

# A Review on Fabrication and Characterization of Composite Material and its Buckling Analysis through FEM

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## Abstract

Manufacturing of composite is one of the prominent and economical routes for development and processing of metal matrix composite materials. Composite is a multiphase material that exhibits a significant proportion of the properties of both constituting phase such that a better combination of properties is realized. The composite industry has begun to recognize that the commercial application of composites promise to offer much larger business opportunities than the aerospace sector due to the sheer size of transportation industry. A vast majority of the scientist reported that production of composites using mechanical properties as tensile strength, hardness, impact strength more uniform distribution of reinforced particle, metal matrix composite poses some attractive properties when compared with organic matrices. These include strength retention at higher temperature, higher transverse strength, better thermal conductivity, higher erosion resistance. Buckling behavior of such materials are the keen area of research due to the instability of various materials subjected under variable loads and dynamic conditions. This article is a survey of literature on composite materials regarding their fabrication and characterization and its buckling behavior analysis.

## 1. Introduction

The concept of making composite materials came from ancient when different materials are combined in various proportions to produce new materials with the performance unattainable by the individual constituents. Most commonly, composite materials have a bulk phase which is continuous known as matrix, and one dispersed, non-continuous phase known as reinforcement, which is usually harder and stronger than matrix. Dispersed phase or reinforcement consists of fibers and/or particulates like glass, carbon, cellulose, silicon-carbide, and metal-oxide whiskers etc., used to improve the structural characteristics of the matrix phase. The accurate material characterization of composite

structures is done via various methods like micro-mechanical models, experimental techniques and finite element methods (FEMs). Finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for differential equations. It uses variation methods (the calculus of variations) to minimize an error function and produce a stable solution.

### 1.1. Fabrication and Characterization of Composite Materials

Today's requirements for more radical interventions impose their more intensive development and implementation, light metals, polymers and their composite products in industrial practice are no unknowns and have already started to be used as substitute solutions. Light metals such as

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aluminum, magnesium and titan both because of the production price and because of the limitations by basic properties make it difficult to expand the usage spectrum. These high requirements have brought the composite materials into the focus of present research. The potential of composite materials, as macroscopic combinations of dissimilar materials has been recognized in unlimited possibilities of moderation and combination of the desired properties of the constituents. However, their share in the total mass reduction is significantly reduced by improving the vehicle design, transmission efficiency, safety-critical structures and comfort (anti-block systems, airbags, air-conditioning systems, etc.).

Depending on the purpose of composites, one or several materials (hard phase), of different morphologies are integrated into the matrix material, forming very diverse spectrum of properties of hybrid products – composites, which regarding purpose exceed greatly the usage limits defined for the traffic means. The hard phase can be in several main forms: continuous and discontinuous fibers, needles or whiskers and spherical particles. The best mechanical properties of composites are achieved by using continuous fibers and the worst by using particle forms. However, the non-isotropic properties of composites with continuous fibers due to complexity of production make them very expensive and mainly intended for high-value applications. The use of particles as hard phase is based on the isotropic properties of composites and the simplicity of the production process and consequently low price. From the technological aspect, after having selected the constituents, the basic aim in the production of composites is the achievement of good bonding of the matrix and the hard phase and homogeneous distribution of hard phase within the matrix.

Unlike other light metals, aluminum with its characteristic properties such as high strength/density ratio, good corrosion resistance and thermal conductivity, mach inability and recyclability and relatively low price, is one of the most prospective matrix metals for the production of composites. Independent of the composition, production techniques and processing, all of them show very poor tri biological properties.

## 1.2 Buckling behavior of Composite Materials

Buckling is a failure mode characterized by a sudden failure of a structural member that is subjected to high compressive stresses where the actual compressive stress at failure are smaller than the ultimate compressive stress that the material is capable of withstanding. This mode of failure is also described as failure due to elastic instability. The use of finite

element method shows innumerable advantages of economical and practical order due, on the one hand, to the cost that plays the realization of real tests, and on the other hand, to the technical difficulties of the same. Because it is based on the variation formulation of differential equation, it is much more flexible than finite difference and finite volume methods, and can thus be applied to more complicated problems. In general, engineering problems are mathematical models of physical situations. Mathematical models are differential equations with a set of corresponding boundary and initial conditions. The differential equations are derived by applying the fundamental laws and principles of nature to a system or a control volume. These governing equations represent the balance of mass, force, or energy.

