IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 3 Ser. II (May. - June. 2019), PP 30-37
www.iosrjournals.org

Study of Fracture Behaviour of a Composite Laminate [$0^o/90^o$] With Circular Crack Subjected To Temperature Fall Loading

V.V.Venu Madhav[a], A.V.S.S.K.S. Gupta[b] , P. Rakesh[c]
[a]*Department of Mechanical Engineering, V. R. Siddhartha Engineering College, Vijayawada, Andhra Pradesh-520007, India*
[b]*Department of Mechanical Engineering, JNTU College of Engineering, Hyderabad, Telengana-500085, India.*
[c]*Sr. Engineer, DesignTech Systems Ltd., APCOE, VRSEC, Andhra Pradesh-520007, India.*
Corresponding Author: V.V.Venu Madhava

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 condition where the temperature was considered to be falling to study the fracture behaviour. The fracture behaviour of the composite laminate was studied using the strain energy release rate (SERR) value calculated using Virtual crack closure technique (VCCT). The effect of temperature fall on the SERR value in the 3 different modes of fracture with a circular crack located in the middle of the composite laminate was studied and the influence of these parameter was discussed in this paper.*
Keywords: *Thermal Fall Loading, SERR, VCCT, Composites Fracture, FEA.*

Date of Submission: 13-05-2019 Date of acceptance: 30-05-2019

I. 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 20^{th} 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 falling 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…etc., Jin et. al. [1] considered an edge crack in a multi-layered FGM stressed under the transient thermal loading. 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. Rolfes et. al. [2] 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. These elements have been verified with the help of different thermal lamination theories. Matsunaga. [3] presented a 2-D global higher order deformation theory for thermal buckling analysis of angle-ply laminated composite and sandwich plates. He used the virtual energy method to derive the governing equations which takes the shear and normal stresses in to 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. Tsang et. al. [4] used 2-D fractal elements in analysing the cracks on thermo-elastic problems. Transformation functions were analytically established to check thermal stress intensity factor with respect to thermal loading. Kerezsi et.al. [5] 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 it. 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. The two stages of model correspond to the high strain fatigue region and linear elastic fracture mechanics respectively. Herrmann et.al. [6] 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. They found that the real contact zone length and its corresponding stress intensity factors depends on normal shear loading and heat flux. Panda et.al. [7] assumed linear elasticity for mechanical loading which super imposed the thermal stresses where strain energy rates were calculated at delamination front. 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. Gardinet.al. [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. Shahani et.al. [9] 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. Pradhan et.al.[10] discussed the manufacturing defects that causes inter laminar elliptical delamination's to forego crack growth influenced by ply angle and thermo-elastic loading. Bhalla et.al.[11] describes about the energy consumed in the crack growth and about the material damage. They used infrared cameras to study the crack growth by analysing thermal images. by calculating the energy flux, crack growth can be studied. Tang [12] studied a crack line subjected to thermo-mechanical loading in an infinite plate. 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 had been effectively used to calculate applied failure stresses. It was 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 [13-30].

II. Fea Work

2.1. Problem Description:

An composite laminate containing a circular hole & a virtual crack at its centre was considered. The Effect of temperature fall on the crack propagation present in the composite laminate with circular hole 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,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 fig.1 and the geometry of the edge crack is shown in the fig.2. Different configuration used for the analysis are shown in the fig.3.

