EXPERIMENTAL AND NUMERICAL STUDY OF BENDING BEHAVIOR FOR HONEYCOMB SANDWICH PANEL WITH DIFFERENT CORE CONFIGURATIONS

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ABSTRACT :-
Honeycomb sandwich panel dies are manufactured with different core shapes (hexagonal, circular and square), each shape have two types of facing, one of aluminum facing AA3003 with different thicknesses(0.5mm, 0.9mm &2mm) and the other of composite facing (E-glass+epoxy resin) with(2-layers and 3-layers). Three point bending test is used to investigate the strength of these honeycombs. The results shown that the square honeycomb's core shape have the highest load from the other core shapes and the hexagonal have the lowest value and this value increased by increasing the facing thickness, and the aluminum skin facing have higher load than the composite skin facing. The strength to weight ratio was calculated and its conclusion observed that the square honeycomb core shape have the maximum ratio and the circular honeycomb core shape have the minimum ratio. ANSYS software was used to analyze the honeycomb structure by madea model in APDL-ANSYS program in static and natural frequency tests using solid and shell elements and MPC algorithm. Results shown that there are the variations in deflection by percentage of error 27%. The dynamic test observed that the changing of skin facing thickness effect in the natural frequencies by (3%-30%) and the changing of the core configurations by (19.7%-38.8%), and by changing the facing material the natural frequencies effected by (10.6%-37.3%).

KEYWORDS: honeycomb sandwich structural panel, failure mode, ANSYS, composite material, Aluminum-3003, natural frequency .

دراسة نظرية وعملية لسلوك الانحناء لقلب لوح خلية النحل لأشكال مختلفة

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الخلاصة :-

في هذا البحث تم تصميم وتصنيع قوالب ألواح شطيرة خلية النحل لإنتاج ثلاثة أشكال مختلفة لقلب خلية النحل (سداسي، دائري، مربع) كل شكل يتضمن نوعين من ألواح الألمنيوم احدهما ذو غلاف من الألمنيوم (AA3003) وبأسماك مختلفة (0.5 مم، 0.9 مم،2 مم) بينما يحتوي النوع الثاني على غلاف مركب من طبقتين وثلاث طبقات من الألياف الزجاجية والمادة الرابطة. تم إجراء الفحوصات لعينات خلية النحل باختبار الانحناء وقد أظهرت النتائج إن خلايا النحل المربعة الشكل تتحمل أحمال أعلى من الأشكال الأخرى بينما الخلايا السداسية الشكل تتحمل اقل حمل من بين الأشكال الأخرى وان قيمة التحمل هذه تزداد بزيادة سمك الغلاف للخلية كما إن غلاف الألمنيوم له القابلية على تحمل أحمال أعلى من الصفائح المركبة لنفس السمك .

تم إيجاد نسبة الإجهاد إلى الحمل وقد أظهرت نتائج الحسابات إن الخلايا المربعة الشكل حققت النسبة الأعلى أما الخلايا الدائرية الشكل فقد حققت اقل نسبة من بين الأشكال الأخرى. تم استخدام برنامج ANSYS لتحليل تركيب خلايا النحل عدديا لإجراء اختبار الحمل المنتظم واختبار التردد الطبيعي وقد أظهرت النتائج إن هنالك اختلاف في التشوهات الحاصلة مع النتائج العملية وان نسبة الاختلاف كانت 27%. كما أظهرت تحليلات الترددات الطبيعية إن التغير في سمك طبقة الغلاف يؤثر على الترددات الطبيعية بنسبة (3-30%) كما وجد إن تغيير شكل الخلية يؤثر على الترددات الطبيعية بنسبة (19.7%-38.8%) كما إن تغيير معدن الغلاف يؤثر على الترددات الطبيعية بنسبة (10.6% - 37%).

1-INTRODUCTION :

Sandwich panels are used for design construction of light weight transportation systems such as satellites, aircraft, missiles, high speed trains. Weight saving structural is the major consideration and the sandwich construction is frequently used instead of increasing material thickness. Sandwich panels consisting of relatively thin but stiff face sheets and a thick but soft honeycomb-type core which have several types of shapes and materials **[K.K. Rao et al.,2012]**.The Sandwich Panel which is composition of a "weak" core material with “strong and stiff” faces bonded on the upper and lower side. The facings provide practically all of the over-all bending and in plane extensional rigidity to the sandwich. In principle, the basic concept of a sandwich panel is that the faceplates carry the bending stresses whereas the core carries the shear stresses. The core plays a role which is analogous to that of the I beam web while the sandwich facings perform a function very much like that of the I beam flanges. The sandwich is an attractive structural design concept since, by the proper choice of materials and geometry, constructions having high ratios of stiffness-to-weight can be achieved. Since rigidity is required to prevent structural instability, the sandwich is particularly well suited to applications where the loading conditions are conducive to buckling **[M. KashifKhan,2006].[C. W. Schwingshackl et al.,2006]**studied the honeycomb orthotropic material properties analytically and experimentally. A good agreement between the major theoretical out-of-plane material properties of honeycomb was found.**[Davide C.,2008]** studied the application of honeycomb sandwich structures in automobile industry. Proposed amathematical model based on multi-scale asymptotic technique**. [Paulius G. et al.,2010]** discussed the experimental deformation behavior of sandwich structures with honeycomb core in the cases of dynamic loading and quasistatic.**[K. K. Rao et al.,2012]** discussed theoretically the bending behavior, of sandwich panels and compared the strength to weight ratios of Normal Aluminum rod(panel) and Aluminum Honey Comb Panel. **[Ch.Nareshet el.,2013]** studied different honeycomb core, such as square and hexagonal and made a comparison of their responses. Simulation using finite element method were used for the sandwich panels behavior under uniform distributed loads. **[Joshua M. Lister,2014]**studied the experimental, numerical and analytical characterizations of composite sandwich structures and discussed the effects of varying honeycomb core ribbon orientation and varying face sheet thickness's. In this paper the experimental and finite element analysis via ANSYS code are investigated using different core configurations.

2-EXPERIMENTAL WORK :

Two methods are generally used to manufacturing the honeycomb structure, first by rolling (corrugating process) and the other by pressing (stamping process)**[HexWeb™HoneycombAttributes andProperties] .** In this work pressing method was used, three types of dies were manufactured to prepare the honeycomb cores (hexagonal, circular and square).Fig.1 shows the assembled of the dies.