## 2. Literature review

Survey of literature has been done in two categories first is fabrication and characterization and second in terms of buckling analysis of composites.

### 2.1 Fabrication and Characterization of Composites Materials

Lots of researches have been conducted on the fabrication and characterization of composites materials. The various researches have been contributed their research on composite materials and its analysis. F. Fiori, E. Girardin, A. Giuliani, T. Lorentzen, A. Pyzalla, F. Rustichelli and V. Stanic, (2000) used fabrication of composite material AA359 to obtain tensile and fatigue strength on both matrix and reinforcement through the thermal micro-stresses which is existing due to heat treatment prior to mechanical tests [1].

Yoshitada Watanabe, (2008) conducted a number of experiments with focus on the low-speed sliding characteristics and examined the characteristics Cu–Sn-based composite materials during high-speed sliding from the viewpoints of both contact resistance and coefficient of friction. He examined the applicability of sliding electric contact materials with focus on changes in contact resistance and coefficient of friction when the revolution speed was increased up to a maximum speed of about 2000 rpm in contact between a pin and a cylindrical circular surface. As a result, in a sliding contact between copper and composite materials containing a lamellar solid lubricant, wear loss decreased by over a figure compared with copper–copper contact, as one of the merits. It has been clarified that within composite materials based on Cu–Sn, the composite materials CMML-10 and CMML-11, which contain

only WS2 and graphite, showed excellent sliding characteristics [2].  
 A.G. Mamalis, K.N. Spentzas, D.P. Papapostolou, and N. Pantelelis,(2013) used explicit finite element, code LS-DYNA3D to investigate the influence of selected material properties in the crash energy absorption characteristics of composite sandwich panels subjected to in-plane compressive loading. The first step in this investigation was to simulate as accurate as possible representative tests corresponding to the collapse modes that occurred in a series of static edgewise compression tests performed in the National Technical University of Athens (NTUA) using various types of composite sandwich panels[3].

characteristics [2].

Zhi-Qiang Yu, Yong-Liang Feng, Wen-Jing Zhou, Yu Jin, Ming-Jie Li, Zeng-Yao Li, Wen-Quan, Tao,(2013) have performed various are numerically investigation to find the heat transfer characteristics of porous material adopted in the receiver of a concentrated solar power (CSP) with different structure parameters. The commercial software FLUENT and the user defined function program (UDF) are adopted to implement the simulation. Porous material geometry is represented by periodic structures formed with packed tetrakaidecahedron which shown in given figure1.

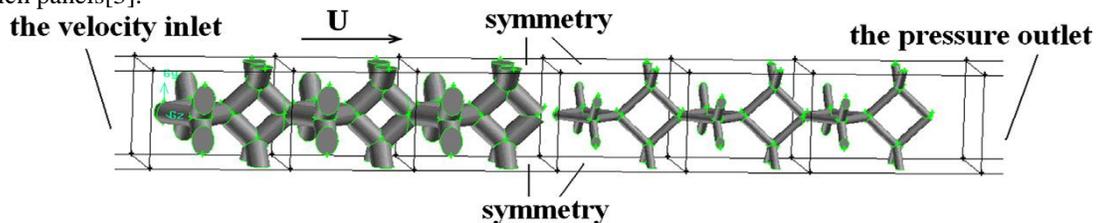
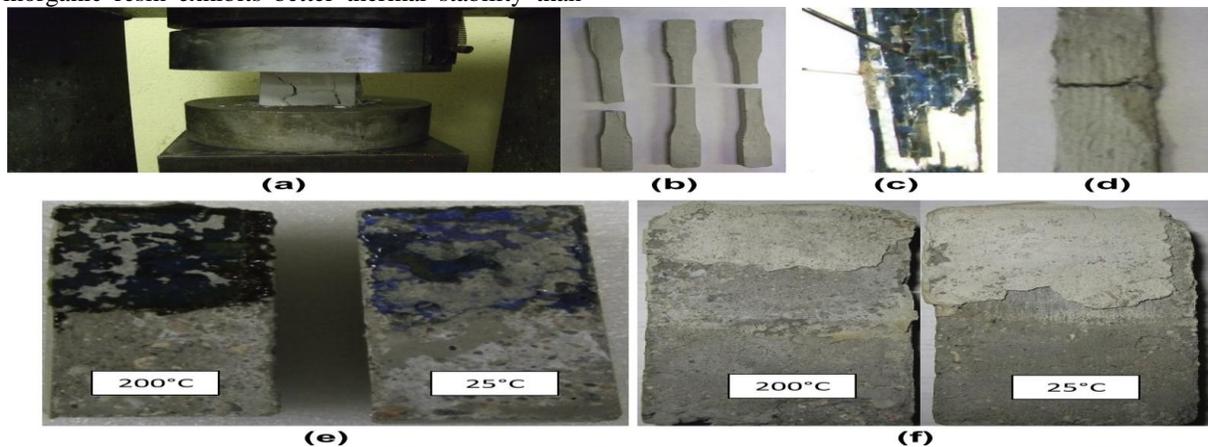


