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Experimental and modeling stress concentration factor (SCF) of a tension poly lactic acid (PLA) plate with two circular holes

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ABSTRACT

The design of high performance aircraft structures frequently includes various shape and size discontinuities for various purposes. The zones near to these notches become critical regions under various working loading. The stress concentration factor (SCF) and tensile strength degradation of poly lactic acid (PLA) plates are addressed in the current study through a combination of experimental and numerical studies using finite element (FE) modeling techniques. The present work performs stress concentration factor (SCF) of rectangular plates with two symmetrical circular holes under uniaxial tension load of two various types (PLA, PLA/15%carbon), which were determined in the current work experimentally and numerically using finite element method with help of Ansys software. The results of experimental test showed decay in tensile modulus and tensile strength is less than that of using plates without holes by (10%, 22.1%) for (PLA, PLA/15%carbon) respectively, and the apparent stress concentration factor is (3.33, 3.61) respectively. And showed decay in tensile strength is less than that of using plates without holes by (28.35%, 27.77%) for (PLA, PLA/15%carbon) respectively, due to the concentration of stresses around the holes. A finite element analysis is carried out and the outcomes have been estimated with experimental results for checking the efficient use of this article. The numerical results show the Von Mises stress distribution and stress concentration factor is (2.16, 2.35) for (PLA, PLA/15%carbon) respectively.

Keywords: PLA, PLA/15% Carbon Particles, Mechanical properties, Finite element, Stress concentration.

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1.1. Introduction

In recent times, environmental waste has become a large concern due to the elevated effect of plastic pollution in everyday use. One of the likely solutions to this trouble is to replace the material artificial polymers with the biodegradable polymers. PLA polymers aim to replace material synthetic polymers, the cost of PLA and high brittleness is the main reasons for many applications and their commercialization such as packaging. Thus, to improve the lower the production cost and various properties, different researches on PLA blends as composite materials [1].

Composites materials are they made up of two or more materials with different chemical and physical properties but the single components remain distinct and separate in final product. [PLA] is famous for its renewability and biodegradability when compared with other composite resins due to this PLA is gaining more attention from the researchers. Moreover the poly lactic acid is obtained from the natural resources which will reduce carbon foot print. Along with this PLA is also eco-friendly and is compatible with other resins, fibers and additives. Among the entire feature nowadays researcher's attention is more on the biodegradable properties due to hard regulations and environmental rules. However, always the non-biodegradable composites have more stability and strength, researchers adding various additives, blending resins and fibers which are biodegradable to get the stability and strength on par with non-biodegradable composites. It can be reused and recycled [2].

PLA is distinguished by being environmentally friendly and biodegradable, as PLA can be degraded into water, carbon dioxide, and humus without contaminate the surroundings. Moreover, PLA has stiffness and ease of industrialization, which qualify it as important elect for manufacturing material. Furthermore, the defect of PLA in terms of poor flexibility, brittleness, low temperature resistance, low endurance, and can be improved by the doctrinaire of its properties and structure. There are numerous published researches on the composites that are made with other materials in order to have new mechanical properties. These materials include carbon material, fibers, and mineral powder, and the composites are so rendered with different properties as a product of combination these different reinforcements. Among these strengthening, carbon particles are a significant applied to obtain particular properties for new engineering material [3].

Vents are used for practical purposes and to minimize the weight of structures for spacecraft or aircraft as in Figure 1.The presence of these openings plays an important role in the design of mechanical structures and the deterioration of their behavior, which leads to the redistribution of stresses in the plate, which leads to a significant reduction in the stability of the structure, which has been noticed by many researchers in the past years.The openings in the engineering designs are one of the complex problems facing the designer because of the local stress concentration areas near these openings resulting from the presence of these openings.