After the bending process of the sheets, the epoxy is used as an adhesive material to join the 0.5mm thickness aluminum AA3003 shaped sheets to form the aluminum honeycomb cells (cores) as shown in Fig.2

Two materials were used as facing skin to cover the top and bottom of the panel (aluminum and E-glass composite). In case of aluminum, three thickness of the sheets are taken (0.5, 0.9

and 2 mm), while for composite facing, two thickness are investigated (2 and 3 mm). A three-points bending test was carried out and the displacement of the central loading point was monitored versus applied loading to determine the strength of honeycomb structure. The fifteen honeycomb sandwich specimens were tested having different core shapes and facing skin in three point bending device by applying load through a roller of diameter (5mm) accordance with the ASTM standard C393. The cross-head speed is held constant and is chosen (0.01mm/sec).

3- ANSYS MODEL OF HONEYCOMB PANEL :

The mechanical responses of honeycomb aluminum during static and dynamic loads are investigated by finite element simulations via Ansys code. In this study, the suggested structural model is investigated in static and dynamic modes. First, static three-dimensional models are developed to determine the stress-strain behavior. Later, the three dimensional models are used in ANSYS 15 nonlinear transient solution. Shell Element (shell181) used in meshing of honeycomb core and Solid Element (SOLID186) used for meshing the facing skin of honeycomb. The 3-D shell-solid assembly provides a transition from a shell element region to a solid element region. This approach is useful when local modeling requires a full three-dimensional model with a relatively fine mesh, but other parts of the structure can be represented by shell elements. No alignment is required between the solid element mesh and the shell element mesh. The contact surface or edge must be built on the shell element side. The target surface must be built on the solid elements side. To define a shell-solid assembly, the internal MPC approach is used. In most cases, the program automatically constrains both translational and rotational degrees of freedom for a shell-solid assembly as shown in Fig.3.

4-RESULTS AND DISCUSSION :

4-1 Bending moment Test

Due to bending load, the failure in the honeycombs areexisted as shown in Fig. 4, 5&6 .
It can be concluded that the debond between skin facing and core is shown in all the experimental tests, of(composite with all core shapesand aluminum with facethickness(2mm)) since in bending sandwich panel, the facing skin sheets bearing all the compression stresses and the tensile stresses. Also it can be shown that facing skin of (0.5mm) is easy to fail. When the sheet's skin are very thick and very strength to be damaged, thus the shear core would be occurred. The map of failure according to the geometry and strength data for the material's skin and core and it can be shown the modes of failure static test. Good agreement is evidence in all specimens unless those with (0.5mm) face sheet and square core shape.The failure modes observed in the bending experiments are shown in Fig. 4, 5&6. The upper face sheet's wrinkling and the lower skin facing and the core may be occurred. The face wrinkling and debending appear when the deflection of sandwich panel is large.The specimens with (3layers composite) collapsed in core, recalled that for (hexagonal &circular)they collapsed in an core. The visual and optical observations,Fig.1 mode on the damaged honeycomb sandwich panels point and that all the specimens failed due to face wrinkling (a local buckling of the compressed face). Also an indentation and plastic deformation of the faces are observed. At the load application area as well as cell walls wrinkling in the zone between the application of the loadand supported zone. It appears from these observation that the failure modes depend essentially on the nature of the shape cores itself and facing.Comparisons of force-deflection curves are shown in Fig.7-14. The maximum load under the equivalent failure mode predicted by considering together aramide fibers and aluminum cores. The sandwich panels with aramide fibers have more ductility than those made of aluminum cores.
For the purpose of comparison, finite element calculations are performed on ANSYS15 software as shown in Fig. 15-26. The honeycomb sandwich structure is modeled using shell

and solid elements. Table1 give the variation of deflection for all cases. The numerical models have the same dimensions as the specimens used in the experimental study.

4-2 Natural Frequencies & Mode shapes

The natural frequencies are calculated by ANSYS15. Table 2 observed the natural frequencies for all cases and Table (3) observed their mode shapes. The figures shown in table 3 illustrated that the square mode shape become smaller compared with hexagonal and circular. Six natural frequencies of honeycomb with different configurations are calculated the frequencies are tabulated in Table 2. It can be observed that these frequencies may be reduced/increased by changing the parameters of the sandwich honeycomb. For instance, changing the skin thickness affects the natural frequencies by (3%-30%). Also changing the configurations of the core effect the natural frequency by (19.7%-38.8%), and by changing the skin facing material the natural frequencies changed by (10.6%-37.3%). These results shown that by changing the parameters of honeycomb, the natural frequency can be modified. The higher modal frequency of the sandwich are mainly due to the weight, shape and material types.

4-3 Strength To Weight Ratio

Three point bending test is conducted on hexagonal, square and circular honeycomb sandwich panels with different skin material and thicknesses (aluminum with 0.5, 0.9 and 2mm thicknesses and composite material with two layers and three layers) as shown in Table(4) and Figure(27). It is observed that square honeycomb core configuration has more strength to weight ratio. Also these ratio increased by increasing skin thickness and that aluminum skin has more ratio by comparison with composite skin for the same thickness.

5- CONCLUSIONS :

This study focused on design and modeling of the honeycomb sandwich panel with different core configuration (hexagonal, circular and square) and with different material and facing thickness. In the experimental part of this study, a three point bending test was conducted, the result of test show that:

1-The square honeycomb sandwich construction have the highest maximum load as compared to other core shapes and the hexagonal have the lowest value.

2-The maximum load increased by increasing the facing thickness.

3-Aluminum skin facing have high maximum load in comparison with composite skin facing.

4-The square honeycomb core shape have higher strength to weight ratio than the other shapes and the circular have the lowest value.

5-Maximum springback on hexagonal shape then the square shape and the circular shape have the lowest value.

In the numerical part APDL-ANSYS program is achieved. Two main computer programs have been built up to carry out the analysis required through this work, the results show:

1-The static test in ANSYS show that there is a variation of deflection with the experimental result for all the cases; the error percentage that achieved from this variation is 27%.

2- The natural frequencies were calculated by ANSYS explain:

. Changing the skin thickness affects the natural frequencies by (3%-30%)

. Changing the core configuration affects the natural frequencies by (19.7%-38.8%).

. Changing the facing material affects the natural frequencies by (10.6%-37.3%).

3- Numerous analyses shown that the MPC-contact between solid &shell given reasonable results in which honeycomb core walls are meshed with shell elements and face sheets are modeled with solid elements.

