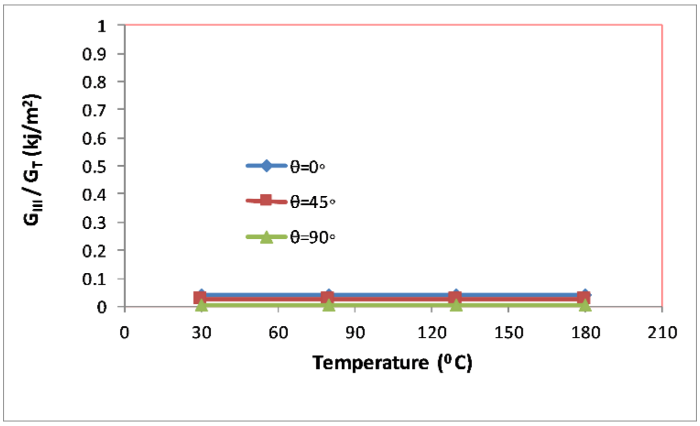

Figure 11: SERR vs Temperature for different fiber angles for mixed fracture Mode-III

3.2 Effect of Combined (Thermal + Mechanical) Loading

The variation on the SERR values for different fracture modes, for the circular hole & crack that is located at the middle of the composite laminate due to the application of the combined loading, for different fiber angles of the composite are shown in the figures 12,13,14.

From the figure 12, it can be observed that as the temperature is increasing and the pressure load remains the same, there is no evident change that is observed in the SERR value. This trend is observed in the case of all the angle ply composite laminates with the different fiber angles. But as the fiber angle is increasing, the SERR value is decreasing, but that change is also minimal. So, there is no evident effect of temperature rise and a slight effect of the fiber angles on SERR value is observed in fracture mode -I (G_I), for the laminate with the circular hole & crack at the middle of the laminate is subjected to combined (temp rise + pressure) loading.

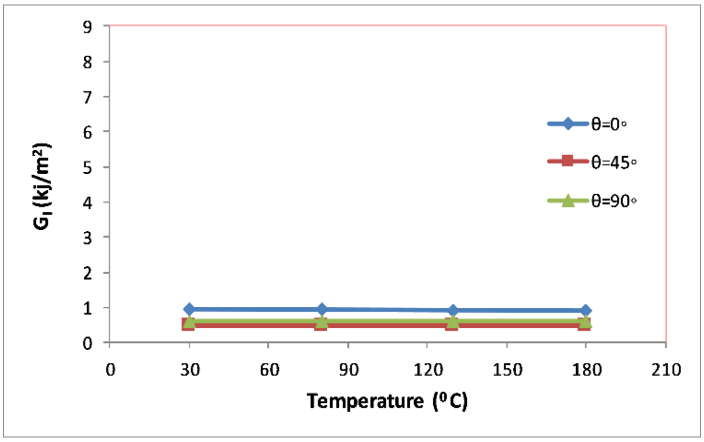

Figure 12: SERR vs Temperature (combined) for different fiber angles for Fracture Mode-I

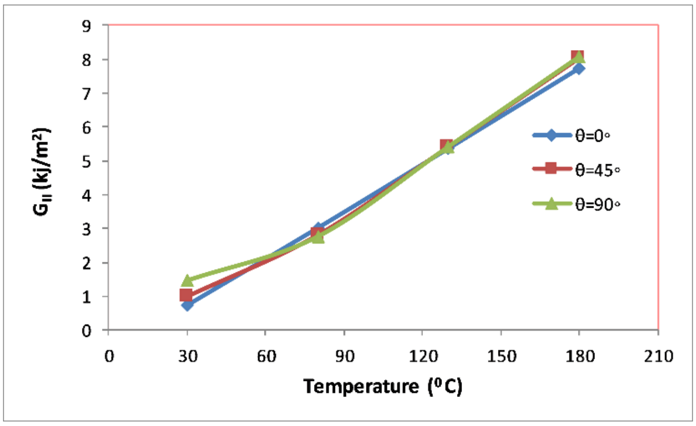

Figure 13: SERR vs Temperature (combined) for different fiber angles for Fracture Mode-II

From the figure 13, it can be observed that as the temperature is increasing, and the pressure load remains the same and the SERR value is also increasing. This trend is observed in the case of all the angle ply composite laminates with the different fiber angles. As the fiber angle is increasing the SERR value is also increasing, but that change is also minimal. The maximum effect of the fiber angle is observed at higher temperatures in the case of the combined loading. So, there is an evident effect of temperature rise and a slight effect of the fiber angles on SERR value is observed in fracture mode -II (G_{II}), for the laminate with the circular hole &crack at the middle of the laminate subjected to combined (temp rise + pressure) loading.