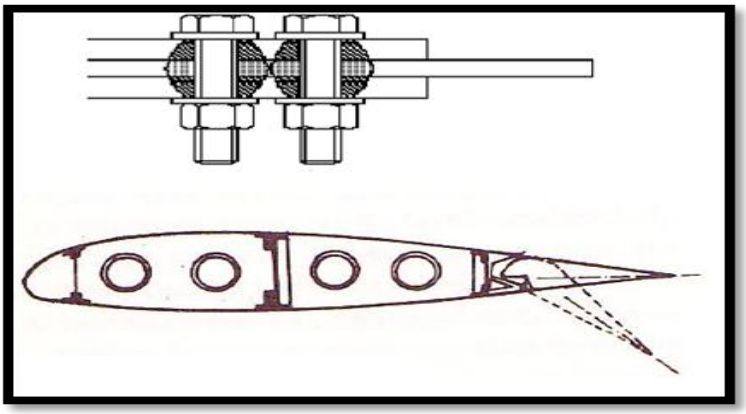


Figure1. Structures for Aircraft

It is well known that the opening or aperture in the structure leading to the composition of the interruption due to sudden change in geometry. Disruption of any structure under the influence of pregnancy results in a localized effect in the form of stress concentration. Stress concentration increases the stress that increases the amount of stress on the surface of the breakout and proximity. These high-tension locations act as convenient locations to initiate damage, which eventually leads to structural failure. Therefore, knowing the effect of discontinuity assumes high practical importance to ensure the safe operation of the intermittent structure when pressed in service [4].

Aircraft are always subject to different structural loads. Yet, when these bodies are underwent to various loading conditions, the concentration of undesirable elevated stress, which affects their performance, is created around these cracks. Through the past little decades, the concentration of emphasis on stress about the slots has always been a large concern and efforts have been made to research the effect of cracks on composite strength. The influence of these cracks on the universal manner of structures is an important issue because of causing a considerable reduction in the age and strength of service of structures. There are different ways to evaluate the stress concentration in laminate panels due to engineering abnormalities. Stress distribution around slots can be assessed using computational methods, experimental and elasticity theory stress analysis. Considerable efforts have been formed in the development of precise analytical samples to define the distribution of stress in the segments of the compound [5].

There are several ways to study stress concentration and each of these methods has different benefits and outcomes. Beside the specific elements method, there are some analytical and practical methods that can get some results for stress jacks. Analytical methods can predict stress-concentration coefficients but cannot illustrate the area of stress. The impropriety of finite element method is related to its requires for a lot of time to arithmetic operations in order to dealing with the accuracy and sensitivity of precise networking, in addition to work around stress concentration areas to obtain realistic results around critical areas. However, practical methods remain the most reliable methods for measuring the actual behavior of structures with openings, but it is difficult (often impossibility) to obtain stress concentration by old means (e.g. strain gauge) if there is a significant gradient in stress values. There are modern non-destructive methods such as the Digital Image Correlation (DIC Method) [6].

Moreover, with the coming of finite element technique that is also based on elasticity formulations but is much faster, reasonably exact and commercially more applicable, study on classical elasticity procedures has to some extent lost the activity [7].

1.2. Objective of the Research

The calculation of the stress concentration coefficient and the distribution of the stress area of the perforated plates is an important factor in calculating the stability of structures. The knowledge of the concentration coefficient of stress is one of the basic tasks of the designers to provide the materials used in the components of manufacturing equipment with holes to use a high safety factor and this leads to an increase in the materials used. Where the study was conducted in practice using a tensile test and obtains the results. Numerical analysis was also carried out using the specific element method technique using the ANSIIS program .The advantages of this method are to reduce the cost, try and error in the use of materials in engineering applications, and to reduce the need for practical methods, which need more time and effort to obtain the results processed by the research.