Table (1) Variation of deflection in honeycomb with different core configurations

Case study			Max. load (N)	Deflection at max. load		Error%
				Exp.(mm)	Ansys(mm)	
Hexagonal	AL	Th=0.5mm	480	8	5.1622	35.4725
		Th=0.9mm	840	4	2.77475	30.63125
		Th=2mm	5840	25	18.611	25.556
	composite	2layers	1440	22	32.5465	32.4044
		3layers	3800	15	25.0017	40.004
Circular	AL	Th=0.5mm	840	11	13.72	19.825
		Th=0.9mm	880	2.5	1.8	28
		Th=2mm	6160	25	24.487	2.052
	Composite	2layers	1600	20	13.29	33.55
		3layers	3960	16	24.628	35.0032
Square	AL	Th=0.5mm	1800	1.8	2.641	31.8439
		Th=0.9mm	1600	1	0.66	34
		Th=2mm	6280	20	18.552	7.24
	composite	2layers	2560	18	28.697	37.2756
		3layers	4600	17	19.654	13.5036
						27.09%

Table (2) The natural frequency of honeycomb

Core shape			ω_{n1}	ω_{n2}	ω_{n3}	ω_{n4}	ω_{n5}	ω_{n6}
Square	Al	0.5(mm)	1452.11	2100.76	2203.51	3640.96	4229.88	4550.29
		0.9(mm)	1839.86	2271.38	2479.26	3963.09	4652.47	4889.73
		2(mm)	2088.64	2289.17	2726.59	4130.17	4628.12	4684.37
	Composite	2layer	1447.15	1577.52	1656.39	2556.31	3626.22	3783.34
		3layer	1441.88	1493.99	1616.76	2379.25	3440.97	3746.68
Hexagonal	Al	0.5(mm)	2423.95	3163.4	3402.06	4178.11	4646.59	4668.07
		0.9(mm)	2553.13	3073.78	3348.39	4479.17	5955.9	6042.8
		2(mm)	2478.95	2680.41	2984.38	4415.87	5267.35	5546.99
	Composite	2layer	2091.26	2144.37	2763.78	3007.56	4330.97	5502.79
		3layer	2090.4	2107.66	2579.73	2936.42	4174.16	5222.09
Circular	Al	0.5(mm)	2447.43	2700.13	3852.49	4289.64	5809.97	5839.77
		0.9(mm)	2721.69	2916.59	4256.03	4867.68	6176.5	6603.27
		2(mm)	2861.16	2882.05	4457.95	5323.89	5764.45	6598.9
	Composite	2layer	2030.24	2236.62	2978.07	3337.7	4276.82	5898.97
		3layer	2036.25	2348.49	3033.61	3344.66	4205.8	5872.49