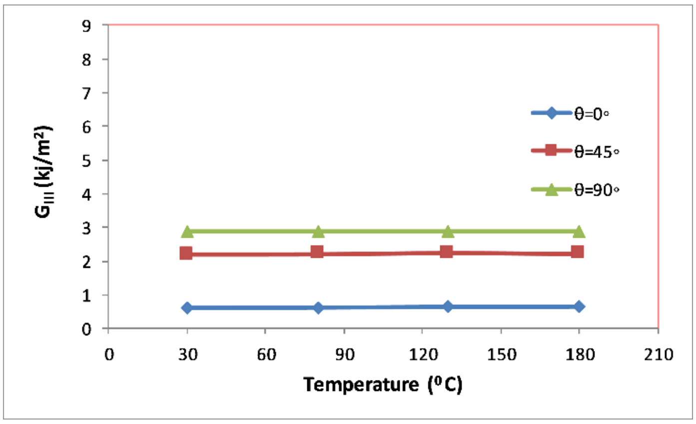

Figure 14: SERR vs Temperature (combined) for different fiber angles for Fracture Mode-III

From the figure 14, it can be observed that as the temperature is increasing and the pressure load remains the same, there is no evident change that was observed in the SERR value. This trend was observed in the case of all the angle ply composite laminates with the different fiber angles. But as the fiber angle is increasing, the SERR value is also increasing, with a considerable change in value. So, there is no evident effect of temperature rise and a great effect of the fiber angles on SERR value is observed in fracture mode -III (G_{III}), for the laminate with the circular hole & crack at the middle of the laminate subjected to combined (temp rise + pressure) loading.

The variation on the SERR values for different mixed fracture modes, for the circular hole & crack that is located at the middle of the composite laminate due to the application of the combined loading for different fiber angles of the composite are shown in the figures 15,16,17.

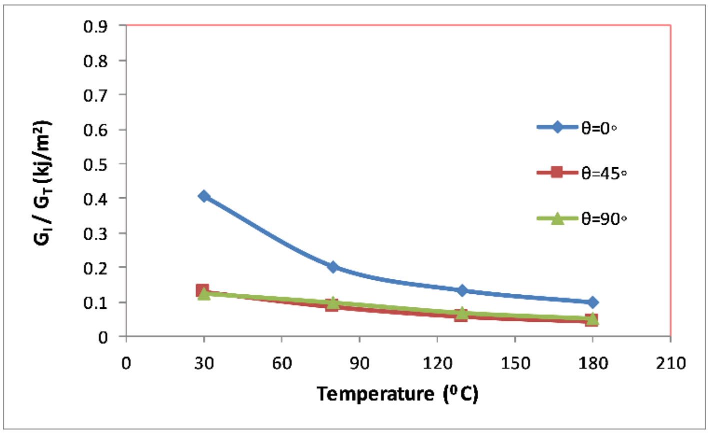

Figure 15: SERR vs Temperature (combined) for different fiber angles for mixed fracture Mode-I

