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An Experimental Study of Circular Cutout Hole Effect of Kevlar/epoxy-Al_2O_3 Composite under Subjected to Quasi-Static Compressive and Tensile Loading

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ABSTRACT

This paper has presented an experimental study of quasi-static compressive and tensile loading of cutout hole specimens of Kevlar-29/epoxy-Al_2O_3 laminated composite. The experimental procedure has been developed to study the performance of (50%, 55% and 60%) volume fraction (v_f) and (0º/90º and +45º/-45º) fiber orientation angle effects of these composites under quasi-static tensile and compressive load using a servo-hydraulic testing machine. The study was concluded that the ultimate load capacity increases as volume fraction increases in tensile test. While, the maximum load bearing capacity increases with the decrease of volume fraction in compression test. Hence, from the results obtained it can have considered the 55% volume fraction of composite panels is a good value for tensile and compression applications.

Keywords: Experimental study, cutout, composite materials and Tensile and compressive load.

دراسة عملية لتاثير الفجوات دائرية الشكل على متراكب كفلر/ايبوكسي-الومنا تحت تاثيراحمال السحب والضغط الاستاتيكي

الخلاصة

تم في هذا البحث دراسة عملية لاحمال الشد والضغط الاستاتيكي للمواد المركبة متعددة الطبقات المصنوعة من مادة كفلر/ايبوكسي–الومينا ذات الثقب الدائري ومركزي الموقع. وقد تم في هذا البحث كذلك دراسة تأثير النسب الحجمية لخلط تلك المواد (50%, 55%,60%) و بزوايا تدوير لالياف الكفلر (90/0 , -45/+45) تحت تاثير احمال الشد و الضغط الاستاتيكي باستخدام جهاز ماكنة هيدروليكية الاداء. لقد تم الحصول على القيم العليا للحمل المسلط على العينات حيث ازدادت تلك القيم مع ازدياد النسب الحجمية في حالة شروط اجهادات الشد او السحب بينما بينت النتائج ازدياد في السعة التحملية للعينات مع نقصان النسب الحجمية في حالة الانضغاط. لهذا يمكن اعتبار ان نسب الخلط عند القيمة (55%) للمواد المركبة المصنوعة من تلك المواد هي مناسبة للتطبيقات و التصاميم التي تتعرض لكلا الحالتين (الشد والانضغاط) لتلك المواد تحت نفس الشروط والظروف التي تم التطرق اليها في هذا البحث.

الكلمات الدالة: الدراسة العملية, الفجوات, المواد المركبة, احمل الشد والانضغاط

Introduction

The composite materials have a significant role in many fields, especially the industrial and applied fields. So many researchers tried to study the properties of these materials and study them with interest to understand the mechanical, physical and chemical behavior of those materials. Today's composite materials have shortened the time and effort in addition to their extensive applications in many fields of industry and engineering (civil engineering, aerospace engineering, industrial engineering, mechanical and other applications). The development in the manufacture and design of these materials have a dramatic effect in increasing the productivity of those materials by increasing the knowledge of the composite materials and changing some substances to obtain new and effective products