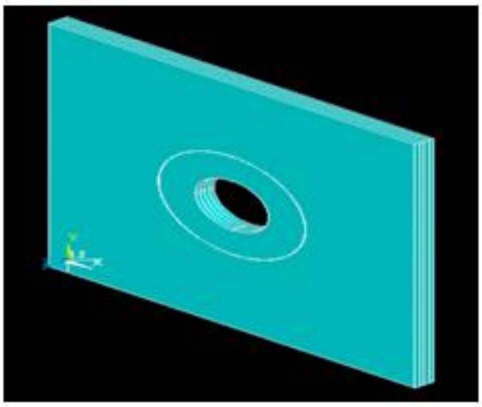

Fig.1: Geometry of the Composite Laminate

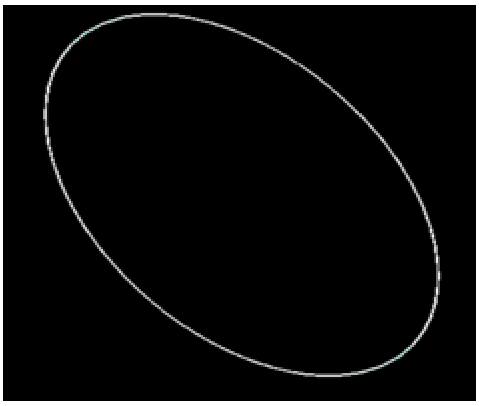

Fig.2: Geometry of the Virtual Crack

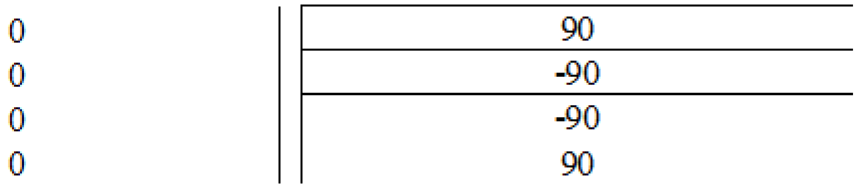

Fig.3: Different configurations of the composite laminate

2.3. FE Model

The above-mentioned geometry was converted in to 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 FEA element used for meshing the composite geometry.

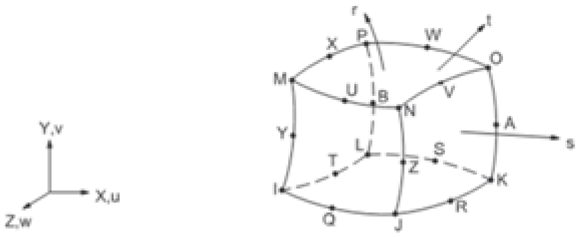

Fig.4: 20 Node 186 Solid Element used for Meshing

2.4 Material Properties

As4 carbon fiber embedded inside the 3501-6 epoxy was the lamina material that was considered for the modelling the composite. The material properties were taken from the textbook of I.M.Daniel & Ori ish [30]. Once the material properties of the lamina with 0^o fiber angle were taken from the reference, these properties of the lamina were used to find out the properties of the lamina with 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

.

α_1 (10^{-6}/^{o}C)	**$\alpha_2 = \alpha_3$ (10^{-6}/^{o}C)**
-0.9	27

2.5 Boundary & Loading conditions:

Simply supported boundary conditions were place at the four edges of the lamina using the displacement constraints in the Ansys Software. In this case, pure thermal loading was considered, different temperature starting from -30 ^{o}C to -180 ^{o}C with a step size of 50 ^{o}C were applied on the composite laminate. Fig.5represents the boundary conditions considered for the present work

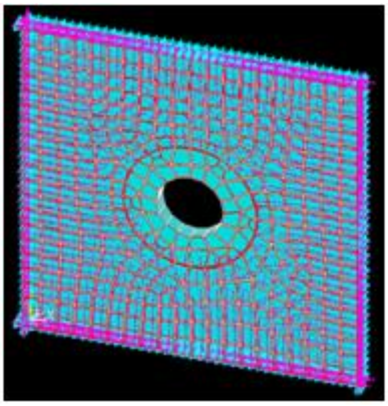

Fig.5: Boundary Conditions applied for the composite laminate

2.6 Validation of FE Model:
Validation of the FE model was conducted using the results taken from V.V. Venumadhav et al. [13]. Different crack lengths were taken and the SERR values obtained from our FE model were validated against the reference. Table.2 shows the results obtained from validating the FE model.

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

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.

III. Results

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.

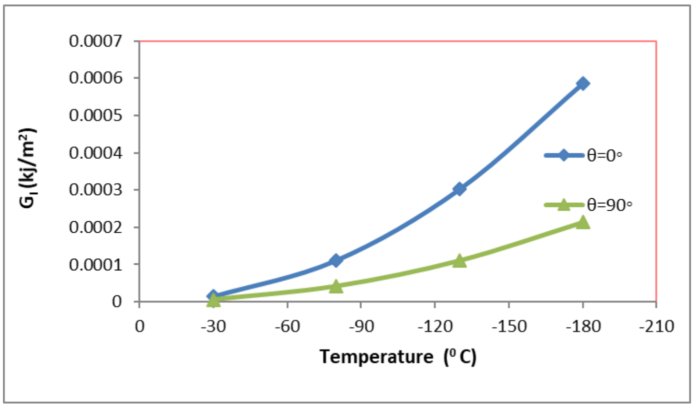

Fig.6: SERR vs Temperature for different fiber angles for Fracture Mode-I

From the figure 6, it can be observed that as the temperature is decreasing, there is no evident (major) 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. Even as the fiber angle is increasing the SERR value is remaining unchanged. So, there is no evident effect of either temperature fall and the fiber angles on SERR value in fracture mode -I (G_I), for the laminate with the circular hole & crack at the middle of the laminate subjected to temperature (fall) loading.