Fig. 1. Boundary condition in porous material [4]

The air flow and heat transfer characteristics under the boundary conditions of constant heat flux and constant wall temperature are studied. The field synergy principle (FSP) and the entransy dissipation extremum principle (EDEP) are used to analyze the flow and heat transfer performance of the composite porous material. From the numerical results the best composite of the porous material is obtained. The effects of different boundary conditions are revealed. It is also demonstrated that the FSP and the EDEP are inherently consistent [4].

Yail J. Kim, Thushara Siriwardanage, Amer Hmidan, and Junwon Seo have obtained residual characteristics of organic and inorganic resins for structural retrofit using Carbon fiber reinforced polymer (CFRP) composites exposed to thermal stress states. A three-phase experimental program is carried out to study the behavior of the inorganic resin, CFRP composites, and resin-concrete interface at elevated temperatures ranging from 25C to 200C. The properties of the inorganic resin demonstrate strong dependency on curing time and are the organic resin, whereas the former illustrates a lower strength than the latter because of insufficient stress-transfer. The composites have failed abruptly, regardless of resin types which shown in figure 2.

influenced by the degree of temperature exposure. CFRP composites show a decrease in strength and modulus with an increasing temperature due to the degradation of bond between the fibers and resin. The inorganic resin exhibits better thermal stability than



**Fig. 2.** Failure mode: (a) cube in compression; (b) dog-bone coupon in tension; (c) CFRP with organic resin in tension; (d) CFRP with inorganic resin; (e) interface with organic resin; and (f) interface with inorganic resin [5]

The interfacial fracture energy of the resins is reduced with temperature, including the deteriorated morphology of the interface between the concrete substrate and the resin [5].

Mei Fuding, Hou Jiaojiao, and Liu Zude, (2012) have tested and analyzed the physical and chemical characteristics of each of phosphogypsum-based silicon and aluminum composite materials. By means of ratio test, it is proved that the range of composite materials' compressive strength is 1.46MPa to 2.78MPa along with the range of the ratio in 1:1:4.7 to 1:1:8. The experiments of active characteristics of composite materials were designed in method of activity ratio Ka value, whose results showed that in early stage, a small amount of hazardous substances in composite materials, such as soluble phosphorus, fluorine and so on, will inhibit free proliferation about the activity of SiO2 and Al2O3, while in medium and late stage, the Ka value that showing a inflection point at the age of 28 days has a relationship with the OH-density in alkaline environment. And temperature, an important factor affecting the Ka value of composite materials, was set 80 °C as an optimal temperature in reactions. In a word, by calculating the Ka value, the degree of activity features affected by the external environment was followed by Temperature>Activation time>Fineness. The research could provide theoretical guidance for large-scale application of utilizing industrial solid waste to fill goof so that ensure the safety of mines. [6]

**2.2 Buckling analysis of composites**

The Buckling analysis through FEM is showing the various characterizations of composite materials. The buckling has a vital role in the composite materials strength. The FEM give the better prediction of composite materials before the failure through Buckling loads.