Table (3) mode shapes of the honeycomb with different core shapes

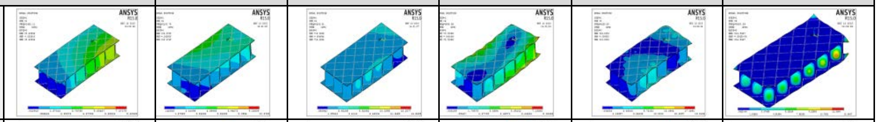
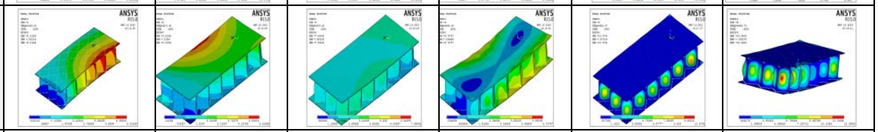
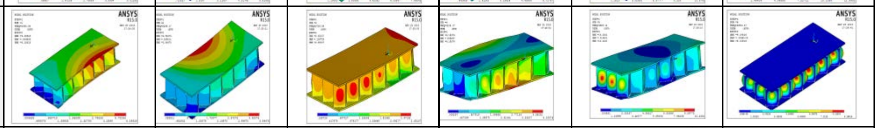
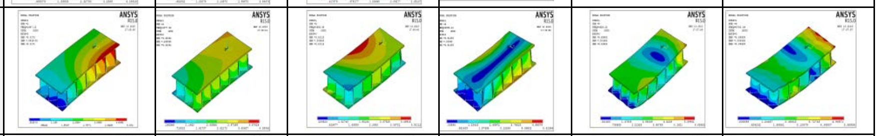
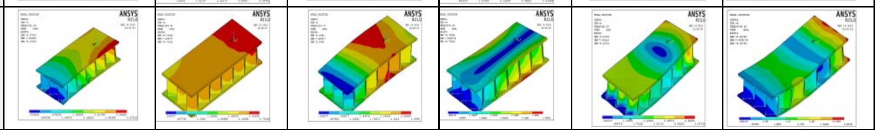
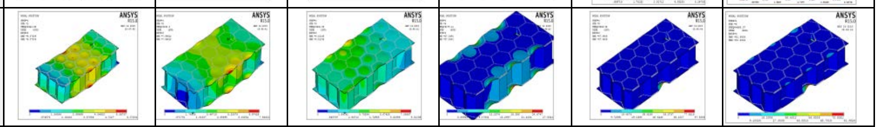
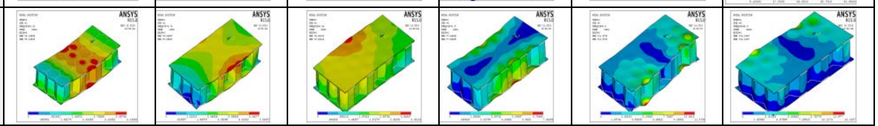
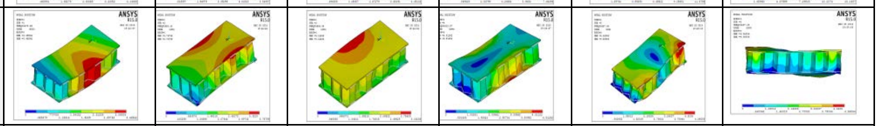
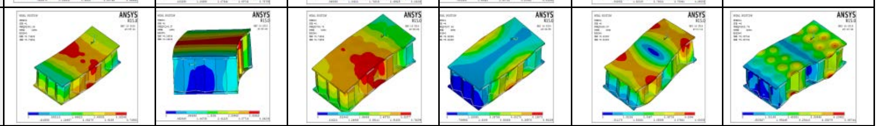
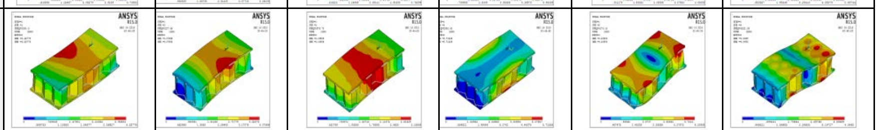
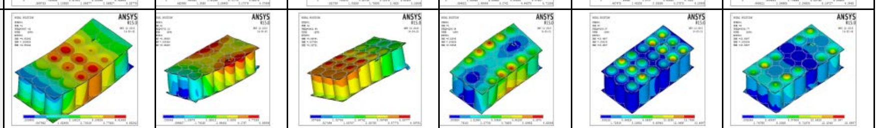
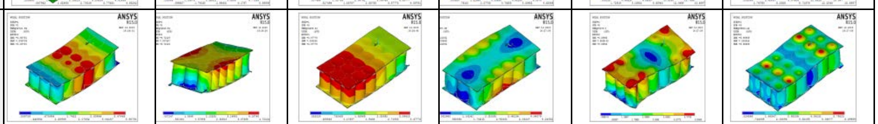
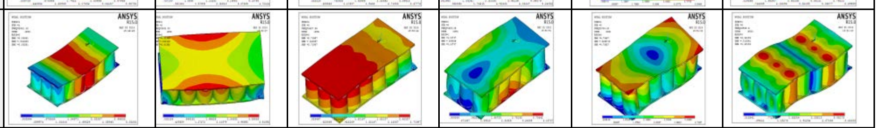
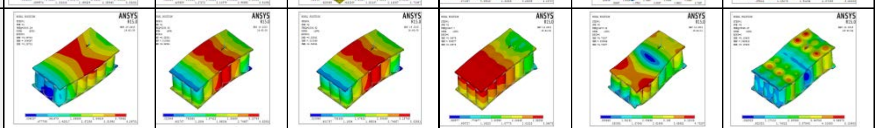
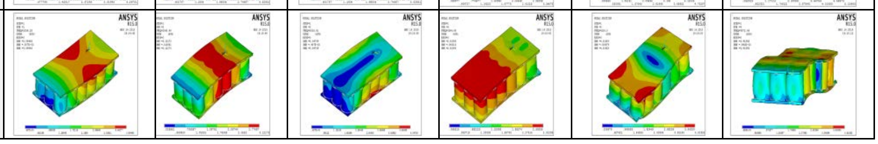
<table>
<tr><th colspan="2">Core shape</th><th></th><th>Mode-1</th><th>Mode-2</th><th>Mode-3</th><th>Mode-4</th><th>Mode-5</th><th>Mode-6</th></tr>
<tr><td rowspan="5">Square</td><td rowspan="3">Al</td><td>0.5</td><td colspan="6"></td></tr>
<tr><td>0.9</td><td colspan="6"></td></tr>
<tr><td>2</td><td colspan="6"></td></tr>
<tr><td rowspan="2">Composite material</td><td>2 layer</td><td colspan="6"></td></tr>
<tr><td>3 layer</td><td colspan="6"></td></tr>
<tr><td rowspan="5">Hexagonal</td><td rowspan="3">Al</td><td>0.5</td><td colspan="6"></td></tr>
<tr><td>0.9</td><td colspan="6"></td></tr>
<tr><td>2</td><td colspan="6"></td></tr>
<tr><td rowspan="2">Composite material</td><td>2 layer</td><td colspan="6"></td></tr>
<tr><td>3 layer</td><td colspan="6"></td></tr>
<tr><td rowspan="5">Circular</td><td rowspan="3">Al</td><td>0.5</td><td colspan="6"></td></tr>
<tr><td>0.9</td><td colspan="6"></td></tr>
<tr><td>2</td><td colspan="6"></td></tr>
<tr><td rowspan="2">Composite material</td><td>2 layer</td><td colspan="6"></td></tr>
<tr><td>3 layer</td><td colspan="6"></td></tr>
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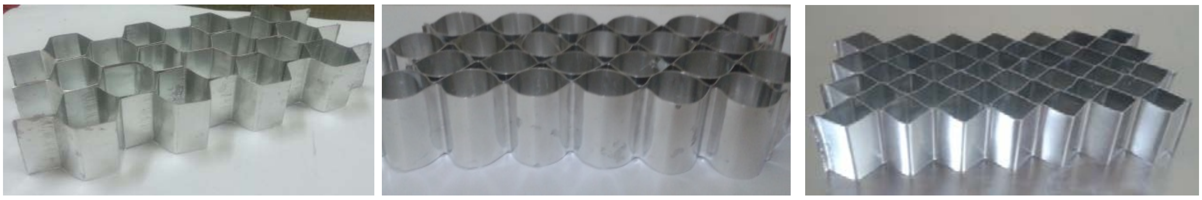
Table (4) Strength to weight ratio

Case study			$P_{max.}$	W	Ratio %
Hexagonal	AL	0.5	480	0.7996	600.29
		0.9	840	1.1369	738.79
		2	5840	2.1908	2665.61
	composite	2layers	1440	1.4325	1005.19
		3layers	3800	2.0467	1856.59
Circular	AL	0.5	840	1.0384	808.86
		0.9	880	1.4431	609.777
		2	6160	2.4268	2538.22
	composite	2layers	1600	1.7305	924.54
		3layers	3960	2.3544	1681.95
Square	AL	0.5	1800	0.9398	1915.10
		0.9	1600	1.4047	1138.95
		2	6280	2.3449	2678.05
	composite	2layers	2560	1.6630	1539.30
		3layers	4600	2.2804	2017.16