From the figure 7, it can be observed that as the temperature is decreasing, the SERR value has increased. This trend was 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 higher temperatures the effect of fiber angle on the SERR value of the laminate was minimal. But as the temperatures have decreased the SERR rate was decreasing with the increase in the fiber angle. The most profound effect of the fiber angle on the SERR value was found at lower temperatures, when the laminate is subjected to thermal loading. So, there is an increased effect of either temperature fall & 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 subjected to temperature (fall) loading.

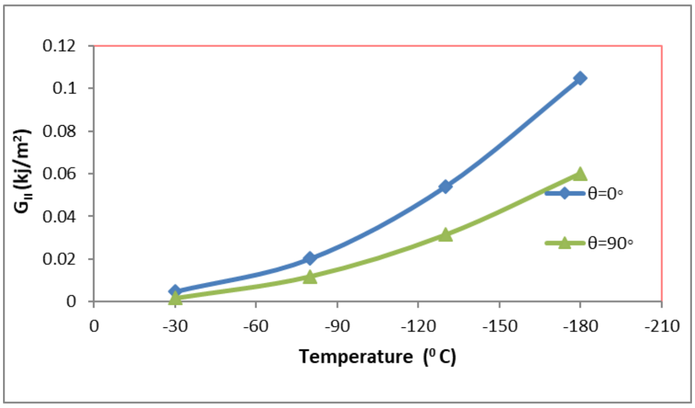

Fig.7: SERR vs Temperature for different fiber angles for Fracture Mode-II

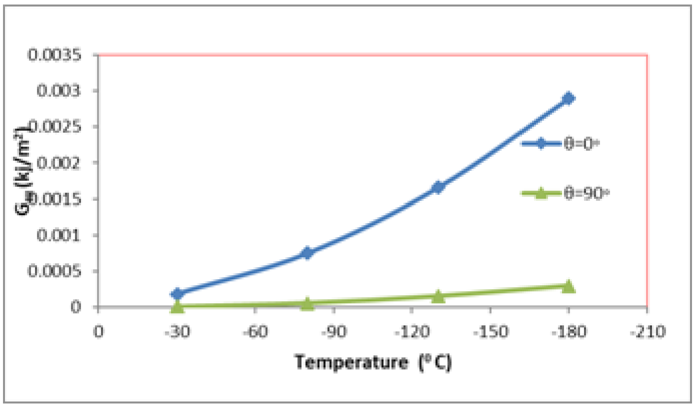

Fig.8: SERR vs Temperature for different fiber angles for Fracture Mode-III

From the figure 8, it can be observed that as the temperature is decreasing, there is very minimal 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. At higher temperatures the effect of fiber angle on the SERR value of the laminate was minimal. But as the temperatures have decreased the SERR rate was increasing with the increase in the fiber angle. The most profound effect of the fiber angle on the SERR value was found at lower temperatures, when the laminate is subjected to thermal loading. So, there is an increased effect of either temperature fall & 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 (fall) 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 temperature loading for different fiber angles of the composite are shown in the fig. 9,10.11.

From the figure 9, it can be observed that as the temperature is decreasing, 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. Even as the fiber angle is increasing the SERR value is remaining unchanged. So, there is no evident effect of either temperature fall and 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 (fall) loading.

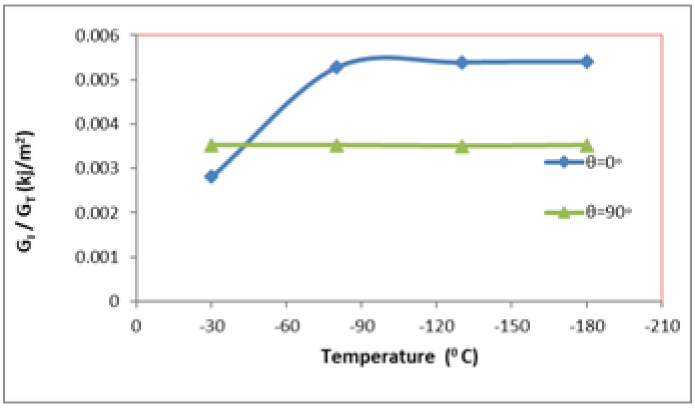

Fig.9: SERR vs Temperature for different fiber angles for mixed fracture Mode-I

From the figure10, it can be observed that as the temperature is decreasing, 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, but that change also minimal. So, there is no evident effect of temperature fall 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 (fall) loading.