and fabrics at the same time according to the requirements of work and market.
The process of composing a composite material needs two or more materials through the interaction with some elements. The formation of new material has the desired properties. After doing the necessary engineering tests, we should know the properties of the new composite material to determine the useful uses of these materials in many areas. Mechanical and engineering tests are done to find out the carrying of such materials for external loads such as pressure, heat, bending, shock, tensile stresses, buckling and other tests [1].
These tests and others have given many different impressions to understand the properties of those materials, their behavior and the possibility of using them in various industrial applications in many fields. This study has been conducted by many researchers who have been interested in studying the composite materials to obtain the ideal and effective design in the fields of work such as plates. They are subjected to compression and bending, which may have a rectangular cross-section that is fixed with a straight [2-3].
The simulation results provided for the ideal design plates such as glass / epoxy, boron / epoxy and carbon-epoxy composite materials. Some studies have tackled thin-walled plates that have high resistance and durability with ease of manufacture as well as light weight. It is therefore important to study the engineering design in precise and effective scientific ways to determine the bearing of these materials in the examination of spore [4]. It was important to know the multi-layered composite materials to increase their uses in the fields of space engineering and other industrial applications for their large and wide capacity in resistance, hardness, light weight, useful mechanical properties, ease of maintenance and to carry them to various loads.
The stresses concentration around the cut out holes, especially the corners holes, have many problems in the applications and designs that need such a kind of metal parts [5]. This problem, the behavior of these materials and the effect of bending load up to the state of buckling were studied by researchers in the early 1970's [6-7].
There is a general and comprehensive review by some researchers in this field [8].
According to Freitas and Reis [9], the impact is carried on composite materials until failure occurs, leading to the cracking of layers made of composite materials with brittleness properties and their weakness to withstand shocks and bending. The failure of bonding between layers in designs made of composite materials with overlapping layers is done sometimes by separating the layers between them or if they are made of fibers that may be damaged and failed even though they do not appear on the surfaces of the sample or product under the impact point. The failure to bond between the samples and cracks resulting from the impact of these loads should be studied and there must be factual attempts to reduce its impact on these materials by manufacturing and designing different materials to protect the manufactured product. The study of laminated plates with cavities and cut out results in high-level loads load with different factors. Variables were also studied as examples of Al Qablan et al. [10] who studied relative variables such as cut out size, angle of fiber rotation, cut out position, concentration, and type of load applied.
Three types of loads were taken into consideration, namely, carrying axial pressure and biaxial pressure load as well as shearing load.
Reducing the buckling load of the output results from increasing the size of the cut out holes and as a result, the columns and plates are less tolerable for bending loads.
The best performance can be carried out whenever close to the edges of the plates, while the cut out of relatively large sizes has less performance as the size of gaps at the middle of the plates. The results were also shown to some researchers through the study of many variables.

Baba and Baltaci [11-12] have shown in their studies the effect of fixation conditions on the bearing of bending and dipping of overlapping plates with the presence of circular, elliptic and semi-circular gaps under the effect of axial pressure loads. They produced results for the loading of the plates of the plates installed by all sides by 75% which were greater than the loading load resulting from the simple fixation and 50% for the cases fixed under the boundary conditions. The increase in the length / thickness ratio by 50% increases the excretion load to rates that are 75%. The effect of the fiber rotation angle has been studied by Al Qablan et al. [10] and Vandenbrik and Kamat [13]. They also carried the spike of the composite material with the large gaps for a higher increase according to the rigid plates from the corners with a 60 ° rotation. Stress and load-displacement analysis of composite laminated plates with fiber reinforced with a circular cut out hole under compressive loading is presented by [14].

This paper focuses on the analysis of stress-strain and displacement for compressive and tensile load capacity on the circular cut-out holes of kevlar-29/epoxy-Al_2O_3 composite laminated plates. The influence of adding alumina powder (Al_2O_3) on epoxy resin, volume fraction and fiber orientation on this composite panel have been studied in this work. Three different volume fractions (50%, 55% and 60%) and fibers orientation ($0^o/90^o$ and $+45^o/-45^o$) have been analyzed in more detail and their results have been compared.

Methodology

Experimental Work (Materials Selection and Specimen Fabrication)

Materials selection has been done after several surveys of the previous studies and thesis's recommendations that studded [9-16] the composite plate panels that are made from a reinforcement and resin. Woven roving Kevlar-29 fiber with 82% epoxy resin (EP-A215C1) mixed with 15% Alumina powder (Al_2O_3) and 3% hardener resin (EP-B215) have been selected to fabricate the composite specimens. Hand lay-up method into glass mold as been used in this work to fabricate all the specimens as shown in Fig.1. Woven roving Kevlar-29 fiber is winded manually using an open mold, and epoxy-Al_2O_3.

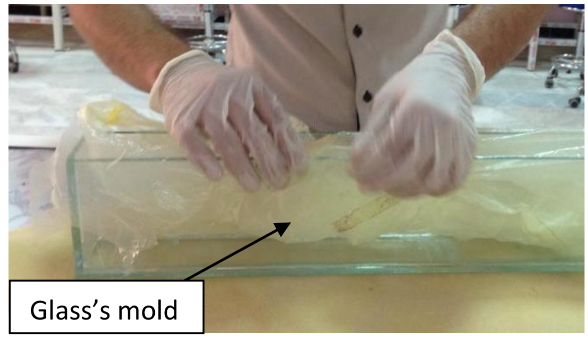

Fig. 1. Glass's mold of hand Lay-Up Process

Two types of Kevlar-29 fiber of angle orientations (0^o,90^o) and ($+45^o$,-45^o) with 50%, 55% and 60% volume fraction(V_f)of Kevlar-29 of panels/epoxy-Al2O3 composite of multi layers with (38mm) cutout circular hole diameter centrally located have been choice to fabricate the composite multi layers of composite plates in this paper presented. The specimens have the same dimensions with specimens' length of 320 mm as presented specimens' specifications in table 1. The active length has been 210 mm (unclamped) will carry the tensile or the compression load (as shown in Fig. 2.) until failure occurs in the compression load by bulking, so (12) specimens are needed. While failure occurred on around of the holes by stress concentration occurred tensile test (apply free force) would lead to failure and delimitations in the specimen on the center.