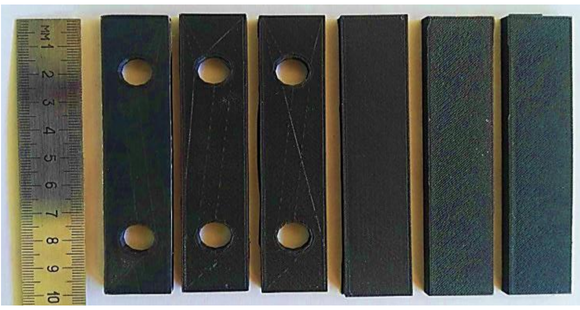
2. Methodology

This research is carrying out by two methods. First method is experiment work and the second method is finite element (FE) by Ansys. The present research is a combination of experimental with analytical and numerical studies by using finite element (FE) modeling method. At the first portion of the present work, a set of tensile experiments on laminates with different fiber direction angles and specimens with various notch diameter/width (D/W) ratios are made and tested to define the SCF and damage mechanisms for notched/ un notched samples. Moreover, failure patterns, strain distribution and fracture mechanisms of laminated specimens with rectangular and square holes with rounded corners have been researched [5]. The current research attempts to form composite plates using a blending of natural polymers and fibers to progress certain properties. The concentrate is to evolve a biodegradable composite of similar properties with those obtainable commercially. The formative plates are tested to measure different mechanical properties such as hardness, impact resistance, tensile strength, etc. A finite element analysis is carried out and the outcomes have been estimated with Graphite epoxy composite results for checking the efficient use of this article. The verification with Riyah and Ahmed who studied stresses of blending plates with various types of cutouts. Furthermore, Isotropic rectangular plate with various loads and support conditions, static analysis are verified with Vanam et al research result. Many recent researches study the effect of cutout on SCF by using finite element analysis (FEA) [8].

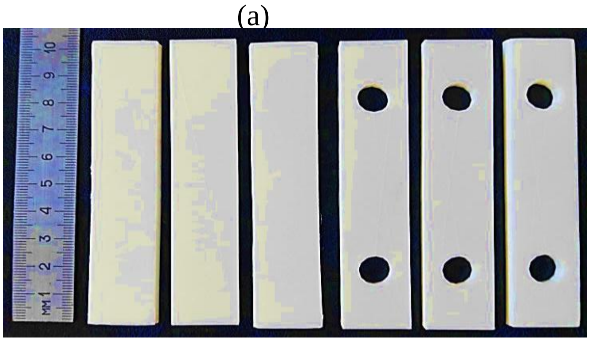
In this research, study the mechanical behavior of a PLA-based package is offered. The stress concentration, may lead to a defeat in the package. The results of this study also confirm the significance of considering the decay of mechanical properties in the design using the PLA-based material [9].

2.1 Experimental Work

Two types of materials were used, pure PLA and PLA+15% Carbon. Printed the samples from these materials by 3D printer, there are many settings that can be set before printing the samples such as, layer height, printing speed and orientation. Print density as the density of internal infill 100% selected to get on the solid part and other parameters as layer height 0.2 mm, angle of print 45^{o} and 40% is printing speed. These parameters selected to obtain on the better results. Figure 2 (a,b) show the samples at printing.



(a)



(b)

Figure 2. Tensile specimen for (a) PLA/Carbon, (b) pure PLA

2.2 Tensile Test procedures

An Instron 4468 (US) measures the tensile strength, Young's modulus, and elongation of the specimens. There are 3 samples for each test, and specimens have a size of 100 mm×20 mm×5 mm. The shape of a typical tensile specimen and its dimensions are illustrated in Figure 3.The grip distance is 100 mm and the tensile machine speed is 5 mm/min. The average of various outcome data is then used to determine the tensile strength, Young's modulus, and elongation of specimens [3].