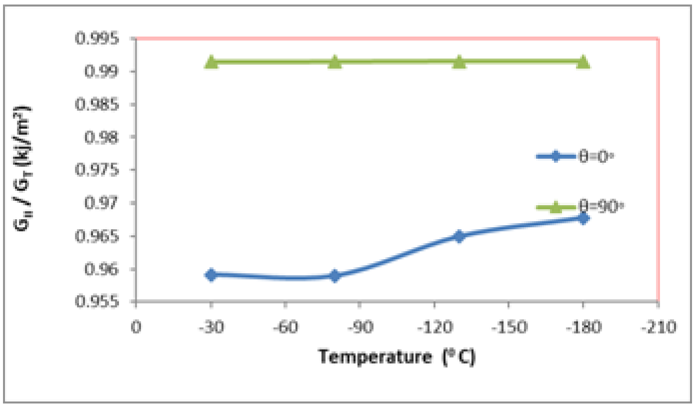

Fig.10: SERR vs Temperature for different fiber angles for mixed fracture Mode-II

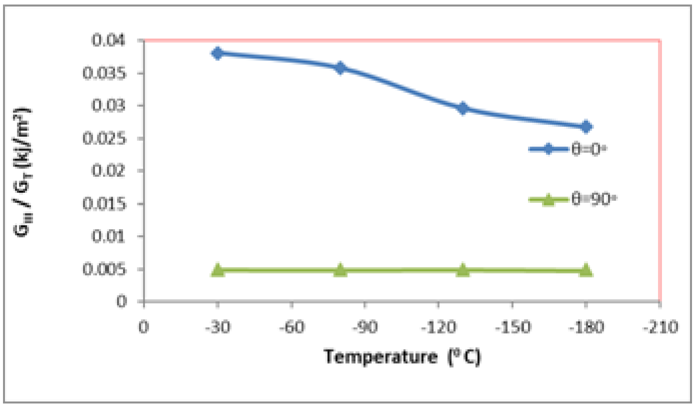

Fig.11: SERR vs Temperature for different fiber angles for mixed fracture Mode-III

From the figure 11, it can be observed that as the temperature is decreasing, there is no evident (Major) 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 decreasing, but that change also minimal. So, there is no evident effect of temperature fall 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 (fall) loading.

IV. Conclusions

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 was modelled and subjected to temperature fall Loading. The crack propagation was 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 compared to all the three principle modes in Thermal fall loading.
- Mixed mode fracture behaviour is observed.
- In Mode-I SERR is high for fiber angle $\theta=0^0$ in Thermal fallloading.
- In Mode-II SERR is high for fiber angle $\theta=0^0$ in Thermal fall loading.
- In Mode-III SERR is high for fiber angle $\theta=0^0$ in Thermal fallloading.
- In mixed mode for Mode-I SERR is high for fiber angle $\theta=0^0$ in thermal fall loading.
- In mixed mode for mode-II SERR is high for fiber angle $\theta=90^0$ in thermal fall loading.
- In mixed mode for mode-III SERR is high for fiber angle $\theta=0^0$ in thermal fall loading.

References

[1]. Z.H.Jin, Glaucioh Paulino, 2001, "Transient thermal stress analysis of an edge crack in functionally graded material", International Journal of Fracture 107;73-98.

[2]. R.Rolfes, K. Rohwer, 2000, "Integrated thermal and mechanical analysis of composite plates and shells", Composite Science and Technology 60;2097-2106.

[3]. Hiroyuki Matsunaga, 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]. D.K.L Tsang, S.O.Oyadiji, A.Y.T. Leung, 2007, "Two-dimensional fractal-like finite element method for thermoelastic crack analysis", International Journal of Solids and Structures 44;7862-7876.

[5]. B. Keresi, J.W.H Price, R. Ibrahim, 2003, "A two-stage model for predicting crack growth due to repeated thermal shock", Engineering Fracture Mechanics 70;721-730.

[6]. K.P.Herrmann, V.V. Loboda, I.V. Kharun, 2004, "Interface crack with contact one in an isotropic biomaterial under thermomechanical loading", Theoretical and Applied Fracture Mechanics 42;335-348.

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

[8]. Hoai Nam Le, C. Gardin, 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]. A.R. Shahani, S.M. Nabavi, 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]. B. Pradhan, S.K. Panda, 2006, "The influence of ply sequence and thermoelastic stress field on asymmetric delamination crack growth behaviour of embedded elliptical delaminations in laminated FRP composites", Composites Science and Technology 66, 417-426.