Table1 shows specimen specifications Kevlar-29/epoxy-Al_2O_3 composite plate panels with cut holes

No.	Fiber orientation	Volume Fraction	Average Specimen Dimensions (mm)			No. of Kevlar-29 layers
			Length (L)	Width (W)	Thick (t)	
1	0^o, 90^o	50%	320	60	4	8
2	$+45^o$, -45^o	50%	320	60	4	8
3	0^o, 90^o	55%	320	60	4	9
4	$+45^o$, -45^o	55%	320	60	4	9
5	0^o, 90^o	60%	320	60	4	10
6	$+45^o$, -45^o	60%	320	60	4	10

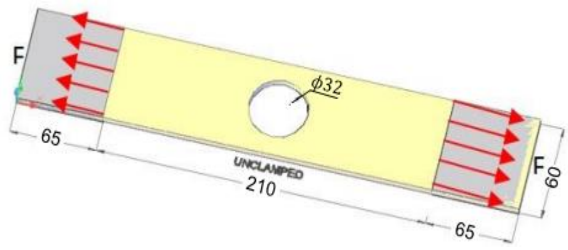

Fig. 2. Specimen dimensions in (mm) with cut holes of Kevlar-29/epoxy- Al_2O_3composite plate

Multi layers plates have been loaded by uniform uni-axial tensile and compression loading, F with orientation (0º, 90º and +45º, -45º) fiber angles. Experimentally, Hydro machine (E.H-Machine, china assembled) shown in Fig.3 has been used to achieve the static mechanical performance tests such as tensile and compression tests that is connected with computer to get the results.

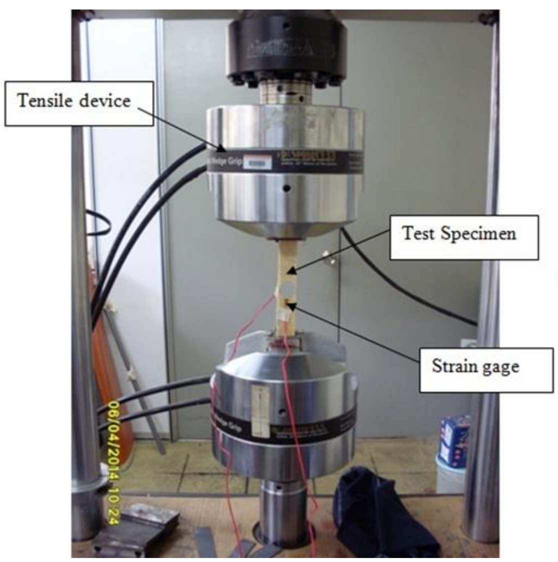

Fig. 3. Clarifies specimen under test which cut out hole.

Theoretical Work

Laminated composites are being useful in mechanical, civil, and aerospace applications due to their high specific stiffness. Fiber-reinforced composites are used extensively in the design of relatively thin plate, and consequently the load carrying capability of composite laminate plates against buckling has been intensively considered by researchers under various loading and boundary conditions [15]. Hand lay-up technique is used in many industries applications that are increasingly demanding as well as, automotive, marine, aerospace, civil, wind energy systems (blades), furniture, telecommunications, transportation and etc. [16-17].