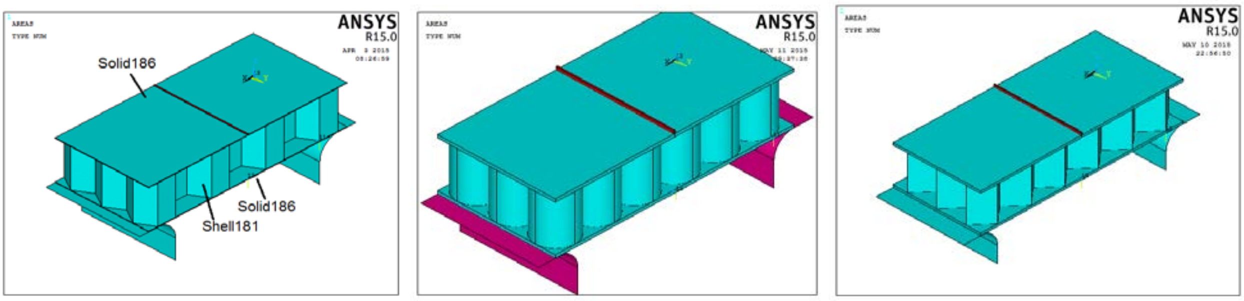
hexagonal **circular** **square**

Figure (1) dies for different core configuration



hexagonal **circular** **square**

Figure (2) Honeycomb core configurations

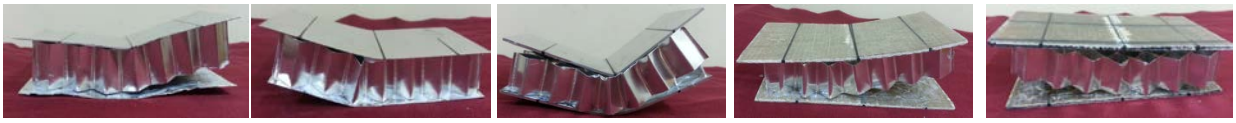


Hexagonal core circular core square core

Figure (3) Ansys honeycomb structural models

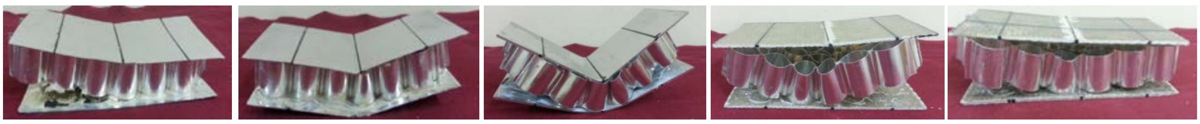
Al-facing ,t=0.5mm Al-facing ,t=0.9mm Al-facing ,t=2mm Composite (2layers) Composite (3layers)

Figure (4) Failure modes of hexagonal honeycomb structure



Al-facing ,t=0.5mm Al-facing ,t=0.9mm Al-facing ,t=2mm Composite (2layers) Composite (3layers)

Figure (5) Failure modes of square honeycomb structure



Al-facing ,t=0.5mm Al-facing ,t=0.9mm Al-facing ,t=2mm Composite (2layers) Composite (3layers)

Figure (6) Failure modes of circular honeycomb structure

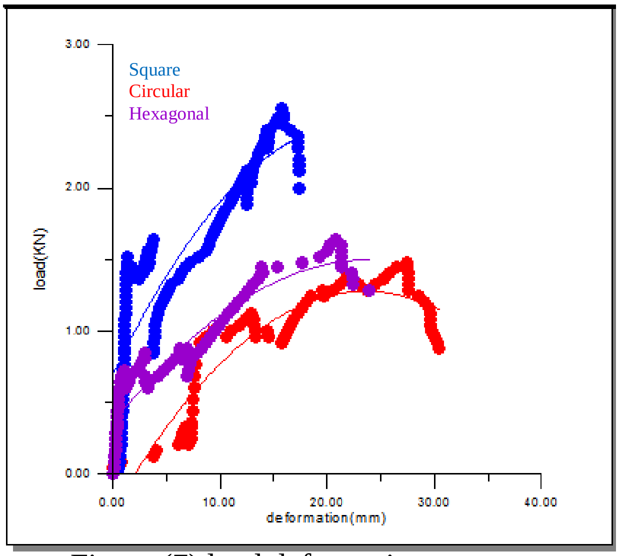
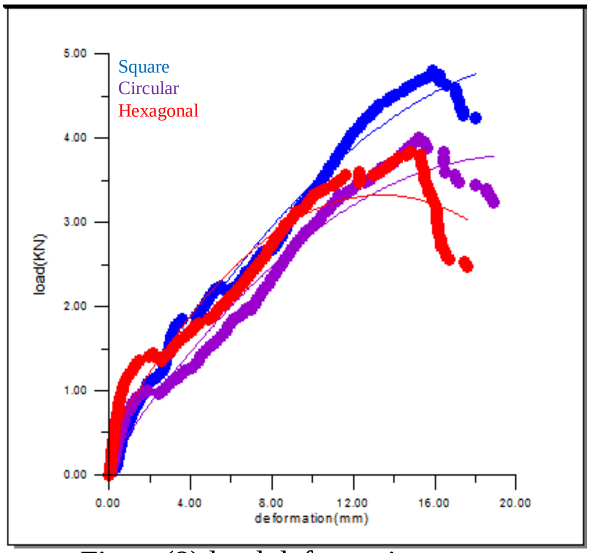


Figure (7) load deformation curve (2layers composite)



Figure(8) load deformation curve (3layers composite)

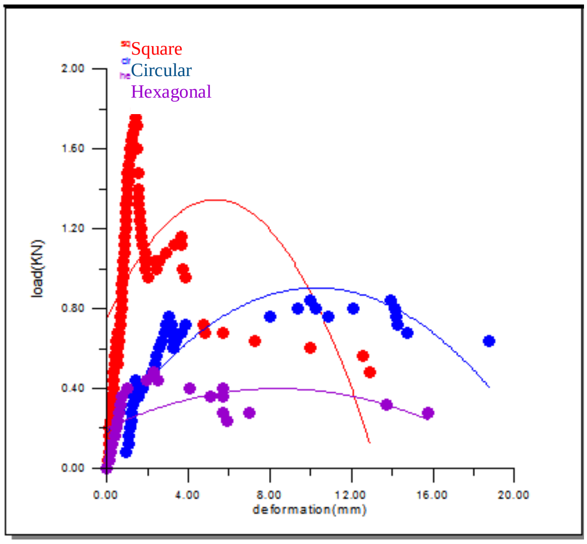


Figure (9) honeycomb with (square, circular and hexagonal) core with facing thickness(0.5mm)

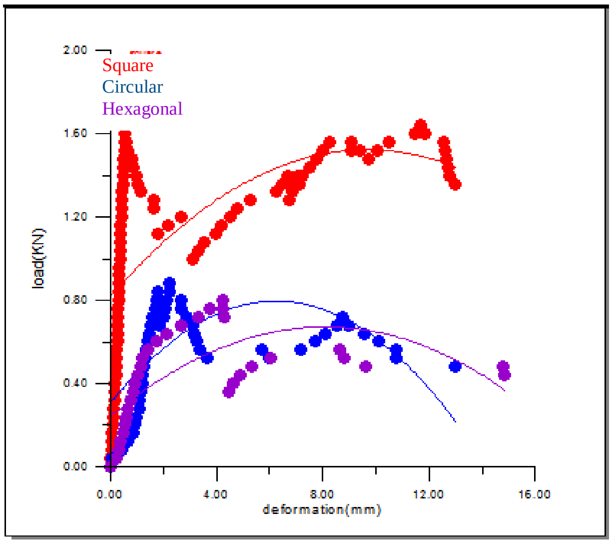


Figure (10) honeycomb with (square, circular and hexagonal) core with facing thickness(0.9mm)