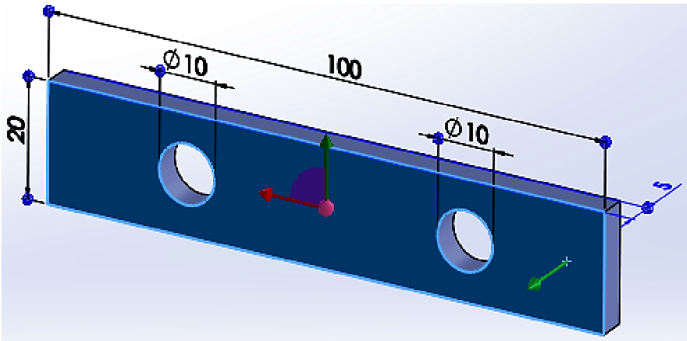


Figure 3. Typicaltensile specimen

Tensile test is a measure of the ability of a material to resist forces that tend to pull it apart and to define to what range the material extends before breaking. This test involves elongation of a rectangular shaped sample properly aligned and firmly gripped between two mechanical jaws that pull the sample at a constant deformation rate with gradual increase of extension load that is measured simultaneously as a function of time until sample failure. The stress-strain curve obtained from the uniaxial tensile testing machine is plotted as in Figure 4-5. The properties namely, Young’s modulus (E), tensile strength (Ts) and percent elongation at break (e%), were calculated using standard procedures and formulae.

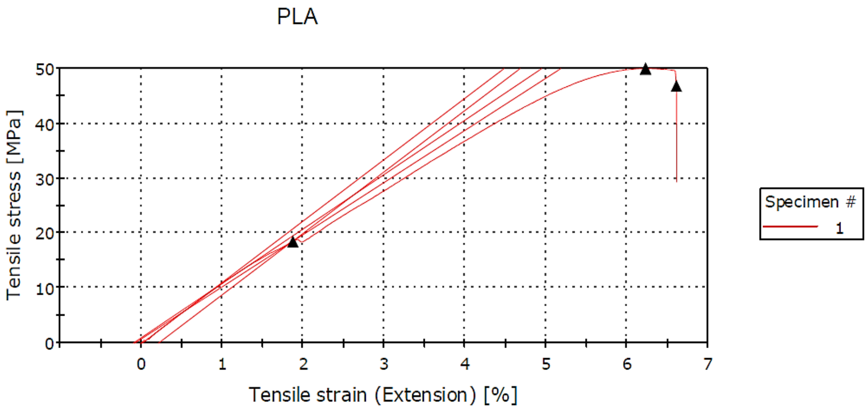


Figure 4. Plotted stress-strain curve obtained from the uniaxial tensile testing machine for (PLA).

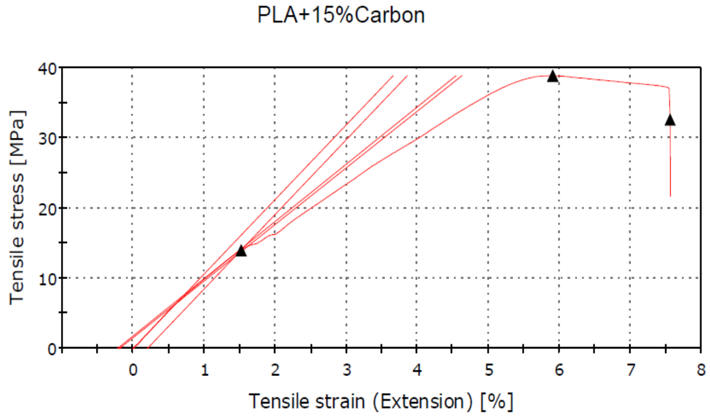


Figure 5. Plotted stress-strain curve obtained from the uniaxial tensile testing machine for (PLA+15%Carbon)

2.3 Hardness test

Hardness is a feature of a material to resist plastic distortion. Through one of the most popular techniques of hardness testing, the Brinell test applies F (a load) to Diameter D (a carbide ball diameter) which is caught for a time period and thereafter separated. The producing impression is determined by two diameters perpendicular to each other and these outcomes mean (d). Thereafter a chart is pointed to convert the mean diameter measure to BHN (Brinell hardness number) [10]. The indentation and hardness is determined as:

$$BHN = \frac{2F}{\pi D(D - \sqrt{D^2 - d^2}} \tag{1}$$

All the results were taken 10 s after the indenter made fixed contact with the sample

2.4 Finite element (FE)

The finite element (FE) is a numerical method of finding solutions to complex engineering problems, which are usually represented in the form of differential and integral equations. The basic principle of FEA is to divide the continuum problem of real structure into discrete problem having smaller elements in order to reduce the numerical complexity and error. The small elements are interconnected at points common to two or more elements (nodal points or nodes) and each of them are singly solved by a relatively simple mathematical equation [9].