The mass of the composite (M) is presented in equation (1) below:

$$M = M_f + M_m \qquad ......(1)$$

Where Mf and Mm are mass of fiber and mass of matrix respectively:

$$\rho v = \rho_f v_f + \rho_m v_m \qquad ......(2)$$

Volume fraction of fiber $(V_f) = \frac{v_f}{V})$ and of matrix $(V_m = \frac{v_m}{V})$

So the total volume fraction as presented in equation (3) below:

$$V_f + V_m = 1 \qquad ....(3)$$

The composite panel is subjected to the longitudinal tensile force as shown in Fig.(4). It can be supposed in this work that the longitudinal extensions resulting

from the tensile force F are the same in the composite, fibers and matrix, which can be presented in equation (4):

$$\epsilon_1 = \epsilon_1^f = \epsilon_1^m \qquad ......(4)$$

With the loading described above the transverse extensions of the fibers and matrix are equal to:

$$\epsilon_2^f = -\upsilon_f \epsilon_1 \qquad ......(5)$$

$$\epsilon_2^m = -\upsilon_m \epsilon_1 \qquad ......(6)$$

Where υ_f and υ_m represent poison's coefficients of the fiber and the matrix reprehensively.

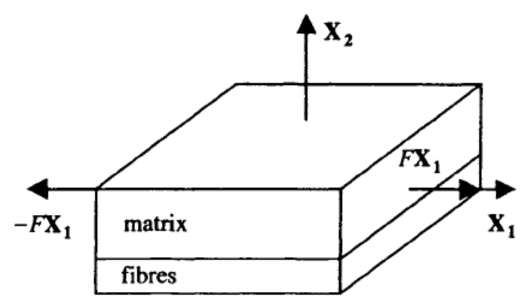

Fig. 4. Manifests Longitudinal tension

To determine the effective axial Poisson's ratio, we consider the loading as in the case applied for determining the effective axial modulus. Here, for this loading we have stress in direction (1) isn't equal zero ($\sigma_1 \neq 0$) and other stresses are zero, so the effective axial Poisson's ratio as $\upsilon 12$ of the composite is defined by equation (7):

$$\upsilon_{12} = -\frac{\epsilon_2}{\epsilon_1} \quad ......(7)$$

From equation (7) it can obtain the expression by following equation (8):

$$\upsilon_{12} = V_f \upsilon_f + V_m \upsilon_m = V_f \upsilon_f + \left(1 - V_f\right) \upsilon_m ....(8)$$

The number of specimens used in this work is 12 specimens, 6 specimens for tensile tests with different volume fraction V_f and fiber orientation, and 6 specimens for compression test.

Results and Discussion

The experimental results presented of load-displacement curve for multi layers of Kevlar-29/Epoxy- Al_2O_3 specimens with (60% volume fraction) and [0/90 and 45/-45] fiber orientation under tensile load as shown in Fig. 5. The results show that the (0/90) fiber orientation of this composite panel is the highest value with the maximum value of 3720 N while for (-45/+45) fiber orientation is 3356 N. The results from stress shear loading and displacement conditions are in very good agreement with the results obtained from this study the composite panels with the selected holes reinforcements. i.e the 9.78% deference value of load capacity in tensile test.

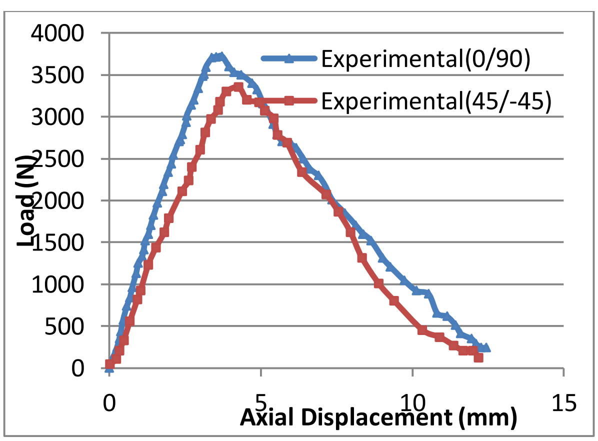

Fig. 5. Demonstrates Load-displacement curve for Kevlar-29/Epoxy- Al_2O_3 (V_f 60%)

The results that have been obtained for other Kevlar-29/Epoxy- Al_2O_3 composite panels under tensile test as shown that the (0/90) fiber orientation of this composite panel is the highest value with the maximum value of (3386 N and 2975N) while for (-45/+45) fiber orientation is (3084 N and 3386N)of (55% and 50%) volume fraction respectively as shown in Figures 6 and 7. The volume fraction has been selected in this type of material i.e.60% of tensile load capacity; it has been an optimum value compared with other volume fractions for fabricating the specimens.