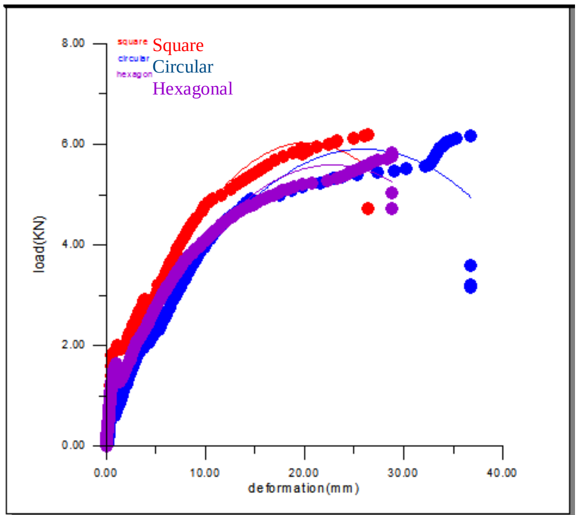


Figure (11) load deformation curve aluminum honeycomb with (square, circular and hexagonal)

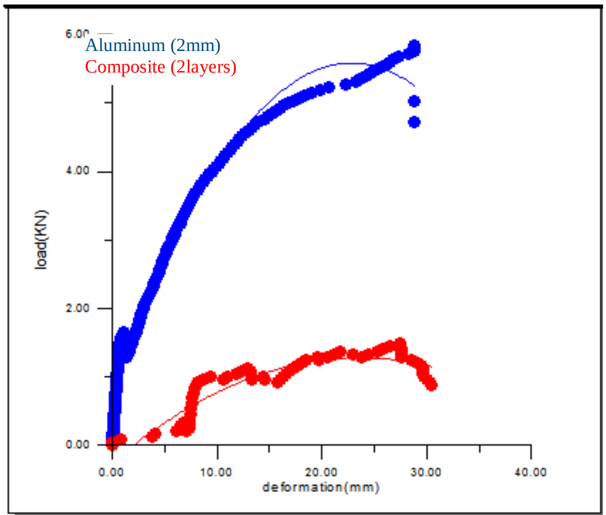


Figure (12) load deformation curve aluminum core with facing thickness (2mm) and composite (2mm) hexagonal shape

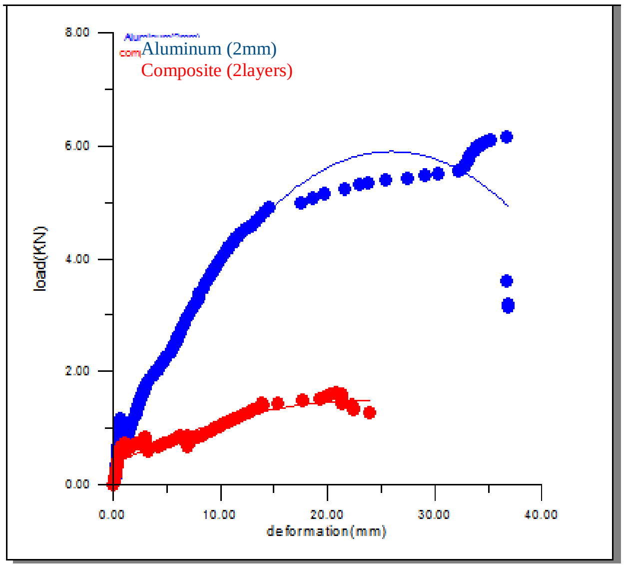


Figure (13) load deformation curve aluminum and composite (2mm) Circular shape

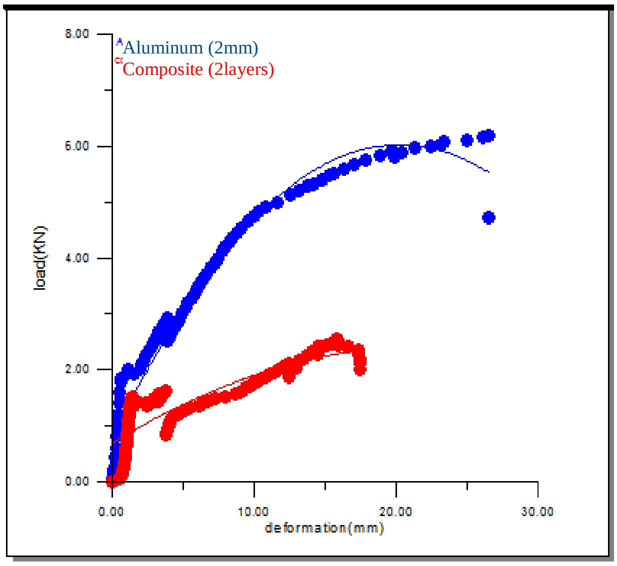


Figure (14)load deformation curve aluminum and composite (2mm) square shape

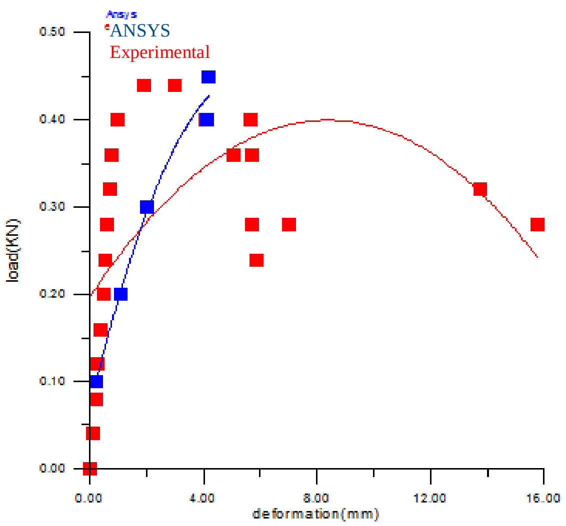


Figure (15) load deformation curve for hexagonal honeycomb shape with thickness (0.5mm)

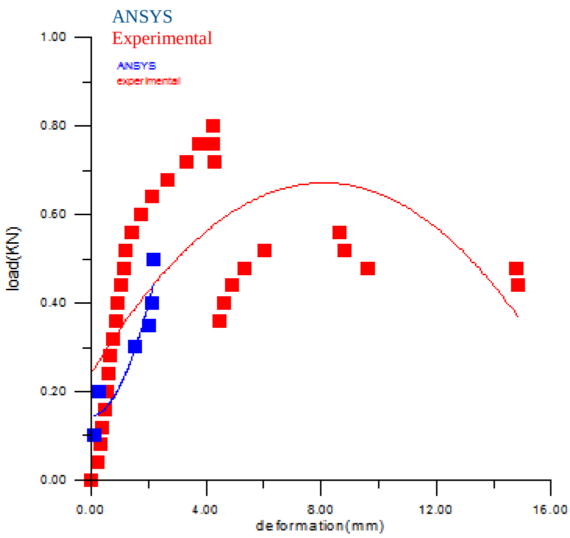


Figure (16) load deformation curve for hexagonal honeycomb shape with thickness0.9mm