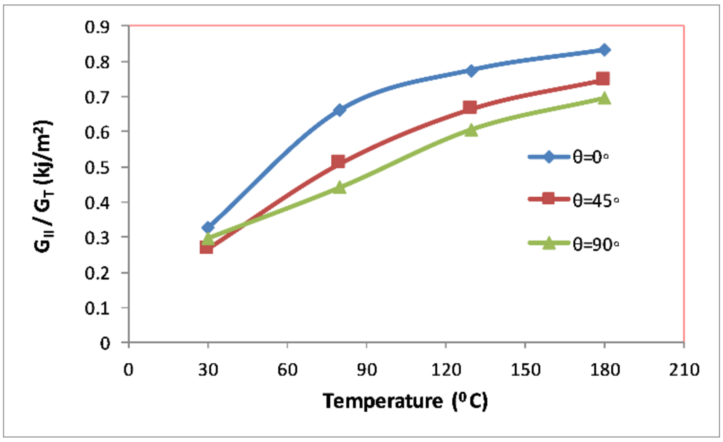

Figure 16: SERR vs Temperature (combined) for different fiber angles for mixed fracture Mode-II

From the figure 15, it can be observed that as the temperature is increasing, the pressure load remains the same, the SERR values are decreasing. This trend is observed in the case of all the angle ply composite laminates with the different fiber angles. But as the fiber angle is increasing the SERR value is decreasing. The profound effect on the combined loading is evident in the case of 0ºfiber angle lamina-based composite. The maximum effect of the fiber angle is observed at lower temperatures in the case of the combined loading. So, there is evident effect of temperature rise and the fiber angles on SERR value is observed in mixed fracture mode -I (G_I/G_T), for the laminate with the circular hole & crack at the middle of the laminate subjected to combined (temp rise + pressure) loading.

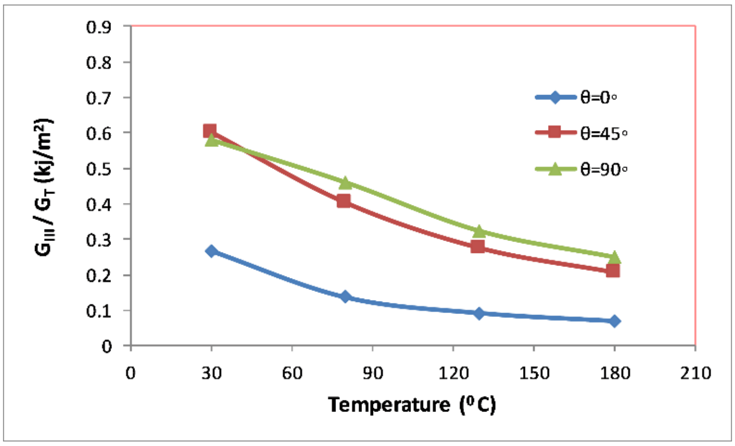

Figure 17: SERR vs Temperature (combined) for different fiber angles for mixed fracture Mode-III

From the figure 16, it can be observed that as the temperature is increasing and the pressure load remains the same, the SERR values are increasing. This trend is observed in the case of all the angle ply composite laminates with the different fiber angles. But as the fiber angle is increasing the SERR value is decreasing. The profound effect on the combined loading is evident in the case of 0ºfiber angle lamina-based composite. The maximum effect of the fiber angle is observed at higher temperatures in the case of the combined loading. So, there is an evident effect of temperature rise and the fiber angles on SERR value is observed in mixed fracture mode -II (G_{II}/G_T), for the laminate with the circular hole & crack at the middle of the laminate subjected to combined (temp rise + pressure) loading.

From the figure 17, it can be observed that as the temperature is increasing and the pressure load remains the same, the SERR values are decreasing. This trend is observed in the case of all the angle ply composite laminates with the different fiber angles. But as the fiber angle is increasing the SERR value is increasing. The profound effect on the combined loading is evident in the case of 0ºfiber angle lamina-based composite. The maximum effect of the fiber angle is observed at lower temperatures in the case of the combined loading. So, there is evident effect of temperature rise and the fiber angles on SERR value is observed in mixed fracture mode -III (G_{III}/G_T), for the laminate with the circular hole & crack at the middle of the laminate subjected to combined (temp rise + pressure) loading.

4. CONCLUSION

Inter laminar fracture analysis of a four-layered angle-ply symmetric simply supported laminate with a circular hole and a crack at the centre of the plate in middle interface is modelled and subjected to uniform transverse pressure and temperature rise. The crack propagation is studied using Virtual Crack Closure Technique using the technique of finite element analysis. The SERRs in principal modes with respect to change in size of the delamination are evaluated.