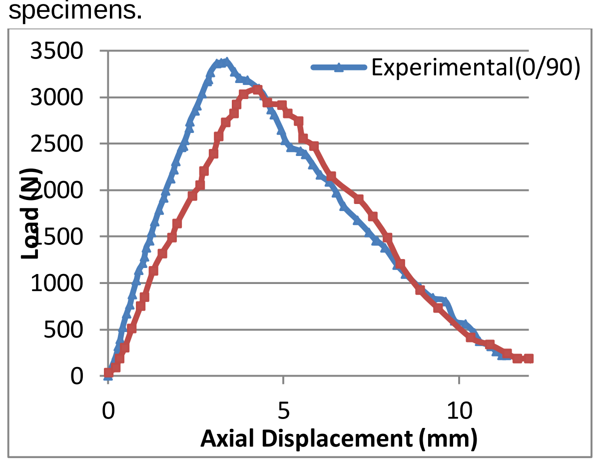

Fig. 6. shows Load-displacement curve for Kevlar-29/Epoxy- Al_2O_3(V_f 55%)

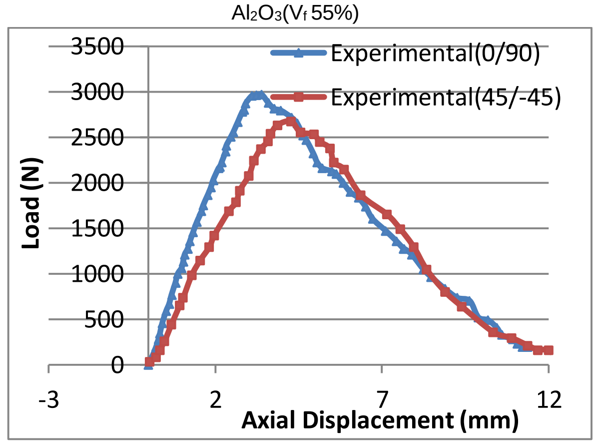

Fig. 7. Manifests Load-displacement curve for Kevlar-29/Epoxy- Al_2O_3 (V_f 50%)

The behaviour of the experimental results has presented the specimens with (0o, 90o) and (+45^o, -45^o) r orientation angles of fiber and the curves under compression test. The curves of the presented results shown in Figures 8, 9 and 10 suddenly drop for specimens with cut-out holes because of the stress concentrations around the holes.

The difference resulting of all composite panels from the above results is due to the different fiber orientation (0/90° and 45/-45) which plays an important role in determining the load capacity.

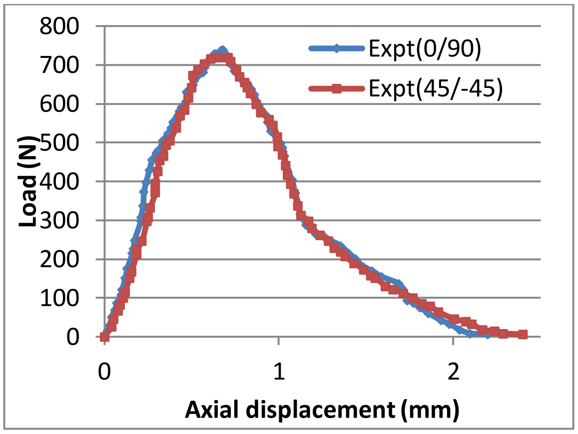

Fig. 8. Explains Load-displacement curve for Kevlar-29/Epoxy- Al_2O_3 specimens with (60% volume fraction)

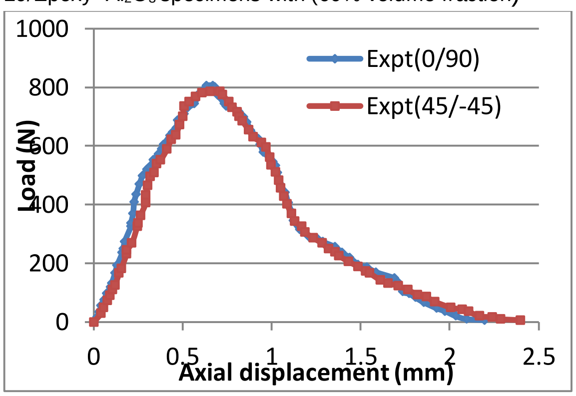

Fig.9. shows Load-displacement curve for Kevlar-29/Epoxy-Al_2O_3 (V_f= 55%)