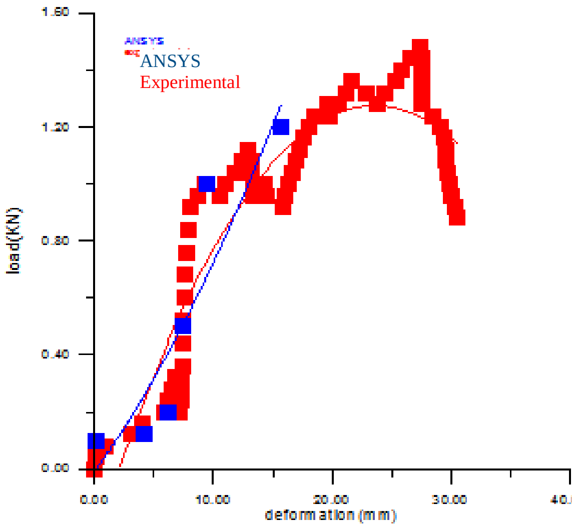


Figure (17) load deformation curve for Composite hexagonal honeycomb with 2layers

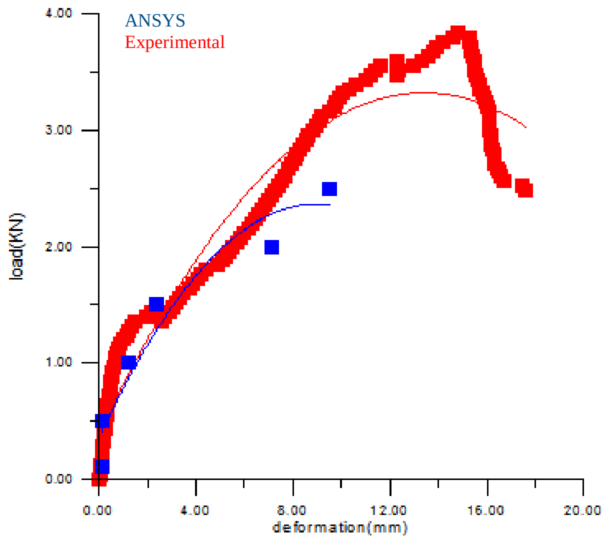


Figure (18) load deformation curve for composite hexagonal honeycomb with 3layers

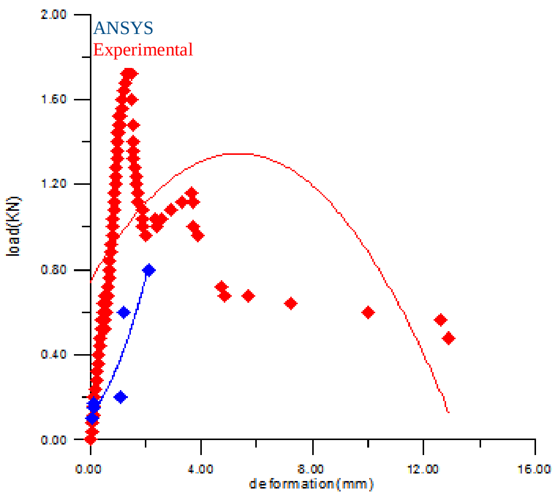
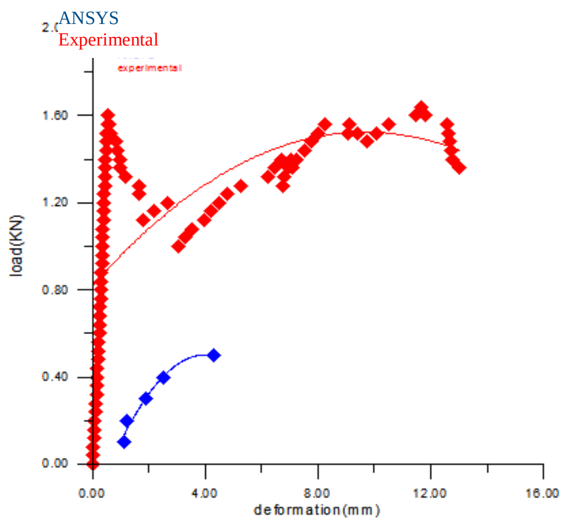


Figure (19) load deformation curve for square honeycomb with thickness (0.5mm)



Figure(20) load deformation curve for square) honeycomb with thickness (0.9mm)

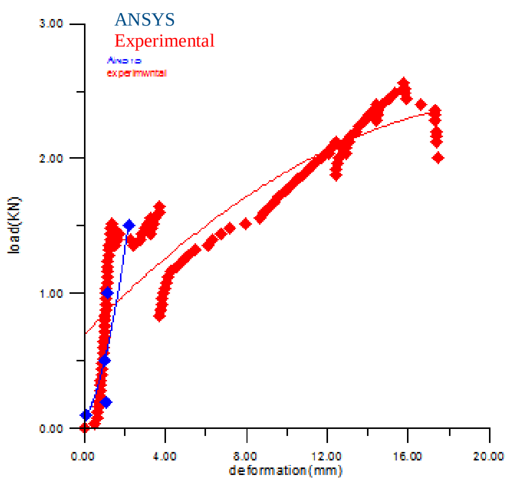
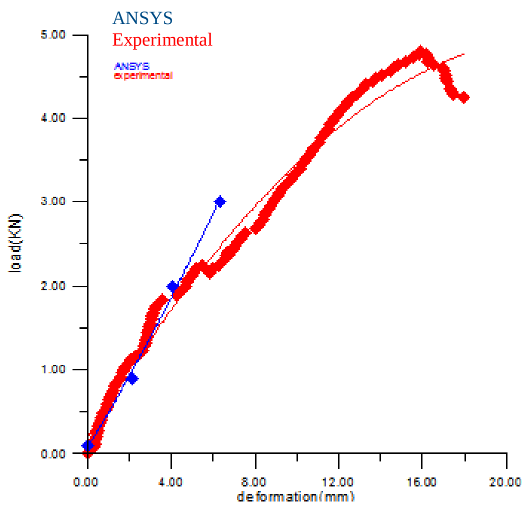