Numerical analysis was performed in a finite element manner with the help of Ansys. All the conditions used in the practical aspect that were applied to the test samples were taken into consideration and applied in the program. To model the tensile test, Element type was analyzed by the element 2-D plane 42, (12 degree of freedom), (6 nodes) and triangular linear elastic element as in Figure 6.

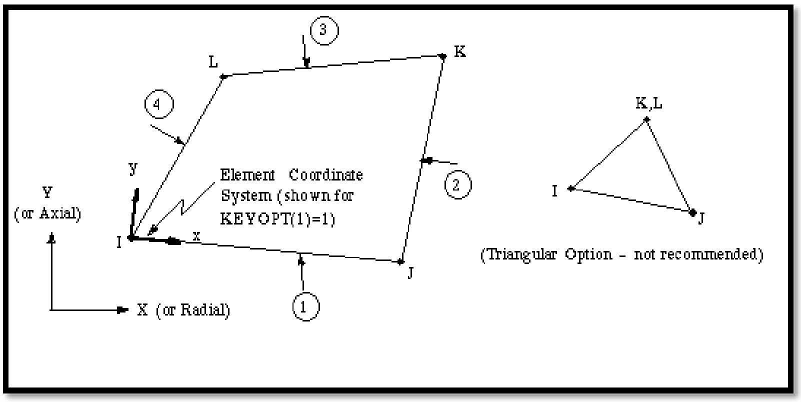


Figure 6. Triangular linear elastic element

Figure 7. shows the meshing process used in the modeling process of tensile testing. Focus on the areas that are near the holes by increasing the number of nodes and for accuracy in the solution. The number of nodes (sedon) and number of elements (entsmele) in the sample were (3674,3380), respectively.

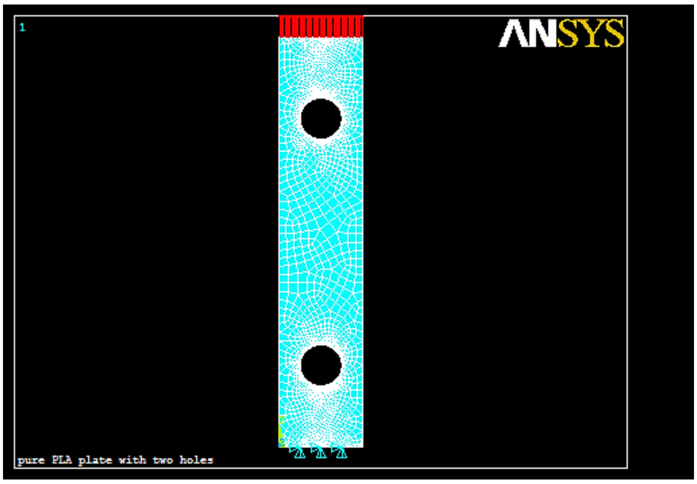


Figure 7. Meshing process used in the modeling process of tensile testing.

3. Results and Discussion

Poly Lactic Acid (PLA) is known for tensile strength and high rigidity. The calculation of the concentration coefficient and the stress field distribution of the perforated plates is an important factor in calculating the stability of the structures. In order to reduce stress concentration factors to the smallest and to make the piece work safely and safely in the life of its service. Rectangular plates (PLA, PLA with 15%carbon) were used in the search. They contained two symmetrical holes under a single axle load and were firmly anchored by two sides exposed to the tensile load. The other two sides of the plate were not fixed for any movement. Found the values of the mechanical properties of the plates used in the research.