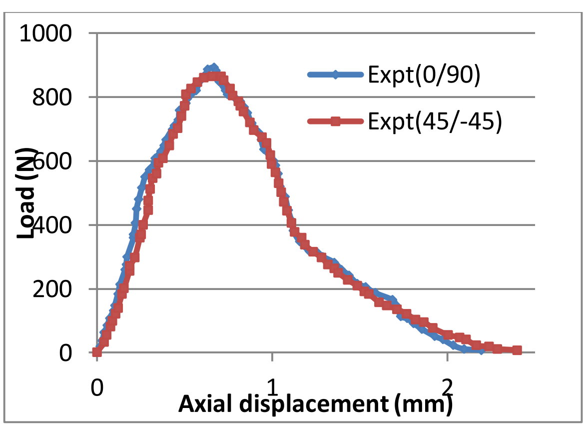

Fig.10. identifies Load-displacement curve for Kevlar-29/Epoxy-Al_2O_3 specimens with (50% volume fraction).

The results obtained for other Kevlar-29/Epoxy- Al_2O_3 composite panels under compression test show that the (0/90) fiber orientation of this composite panel is the highest value with the maximum value of (739, 807 and 893N) while for (-45/+45) fiber orientation is (719, 788 and 863 N) of (60%, 55% and 50%) volume fraction respectively as shown in Figures 8, 9 and 10. The volume fraction has been selected in this type of material50% of compression load capacity; it has been an optimum value compared with other volume fractions for fabricating the specimens.

From the above results, it can be considered that the optimum value for tensile load capacity obtained is increasing with the increasing value of volume fraction and the maximum value obtained at 60%. While for compression test the value of compression load capacity is decreasing with the increase of volume fraction, so the maximum value can be obtained in this work at 50% volume fraction.

The maximum loading test applied and displacement deformation of experimental results for the four panels are shown below in Table 3 and 4. The results obtained from this work show that adding the alumina powder in kevler29/epoxy composites increases the values of load capacity of these composites in compression case if we compare these results with previous works.

Table 3. shows The ultimate tensile load verse displacement of panels (1-6).

Panel	Ultimate Tensile load (N)	Displacement (mm)	Time(s)
	Experimental	Experimental	
1	2975	3.39	14.3
2	2680	4.28	12.9
3	3386	3.93	15.6
4	3084	4.27	15.1
5	3720	3.71	16.3
6	3356	4.27	16.2

Table 4 shows The maximum compressive loading verse displacement of panels (1-6).

Panel	Ultimate Compression load (N)	Displacement (mm)	Time (s)
	Experimental	Experimental	
1	893	0.668	0.045
2	863	0.710	0.044
3	807	0.667	0.039
4	788	0.712	0.033
5	739	0.681	0.034
6	719	0.656	0.031

Results of this work are in good agreement finding for caring load capacity with previous work of A.R. Abu Talib et al [18]. These findings suggest that this kinds of ply configuration is capable of absorbing large amounts of energy before failure occurred, where the energy absorption is given by the area under the load–displacement curve. The compression load capacity of Kevlar-29/epoxy- Al_2O_3 studied in the present work has been found to be 7.05% and 10% higher than those for Kevlar-29/ epoxy[0º/90º] and [+45º/-45º] fiber orientation angle of 60% volume fraction that was presented in previous work as well as [18] as shown in Table 5. Comparing the stress and buckling results between the constant displacement loaded of laminated panels and constant stress has obtained a good agreement results. The FE results have been validated by data obtained from experimental test and the overall agreement between them is very good.

Table 5. The comparison of load – displacement of Kevlar-29Lepoxy-Al2O3 and Kevlar-29Lepoxy

Panel		Ultimate Compression load (N)		Difference	Displacement (mm)	
V_f	Fiber orientation	Kevlar-29/ epoxy- Al_2O_3	Kevlar-29/epoxy by [18]	%	Presented by this work	Presented by [23]
60%	0º/90º	893	830	7.05	0.668	0.263
60%	+45/-45	863	770	10.7	0.710	0.167

Conclusion

That load capacity resulting in this research shows that the specimens that have [0º/90º] fiber orientation angle is greater than in composite panels of [+45º/-45º] fiber orientation angle, as well as an increase in the load capacity for the specimens under pressure loads than they are in the case of tension.

The optimum value that was obtained from the experimental results showed that the increase in the value of the volume fracture leads to increase the load capacity in the case of tensile while the opposite in the pressure case of load capacity. The results difference are due to material Al_2O_3 powder which added to the mixture, which increases the value of carrying these materials for the case of compressibility.

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