T. Nguyen-Thoi, T. Bui-Xuan, P. Phung-Van, H. Nguyen-Xuan, P. Ngo-Thanh, (2013) have analyzed the static, free vibration and buckling of eccentricly stiffened plates by the cell-based smoothed discrete shear gap method (CS-FEM-DSG3) using triangular elements. In this method, the original plate element CS-DSG3 is combined with a membrane element and stiffened by a thick beam element. The eccentricity between the plate and the beam is included in the formulation of the beam where formulation for static, dynamic and pre-buckling analyses is given below.

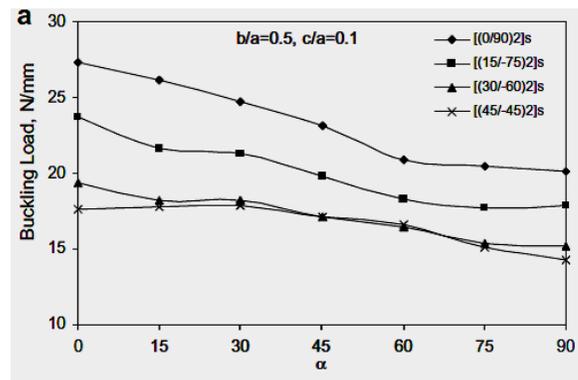
$$Kd= f \tag{1}$$

$$(K-\omega^2M)d=0 \tag{2}$$

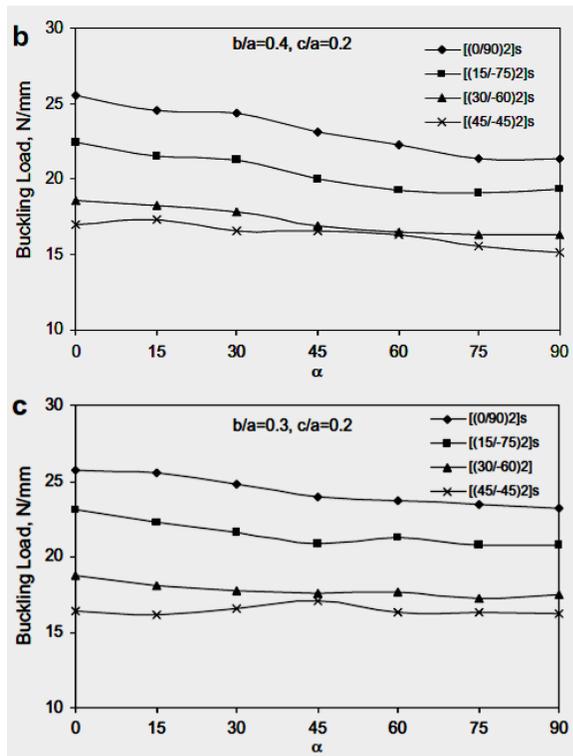
$$(K-\lambda_{CT}K^G)d=0 \tag{3}$$

where K, M, and K<sup>G</sup> are the elastic stiffness, mass, and geometric matrices, respectively, ω is the angular frequency, λ<sub>CT</sub> is the critical buckling load and d is the displacement vector. In this paper, the stiffness matrices K is formulated by the plate element CS-DSG3 and the geometric matrix KG is formulated by the CS-FEM respectively. The compatibility of deflection and rotations of stiffeners and plate is assumed at the contact P positions. The accuracy and reliability of the proposed method is verified by comparing its numerical solutions with those of analytical solutions, experimental results and others available numerical results [7].

M. AydinKomur, FarukSen, Akin Atas, NurettinArslan, (2010) have performed a buckling analysis of a woven-glass-polyester laminated composite plate with an circular/elliptical hole, numerically. In the analysis, finite element method (FEM) was applied to perform parametric studies on various plates based on the shape and position of the elliptical hole. This study addressed the effects of an elliptical/circular cutout on the buckling load of square composite plates. The laminated composite plates were arranged as symmetric cross-ply [(0/90)2]s and angle ply [(15/75)2]s, [(30/60)2]s, [(45/45)2]s. The results show that



buckling loads are decreased by increasing c/a and b/a ratios which shown in given figure 3.



**Fig. 3.** The effect of parameter on buckling load [8]

The increasing of hole positioned angle cause to decrease of buckling loads. Additionally, the cross-ply composite plate is stronger than all other analyzed angle-ply laminated plates [8].