Figure 3. Show the stress–strain diagrams of the (PLA, PLA with 15%carbon). Three samples were tested for each case, and the average values were used to produce this stress–strain curve. (PLA, PLA with 15%carbon) displayed the kind of brittle fracture, with no signal of necking phenomenon.

In this Figure indicates the tensile strength of Mechanical Properties of plate with and without holes(pla, pla with 15%carbon) possess a tensile strength that reduces from (49.86 to 35.72, 38.81 to 28.04MPa), respectively. The results were performed and the tensile test of the samples was conducted as in Table 1.

Table 1. The mechanical properties for the implemented sheet

	Without hole		With hole	
	PLA	PLA+15% Carbon	PLA	PLA+15% Carbon
T_S(MPa)	49.86	38.81	35. 72	28.04
e%	0.06	0.06	0.05	0.05
E (GPa)	1.09	0.98		
Poisson's ratio	0.36	0.36		

Further, strength, elongation and Young's modulus were gained from the stress–strain diagrams, and offered in Figure 8-9 As present in table 2, pure PLA polymer displays the highest Young's modulus (around 1.09GPa), and the Young's modulus of PLA with 15%carbon mixtures were decreased to 0.98GPa, respectively. Furthermore reduction in modulus was obtained, due to immiscibility between PLA and carbon.