Figure (21)load deformation curve for composite square honeycomb with 2layers



Figure(22)load deformation curve for composite square honeycomb with 3layers

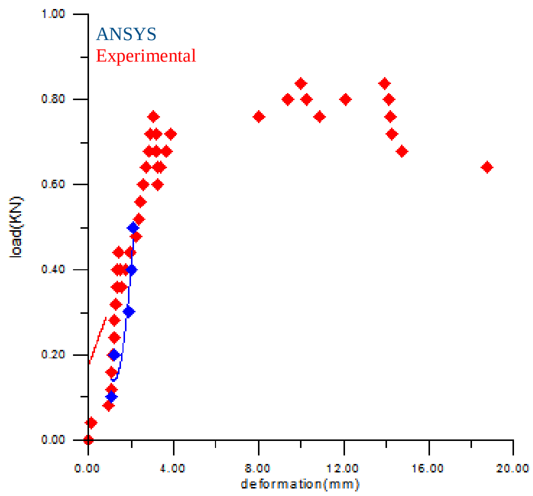


Figure (23) load deformation curve for circular honeycomb with thickness(0.5mm)

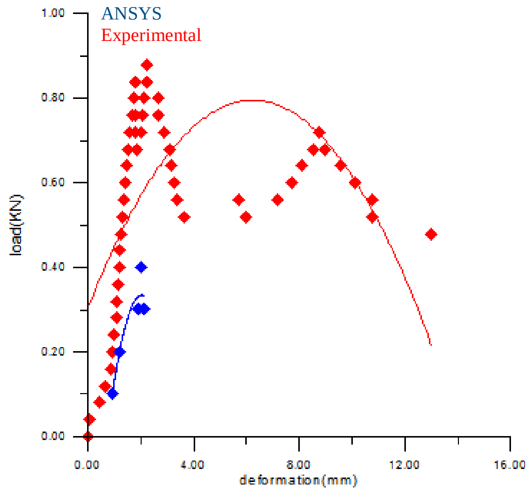


Figure (24)load deformation curve for circular honeycomb with thickness(0.9mm)

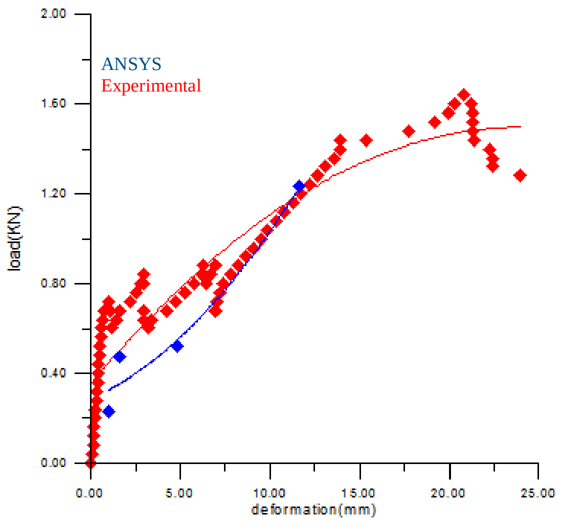


Figure (25) load deformation curve for composite circular honeycomb with 2layers

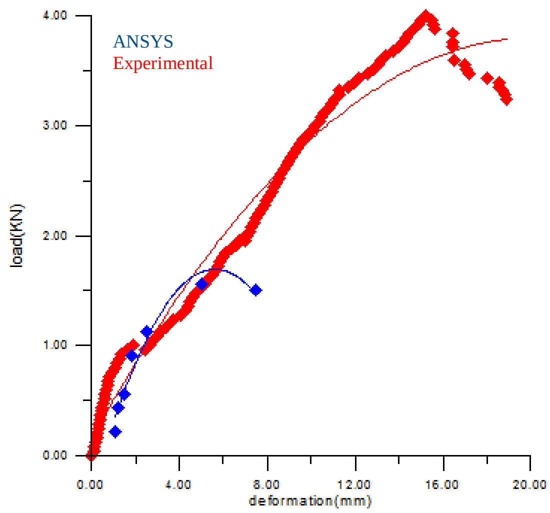


Figure (26) load deformation curve for composite circular honeycomb with 3layers

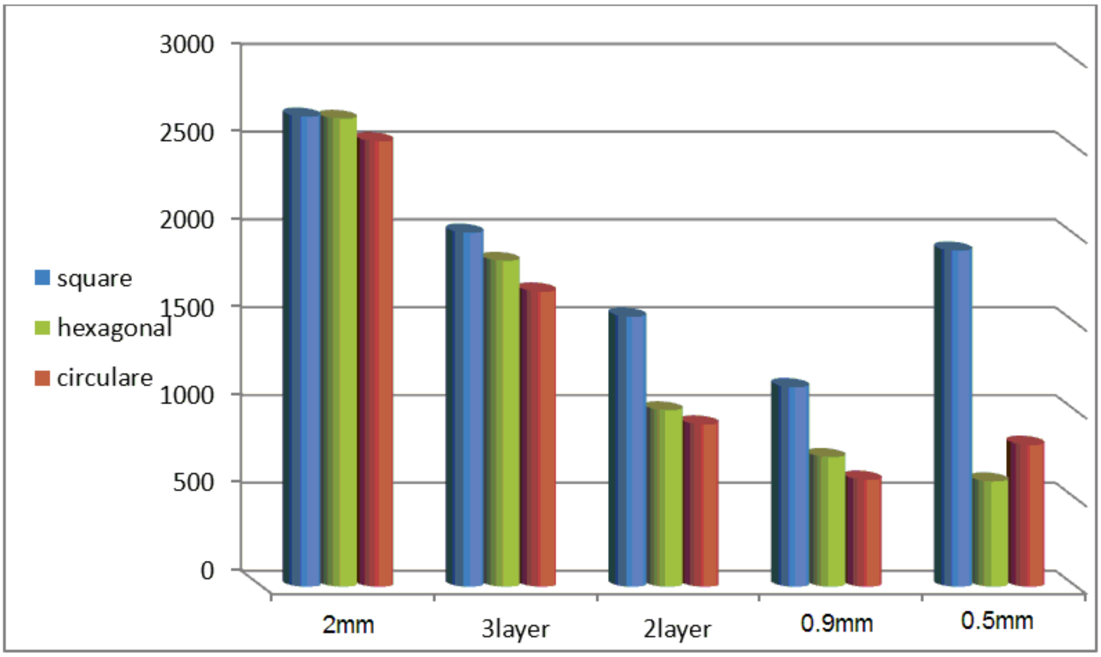


Figure (27) chart of strength to weight ratio

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