- The SERR in mode-II is high when compared to all the three principle modes in Thermal Rise and Thermo-Mechanical Rise loads.
- Mixed mode fracture behaviour is observed.
- In Mode-I SERR is high for fiber angle $\theta=0^0$ in Thermo-mechanical Rise loads.
- In Mode-II SERR is high for fiber angle $\theta=90^0$ in Thermo-mechanical Rise loads.
- In Mode-III SERR is high for fiber angle $\theta=90^0$ in Thermo-mechanical Rise loads.
- In Mode-I SERR is high for fiber angle $\theta=45^0$ in Thermal Rise
- In Mode-II SERR is high for fiber angle $\theta=45^0$ in Thermal Rise
- In Mode-III SERR is high for fiber angle $\theta=0^0$ in Thermal Rise
- In Mixed Mode for Mode-I SERR is high for fiber angle $\theta=0^0$ in Thermo-mechanical Rise loads.
- In Mixed Mode for Mode-II SERR is high for fiber angle $\theta=0^0$ in Thermo-mechanical Rise loads.
- In Mixed Mode for Mode-III SERR is high for fiber angle $\theta=90^0$ in Thermo-mechanical Rise loads.
- In Mixed Mode for Mode-I SERR is high for fiber angle $\theta=45^0$ in Thermal Rise loads.

- In Mixed Mode for Mode-II SERR is high for fiber angle θ=90⁰ in Thermal Rise loads.
- In Mixed Mode for Mode-III SERR is high for fiber angle θ=0⁰ in Thermal Rise loads.

Studies on how the fracture does develop in a composite laminate when they are subjected to combined thermomechanical loading with by taking into effect of temperature fall. This study can be taken forward by considering the effect of different types of joints like bolted, riveted...etc. subjected to combine thermo-mechanical loading conditions. Effect of the crack length, depth.etc. can also be studied when the laminates are subjected to this type of thermo-mechanical loads.

REFERENCES

[1] Jin, Z.H., Paulino, G. 2001. Transient Thermal Stress Analysis Of An Edge Crack In Functionally Graded Material. International Journal of Fracture. 107: 73-98.

[2] Rolfes, R., Rohwer, K. 2000. Integrated Thermal And Mechanical Analysis Of Composite Plates And Shells. Composite Science and Technology. 60: 2097-2106.

[3] Matsunaga, H. 2006. Thermal Buckling Of Angle-Ply Laminated Composite And Sandwich Plates According To A Global Higher-Order Deformation Theory. Composites Structures. 72: 177-192.

[4] Tsang, D.K.L, Oyadiji, S.O., Leung, A.Y.T. 2007. Two-Dimensional Fractal-Like Finite Element Method For Thermoelastic Crack Analysis. International Journal of Solids and Structures. 44: 7862-7876.

[5] Keresi, B., Price, J.W.H., Ibrahim, R. 2003. A Two-Stage Model For Predicting Crack Growth Due To Repeated Thermal Shock. Engineering Fracture Mechanics. 70: 721-730.

[6] Herrmann, K.P., Loboda, V.V., Kharun, I.V. 2004. Interface Crack With Contact One In An Isotropic Biomaterial Under Thermomechanical Loading. Theoretical and Applied Fracture Mechanics. 42: 335-348.

[7] Panda, S.K., Pradhan, B. 2007. Mixed-mode analysis of superimposed thermo-elastic effects in fiber-reinforced composites with embedded interface delamination. Composite Structures. 77: 570-580.

[8] Le, H. N., Gardin, C. 2010. Analytical prediction of crack propagation under thermal cyclic loading inducing a thermal gradient in the specimen thickness – comparison with experiments and numerical approach. Engineering Fracture Mechanics. 78: 638-652.

[9] Shahani, A.R., Nabavi, S.M. 2006. Closed form stress intensity factors for a semi-elliptical crack in a thick-walled cylinder under thermal stress. International Journal of Fatigue. 28: 926-933.

[10] Pradhan, B., Panda, S.K. 2006. The Influence Of Ply Sequence And Thermoelastic Stress Field On Asymmetric Delamination Crack Growth Behaviour Of Embedded Elliptical Delamination In Laminated FRP Composites. Composites Science and Technology. 66: 417-426.