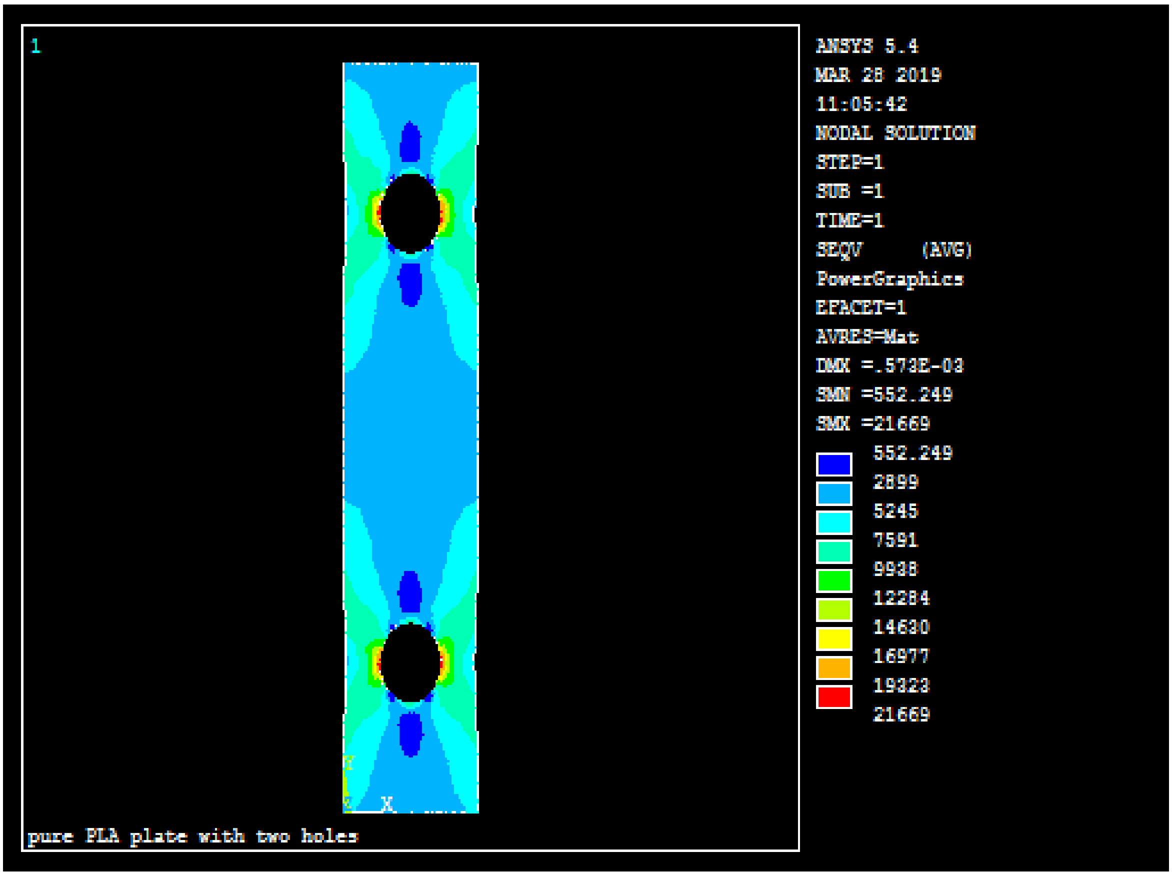


Figure 8. Von MISes Stress distribution for pure PLA plate with two holes

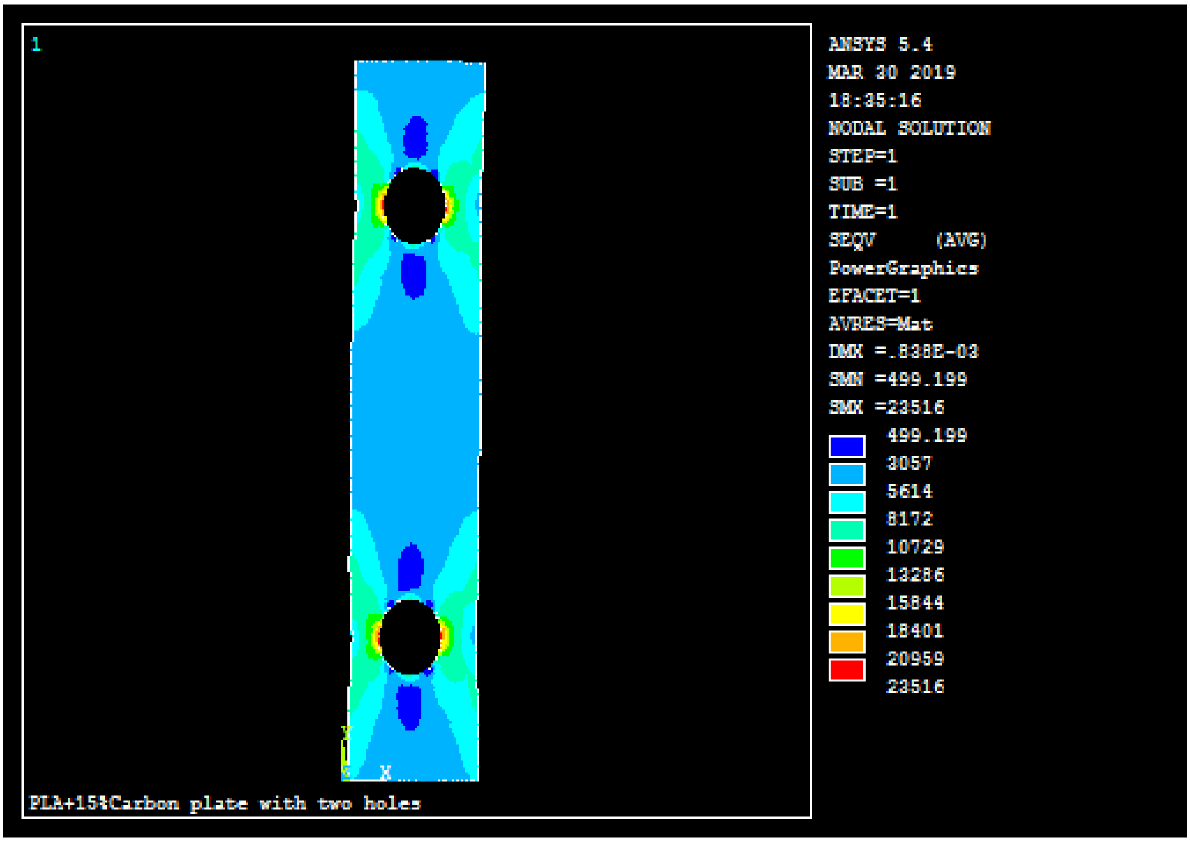


Figure 9. Von Mises Stress distribution for PLA+15%Carbon plate with two holes

The elongation of pure PLA and PLA with 15%carbonis really limited (6 %), as shown in Figure 3. All results show that the brittleness of pure PLA cannot be improved by mixing with 15%carbon. The apparent stress concentration coefficient for all plates is calculated from the maximum tensile stress ratio (TS_o) to the maximum stress of the TSH plate as in equation [2].