Zbigniew Kołakowski, Radosław J. Mania (2013), have investigated and compared the semi-analytical method. (SAM) and the finite element method (FEM) applied to the local post-buckling analysis of thin-walled composite structures with closed cross-sections, in the second order approximation based on the linear analysis. A 'lowerbound' approach by Koiter and Pignataro-improved in, enables us to determine the overall flexural stiffness of an isotropic beam-column after its local buckling. The presented paper verifies the semi-analytical method and the FEM for thin-walled composite structures. The theoretical basis of the present approach is discussed and some typical examples are considered [9].

F. Halvorsen, T. Aukrust, (2006), simulated using Lagrangian FEM software and MSC SuperForm to study the basic mechanisms of buckling or waving of extruded flat sections. The flow conditions have been altered by only varying the feeder geometry. Extrusion experiments have been performed in order to verify both the simulations and the mechanisms observed in the FEM simulations [10].

J.J. del Coz Diaz, P.J. Garcia Nieto, J.A. Vilan Vilan, J.L. Suarez Sierra (2010) have described the development of a numerical model to accurately simulate the non linear buckling of self-weighted metallic roofs by the finite element method (FEM), which has different span lengths, ranging from 22 to 30 m, and the same cross section. In this way, the collapse buckling load was calculated in two steps: firstly a linear buckling was carried out and secondly, an initial imperfection was added to the geometrical model and the non-linear analysis was performed [11].

Dean Deng, Hidekazu Murakawa (2008) have studied a prediction method of welding distortion, which combines thermo-elastic-plastic finite element method (FEM) and large deformation elastic FEM based on inherent strain theory and interface element method, was developed. Then, the inherent deformations of two typical weld joints involved in a large thin plate panel structure were calculated using the thermo-elastic-plastic FEM and their characteristics were also examined. Thirdly, using the developed elastic FEM and the inherent deformations, the usefulness of the proposed elastic FEM was demonstrated through the prediction of welding distortion in the large thin plate panel structures. Finally, the influences of heat input, welding procedure, welding sequence, thickness of plate, and spacing between the stiffeners on buckling propensity were investigated. The numerical simulation method developed in this study not only can be used to predict welding distortion in manufacturing stage but also can be employed in design or planning stage[12].

J.J. del Coz Diaz , F.P. Alvarez Rabanal, P.J. Garcia Nieto, J. Rocés-Garcia, A. Alonso-Estebanez (2012), used finite element method (FEM) for a nonlinear structural analysis to study the structural collapse of a self-weighted metallic roof with and without skylights located in Cabanaquinta's schoolyard (Principality of Asturias, Northern Spain). The collapse of this cable-arch structure was due to huge snow loads in winters of 2004 and 2006. In order to tackle this structural problem, it is proposed a damage assessment based on the nonlinear post-buckling analysis of the entire self-weighted metallic roof by FEM. Firstly, in order to obtain a diagnosis of the failure causes, several FEM models with six tiles of a 0.83 m wide and 1.25 mm thickness, including methacrylate skylights in one of them, were built and then solved as a three steps procedure: a linear pre-stress analysis, a buckling analysis and a nonlinear analysis. Secondly, a procedure based on the design of experiments (DOEs) applying the FEM technique was used to determine the importance of different parameters on the structural integrity of the roof [13].

A.R. Vosoughia,n, P. Malekzadehb, Ma.R. Bananc, Mo.R.Bananhave (2012) analyzed the thermal buckling and post buckling of laminated composite beams with temperature dependent material properties. The governing equations are based on the first-order shear deformation beam theory (FSDT) and the geometrical nonlinearity is modeled using Green's strain tensor in conjunction with the von Karman assumptions. The differential quadrature method (DQM) as an accurate, simple and computationally efficient numerical tool is adopted to discredited the governing equations and the related boundary conditions. A direct iterative method is employed to obtain the critical temperature (bifurcation point) as well as the nonlinear equilibrium path (the post buckling behavior) of symmetrically laminated beams. The applicability, rapid rate of convergence and high accuracy of the method are established via different examples and by comparing the results with those of existing in literature. Then, the effects of temperature dependence of the material properties, boundary conditions, length-to-thickness ratios, number of layers and ply angle on the thermal buckling and post buckling characteristic of symmetrically laminated beams are investigated [14].