[11]. K.S. Bhalla, A.T. Zehnder, X.Han, 2003, "Thermomechanics of slow stable crack growth: closing the lop between experiments and computational modelling", Engineering Fracture Mechanics 70,2439-2458.

[12]. X.S.Tang, 2008, "Mechanical/thermal stress intensification for mode I crack tip: Fracture initiation behaviour of steel, aluminum and titanium alloys", Theoretical and Applied Fracture Mechanics 50,92-104.

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

[14]. Potluri Rakesh, "Mechanical Properties of Pineapple Leaf Fiber Reinforced Epoxy Infused with Silicon Carbide Micro Particles". J. Nat. Fibers.16, 137-151.

[15]. Potluri Rakesh., K. Supriya, Vital, G.V.V.N.G, "Effect of Effect of boron carbide particles inclusion on the mechanical behaviour of S2-Glass fiber based polyester composites", Materials Today: Proceedings5, 20257–20267 (2018).

[16]. V.V.Venu Madhav, A.V.S.S.K.S. Gupta and Potluri. Rakesh , "Fracture Behaviour Study on the Cross-ply Composite Laminate with a Circular Hole Subjected to Thermo-Mechanical Loading with Temperature Rise", International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 23 (2018) pp. 16238-16244.

[17]. V.V.Venu Madhav, A.V.S.S.K.S. Gupta and Potluri. Rakesh , "Fracture Behaviour Study on the Cross-ply Composite Laminate with a Circular Hole Subjected to Thermo-Mechanical Loading with Temperature Fall", International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 23 (2018) pp. 16245-16251.

[18]. Potluri Rakesh., Dheeraj, R.S., Vital, G.V.V.N.G., "Effect of Stacking Sequence on the Mechanical & Thermal Properties of Hybrid Laminates", Materials Today: Proceedings. 5, 5876–5885 (2018).

[19]. Potluri Rakesh., Eswara, A., Raju, M.N., Prakash, K.R, " Finite Element Analysis of Cellular Foam Core Sandwich Structures", Materials Today: Proceedings 4, 2501–2510 (2017).

[20]. Potluri Rakesh., Eswara Kumar, A., Navuri, K., Nagaraju, M., Rao, "Buckling analysis of a ring stiffened hybrid composite cylinder", IOP Conference Series: Materials Science and Engineering (2016).

[21]. Potluri Rakesh., Diwakar, V., Venkatesh, K., Reddy, B.S, " Analytical Model Application for Prediction of Mechanical Properties of Natural Fiber Reinforced Composites", Materials Today: Proceedings. 5, 5809–5818 (2018).

[22]. Potluri Rakesh., Rao, U.K, "Determination of Elastic Properties of Reverted Hexagonal Honeycomb Core : FEM Approach", Materials Today: Proceedings 4, 8645–8653 (2017).

[23]. Potluri Rakesh., Paul, K.J., Babu, B.M. " Effect of Silicon Carbide Particles Embedment on the properties of Kevlar Fiber Reinforced Polymer Composites", Materials Today: Proceedings5, 6098–6108 (2018).

[24]. Potluri Rakesh., K, J.P., Abdul, S., Prasanthi, P, "Mechanical Properties Characterization of Okra Fiber Based Green Composites & Hybrid Laminates", Materials Today: Proceedings4, 2893–2902 (2017).

[25]. Rakesh Potluri, (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, Vol. 14 Issue: 3, pp.589-608.

[26]. Potluri Rakesh., "Comparative Study of Pressure Vessels Made from Laminated Composite Material (COPV) with the Pressure Vessels Made with Sandwich Core Composite Material", J. Mater. Sci. Mech. Eng. 2, 203–207 (2015).

[27]. Potluri Rakesh., Ketha, K.K., "Comparison between GFRP and CFRP Composite Power Take-off Shaft in Helicopters for Prescribed Torque and Geometrical Constraints", J. Mater. Sci. Mech. Eng. 2, 214–219 (2015).

[28]. Potluri Rakesh, 2018, "Natural Fiber-Based Hybrid Bio-composites: Processing, Characterization, and Applications", Green composites, 1-42, Springer Singapore.

[29]. ANSYS Reference Manuals, (2016).

[30]. I. M. Daniel & Ori Ishi, Engineering Mechanics of Composite Materials (2006).

V.V.Venu Madhava. Study of Fracture Behaviour of a Composite Laminate [0o/90o] With Circular Crack Subjected To Temperature Fall Loading." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 16, no. 3, 2019, pp. 30-37