$$K_a = \frac{TS_O}{TS_H} \quad (2)$$

Using equation (2), the apparent stress concentration of the plate (PLA, PLA with 15%carbon) was 3.33 and 3.61, respectively, as in Table 2.

Table- 2. Show result of K_a and K_t

	PLA	PLA+15%carbon
K_a	3.33	3.61
K_t	2.16	2.35

The analysis was conducted in M.E.F method for each sample using tensile strength load in practical conditions, And according to the following equation:

$$Kt = \sigma_{max} / \sigma_{nom} \quad (3)$$

Whereas

σ_{max}: maximum nodal Von mises stress

σ_{nom}: average Von mises stress

Based on the results of the analysis and the use of equation (3), the theoretical stress concentration of the plate (PLA, PLA with 15% carbon) was 2.16 and 2.35 respectively, As in Table (II) which is consistent with the source (12, 13) about that the coefficient of stress concentration is a function depending on the material and geometry of the part. If the material is brittle or ductile with the type of loading mode (type) at the load is static or dynamic.

Moreover, PLA has a low affinity to Carbon. This result restrain the load from being easily convey between the particles and matrices, and then decrease the mechanical features of PLA/Carbon composites .through the tensile tests, composites PLA appear a brittle fail at their yield point after the load is applied.

The hardness of samples for (pla with 15%carbon) plate was measured using Brinell hardness testing machine. The Brinell hardness test, five points were taken for each specimen and the mean value is determined which reaches up to be 265,300 BHN (Brinell Hardness Number) respectively.

Figure 7- 8. Showed the results of the numerical analysis of Von Mises denoted that as well as the stress field and distribution, which in turn helps to easily infer the location of fracture onset and agreement with research. The maximum values were the nearest holes. This gives an acceptable consensus with the practical results showing that the cracks are moving from the position of the maximum value of the stresses at the edge of the hole and outward towards the surface of the plate. In Figure 7-8. Von Mises denotes that **SCF** for (PLA with 15%carbon) plate is larger than that of PLA

4. Conclusion

For all samples, the mechanical properties were still poor**.** PLA is known for high tensile strength and rigidity. Specimens for blends and neat PLA broke before necking and stress increased with the strain above the yield stress. However, for all the blends and neat PLA no yield phenomenon existed and samples broke rapidly after yielding (brittle fracture). Tensile strength decreased with blending of PLA and 15%Carbon. The main drawback procedure is implying of air porosity which drastically decreases the mechanical properties of the composite and then leaves minor porosity, and thereby setup the distortion mechanism. Stress near hole is found to exceed the far field stress in each of the load cases due to the presence of discontinuity. Maximum stress in all the cases is normal and tangential in nature and is found to develop at the surface of the hole that gradually recedes and approaches far field stress state at locations far away from the hole. The nature and the magnitude of stress around the hole is influenced by the type of far field load and therefore differs in each load case. Maximum tangential stress is tensile and three times the applied stress**.** Table (2) shows that the values of tensile strength (σ_t) for perforated plates are lower than those for plates without holes (28.35% and 27.77%) for (PLA, PLA with 15%carbon)respectively, due to the concentration of stresses around the holes.

- Hardness is increased than13.2%.
- The apparent stress concentration coefficient PLA, PLA and 15% Carbon was 3.33 and 3.61 respectively. The results of the stress concentration coefficient for numerical analysis were 2.16 and 2.35respectively.

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