Changliang Li, Dazhi Jiang, JingchengZeng, Suli Xing, Su Juhave (2014) used a kind of conductive polymer-silver paste to fabricate composite frequency selective surfaces (FSSs) with four-legged slot elements. Screen printing and 3D engraving process were carried out to coat the conductive polymer-silver paste onto the fabric preform and sculpt composite panels into composite FSSs, respectively. The substrates of the composite FSS were carbon and quartz glass fabrics, respectively. The equivalent electrical conductivity of the composite material FSS was measured and the results showed that it increased significantly after the fabrics printed by the conductive silver paste. Free space method was adopted to test the electromagnetic transmission characteristics of the composite FSS. Experimental results showed that the conductive silver paste was effective to decrease the minimum transmission loss of the composite FSS and the minimum transmission loss of the quartz glass fabric composite FSS was lower than that of the carbon ones. A finite element model was put forward to calculate the electromagnetic transmission characteristics of the composite FSS. The calculated results were in agreement with the experimental data. Effects of the equivalent electrical conductivity and the thickness of the composite substrate on the minimum transmission loss of the carbon fabric composite FSS were investigated [15].

The characteristics of composite material is using by manual experiment and FEM simulation. Jianping Long, Xin Li, Dedi Fang, PengPeng, Qiang (2013) have fabricated Al-matrix composites reinforced by 50 vol.% diamond particles under a 60 MPa sintering pressure by a vacuum hot-pressing method. The composite obtained a relative density of 96.5%. The coefficient of thermal expansion (CTE) and the thermal conductivity (TC) of the diamond/Al composites were measured by the laser flash method and differential dilatometry, respectively. Results showed that diamond/Al composites have high TC and low CTE with high sintering pressure (60 MPa) and high volume fractions of diamond particles (50 vol.%). The TC of the 50 vol.% diamond/Al composite was 321 W/mK, which is 112 W/mK higher than that of pure Al (209 W/mK). At temperatures ranging from 298 K to 573 K, the composite obtained low CTEs in the range of  $13.2 \times 10^{-6}/K$  to  $8.3 \times 10^{-6}/K$ , which satisfied the CTE of electronic packaging materials. The CTE values obtained in the experiment were approximately equal to the CTE calculated by the Kerner model. The effects of volume fractions of diamond particles and sintering pressure on the density, TC, and CTE of diamond/Al composites were investigated [16].

S. Laurenzi A. Grilli , M. Pinna , F. De Nicola , G. Cattaneoc, M. Marchettihave (2014) presented the numerical process analysis and the experimental investigation for the manufacturing of a reinforced carbon-fiber demonstrator of a large aeronautic beam by resin transfer molding (RTM). The component is a primary structure characterized by several thick sections with abrupt changes in shape that complicates the resin impregnation of the perform. Process simulations based on a finite element method-modified control volume (FEM-CV) were conducted to investigate the resin flow front patterns and find the injection scheme that guarantees both a good impregnation of the perform and a filling time compatible with the resin gel time. The beam component was successfully manufactured, and a good agreement between the numerical analysis and the fabrication process was demonstrated [17].

AchchheLal , H. Neerajan Singh, N.L. Shegokarhave (2012) studied the second order statistics of post buckling analysis of functionally graded materials (FGMs) plates subjected to mechanical and thermal loadings without and with square and circular holes at center having random material properties. Material properties of each constituent's materials, volume fraction index, thermal expansion coefficients and thermal conductivities are modeled as independent random input variables. The basic formulation is based on

higher order shear deformation theory (HSDT) using modified C0 continuity. A nonlinear finite element method (FEM) based on direct iterative technique combined with mean centered first order perturbation technique (FOPT) developed by the author for composite plate is extended for FGM plates to solve the random nonlinear eigenvalue problem. Typical numerical results are presented to examine the effect of volume fractions index, plate length to thickness ratios, plate aspect ratios, types of loadings, amplitude ratios, support conditions and various shaped and sized holes with random thermo mechanical properties. The results obtained by the present solution approach are validated with those available in the literatures and independent Monte Carlo Simulation (MCS). It is observed that the plates with circular and square hole have a significant influence on the post buckling response under mechanical and thermal loading conditions and some new results are presented to demonstrate the applications of present work [18].