[11] Bhalla, K.S., Zehnder, A.T., Han, X. 2003. Thermomechanics Of Slow Stable Crack Growth: Closing The Lop Between Experiments And Computational Modelling. Engineering Fracture Mechanics. 70: 2439-2458.

[12] Tang, X.S. 2008. Mechanical/Thermal Stress Intensification For Mode I Crack Tip: Fracture Initiation Behaviour Of Steel, Aluminum And Titanium Alloys. Theoritical and Applied Fracture Mechanics. 50:92-104.

[13] Venu, M.V.V, Gupta, A.V.S.S.K.S., Balakrishna M.V. 2018. Thermo-Elastic Fracture Analysis of Angle-ply laminates. Materials Today: Proceedings 5: 6045–6052.

[14]Rakesh, P. 2017. Mechanical Properties of Pineapple Leaf Fiber Reinforced Epoxy Infused with Silicon Carbide Micro Particles. Journal Natural Fibers. 1–15.

[15] Rakesh, P., Supriya, K., Vital, G.V.V.N.G. 2018. Effect Of Effect Of Boron Carbide Particles Inclusion On The Mechanical Behaviour Of S2-Glass Fiber Based Polyester Composites. Material Today Proceedings. 5: 20257–20267.

[16] Rakesh, P., Dheeraj, R.S., Vital, G.V.V.N.G. 2018. Effect of Stacking Sequence on the Mechanical and Thermal Properties of Hybrid Laminates. Material Today Proceedings. 5: 5876–5885.

[17] Rakesh, P., Eswara, A., Raju, M.N., Prakash, K.R. 2017. Finite Element Analysis of Cellular Foam Core Sandwich Structures. Material Today Proceedings. 4: 2501–2510.

[18] Rakesh, P., Eswara, K., Navuri, A., Nagaraju, K., Rao, M. 2016. Buckling Analysis Of A Ring Stiffened Hybrid Composite Cylinder. IOP Conference Series: Materials Science and Engineering.

[19] Rakesh, P., Diwakar, V., Venkatesh, K., Reddy, B.S. 2018. Analytical Model Application for Prediction of Mechanical Properties of Natural Fiber Reinforced Composites. Material Today Proceedings. 5, 5809–5818.

[20] Rakesh., P., Rao, U.K. 2017. Determination of Elastic Properties of Reverted Hexagonal Honeycomb Core: FEM Approach. Material Today Proceedings. 4: 8645–8653.

[21] Rakesh, P., Paul, K.J., Babu, B.M. 2018. Effect of Silicon Carbide Particles Embedment on the properties of Kevlar Fiber Reinforced Polymer Composites. Material Today Proceeding. 5: 6098–6108.

[22] Rakesh, P., Kumar, J.P., Abdul, S., Prasanthi, P. 2017. Mechanical Properties Characterization of Okra Fiber Based Green Composites and Hybrid Laminates. Material Today Proceedings. 4; 2893–2902

[23] Potluri, R. 2018. Mechanical properties evaluation of T800 carbon fiber reinforced hybrid composite embedded with silicon carbide microparticles: A micromechanical approach. Multidiscipline Modeling in Materials and Structures.14(3): 589-608.

[24] Potluri, R. 2015. Comparative Study of Pressure Vessels Made from Laminated Composite Material (COPV) with the Pressure Vessels Made with Sandwich Core Composite Material. Journal Material Science Mechanical Engineering 2: 203–207.

[25] Rakesh, P. Ketha, K.K. 2015. Comparison between GFRP and CFRP Composite Power Take-off Shaft in Helicopters for Prescribed Torque and Geometrical Constrain.

[26] Journal Material Science Mechanical Engineering, 2, 214–219.

[27] Rakesh, P. 2018. Natural Fiber-Based Hybrid Bio-composites: Processing, Characterization, and Applications, Green Composites, 1-42, Springer Singapore.

[28] ANSYS Reference Manuals. 2016.

[29] Daniel, I.M.O.L. 2006. Engineering Mechanics of Composite Materials.

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