J. Martíneza,, J.L. Dieguez, E. Aresb, A. Pereirab, P. Hernandezb, J.A. Perezbhave (2013) observed that Laminated parts made of FDM (Fused Deposition Modeling) are becoming increasingly popular in last year. This increment can be explained due to their potential in field of manufacturing in order to allow us to make any kind of geometry, but in another way, these parts have not enough values of stiffness and strength to get an approach to a final constructive part. However, advantages of nowadays FEM programs allow us to analyze behavior and main manufacturing properties; in order get previously mentioned structural parts. Then it we must need to accurately predict the response of composite structures to different load cases. In this way, the adequate modeling tools must be developed. The motivation of this article is to contribute to this development, making numerical simulations of two different composite structures with a ply-level approach, and analyze obtained results [19].

### 3. Methodology

The various methodology have been used in manufacturing and simulation of composite material F. Fiori, E. Girardin, A. Giuliani, T. Lorentzen, A. Pyzalla, F. Rustichelli, V. Stanic (2000) have used fabrication of composite material AA359 to obtain tensile and fatigue strength on both matrix and reinforcement through the thermal microstresses which is existing due to heat treatment prior to mechanical tests [1]. Zbigniew Kołakowski, Radosław J. Mania (2013) used semi-analytical method (SAM) for local post-buckling analysis of

thin-walled composite structures with closed cross-sections, in the second order approximation based on the linear analysis [9].

Dean Deng , Hidekazu Murakawa (2010) have used Thermo-elastic-plastic finite element method (FEM) and large deformation elastic FEM for the inherent deformations of two typical weld joints involved in a large thin plate panel structure. First order shear deformation beam theory (FSDT) and the geometrical nonlinearity is modeled using Green's strain tensor in conjunction with the von Karman assumptions [8].

Fused Deposition Modeling is used by A.R. Vosoughi, P. Malekzadeh, Ma.R. Banan, Mo.R. Banan (2012) used Differential quadrature method (DQM) to discretize the governing equations and the related boundary conditions. A direct iterative method is employed to obtain the critical temperature (bifurcation point) as well as the nonlinear equilibrium path (the postbuckling behavior) of symmetrically laminated beams. The field synergy principle (FSP) and the entransy dissipation extremum principle (EDEP) are used to analyze the flow and heat transfer performance of the composite porous material [14].

### 4. Conclusions

In this research work, aluminum composite material AA359 are fabricated and characterized to study their physical, mechanical and thermal properties using FEM. The experimental results are used for the validation of results obtained by simulation using FEM software. The following silent observations are made:

1. The representative area element (RAE) found to be effective in modeling the said composites and FEM software tool observed to be useful in calculations and simulations purpose.
2. The ideal density remains higher than actual density and both shows increasing magnitude with amount of fiber content. However, void fraction decreases with increase in fiber content.
3. The simulated FEM results show complex nature of stress distribution in the composite, fiber and matrix. The concentration of stress in matrix/fiber and around the fiber (i.e. fiber-matrix adhesion region) plays significant role in damage assessment of the investigated composites.
4. The simulated impact FEM test results are validated against experimental results with an acceptable error of  $\pm 5\%$ . The impact strength observed to be increases with increase in fiber content.

5. It is concluded that the order of composites with effective thermal conductivity is 45 wt.% glass fiber based composite >35 wt.% glass fiber based composite >25wt.% glass fiber based composite >15 wt.% glass fiber based composite.
6. The elastic modulus is evaluated using various models like FE analysis, rule of mixture, Halpin–Tsai and experimental method. The results shows increase in the elastic modulus with increase in fiber content in the composites. The Halpin–Tsai results and FE analysis results are more close to experimental results than the results of rule of mixture. The tensile strength of the fiber reinforced epoxy composites as evaluated experimentally and by FEM shows close resemblance and within the acceptable error range. Similarly, the% elongation observed to improves with fiber content.
7. The flexural strength as evaluated by FEM simulation observed to be higher than the experimental value, however both resembles closely. The flexural strength observed an improvement of 27% as the fiber content increases from 15 wt. % to 25 wt. % thereafter it decreases. The ILSS of the specimen composites observed to have regular improvement with fiber content.

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