DYNAMIC BEHAVIOR INVESTIGATION OF LAMINATE COMPOSITE PLATE

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ABSTRACT :

An experimental investigation had been done to demonstrate the dynamic behavior of laminate composite plate. Four types of composite plates were produced that (E-glass woven roving + unidirectional carbon / unsaturated polyester, E-glass woven roving + unidirectional carbon/ epoxy, unidirectional carbon / unsaturated polyester and unidirectional carbon/epoxy) with 6 layers at (30%) fiber volume fraction. Mechanical properties were evaluated in terms of tensile and impact strengths. In fatigue tests, the specimens were investigated to estimate the basic S-N curve and deduce their relations. Plate fixed from all sides and a steel ball of 23g was freely dropped from height of 1m. Dynamic response of plate was investigated by measuring strain using vibration data collector (TVC200). The mechanical properties and the dynamic response tests done at 30ºC, 0ºC and (-30) ºC temperature which is realistic and exist within everyday life in winter. A special refrigerator for this purpose was manufactured to get the temperature required. The results showed that the Carbon/Epoxy composite plate has higher mechanical properties and fatigue limits, with lower deflection as compared with other plates. The mechanical properties were found to be increased and the deflection decreased with the temperature decreased.

Keywords: composite laminate plate, fatigue, dynamic response.

الخلاصة :

حققت الدراسة العملية لوصف السلوك الديناميكي للمواد المركبة. تم انتاج اربعة انواع من الصفائح المركبة (الياف الزجاج + كاربون مع البولي استر الغير مشبع، الياف الزجاج +كاربون مع الايبوكسي ، الياف الكاربون مع البولي استر الغير مشبع، و الكاربون مع الايبوكسي) لستة طبقات بكسر حجمي مقداره 30%. تم حساب الخواص الميكانيكية من حيث مقاومة الشد و مقاومة الصدمة . في اختبار الكلال، تم التحقق من العينات لإيجاد منحنى S-N و استنتاج العلاقات. ثبتت الصفيحة المركبة من جميع الجهات و تم اسقاط كرة من الفولاذ بوزن 23g بحرية من ارتفاع مقداره 1m. الاستنتاجات الديناميكية للصفيحة تم التحقق منها بواسطة قياس الانفعال باستخدام جهاز جامع بيانات الاهتزاز (TVC200). الخواص الميكانيكية و اختبار الاستجابة الديناميكية نفذت في (درجة حرارة الغرفة 30^oC ، الصفر، و -30^oC) ، لذلك تم تصميم و تصنيع ثلاجة خاصة لتحقيق درجة الاختبار المطلوبة. اثبتت النتائج ان الصفائح المركبة المصنوعة من الياف الكاربون مع الايبوكسي تمتلك اعلى خواص ميكانيكية و حد كلال مع اقل انحراف مقارنة مع بقية الصفائح. الخواص الميكانيكية تزداد و الانحراف يقل مع انخفاض درجة الحرارة .

INTRODUCTION :

The higher strength /weight ratios are the most features of fiber reinforced composite material than other metals. In which used in most engineering applications. An impact loads due to external objects will still the most concern for such plates in comparison to a metallic one. In this study the dynamic response test, fatigue test and Charpy impact test are used to demonstrate the dynamic behavior of laminated composite material experimentally. Many trail studies investigate the impact load on a composite structure. (Alpaydin 2009), investigate the dynamic behavior experimentally and numerically of sandwich panels subjected to impact load. The dynamic response of the panel investigated by measuring strain on the panel**. (**Akin 2010), deals with the response of E-glass/epoxy laminated plates subjected to low velocity impact loading using a specially designed vertical drop-weight testing machine. The impact test was carried out at a constant weight with different impact energies and carried out on plate dimension of 140mm x140mm with both four and two opposite sides clamped. (Jaafer 2010), demonstrate the effect of fiber on the damping behaviour at (V_f=1%, 2% and 3%). It was found that with volume fraction increases, stiffness, vibration damping, damped period and natural frequency increased. (Heimbs 2008), present the behaviour of a carbon fiber- reinforced composite plate (CFRP) under low velocity impact and compressive preload experimentally and numerically. It was present modeling strategies for a compressive preload and low velocity impact of CFRP plate using LS–DYNA. (Sinan Zuhair 2013), demonstrate the effect of filler on the dynamic behavior of sandwich panel, and present that the deflection decrease with the graphite filler increase up to 7.5%. (Ahmed 2013), demonstrate the effect of fiber type on dynamic behavior of composite plate. It was show that the endurance limits and mechanical properties increased, whereas deflection decreased with using carbon fibers in compare with using E-glass fibers.

The objective of the present work is to demonstrate the effect of resin (epoxy and unsaturated polyester), fibers (E-glass woven roving, unidirectional carbon) and temperature on the behavior of laminate composite plate under dynamic load experimentally.

Most previous researchers studied the effect of temperature rise or fall in cryogenic temperature range on the behavior of composite material and finding mechanical properties in that class. But in this research, the behavior of laminated polymer composite material under static and dynamic load at room temperature and decreases to zero, even to -30oC were studied. These classes are realistic and exist within everyday life in winter. A few research (Ebtihal 2009) studied theoretically the effect of cryogenic temperature on the dynamic response of composite material. Also, a few researches (Alpaydin 2009), studied experimentally, the sandwich panel dynamic response due to drop weight impact load at room temperature. But in this research, the effect of drop weight impact load on dynamic response of laminated plate composite material at room, zero and subzero (-30^{o}C) temperature were studied experimentally.

Experimental program and Materials selection

The materials used are fiber and resin. The fibers are E-glass woven roving (W) and unidirectional carbon fibers (C) as shown in Fig. 1. Table 1 contains the properties of these fibers (Sinoma and Abdalla 2008). The resins are unsaturated polyester (UP) and epoxy (EP) type Quick mast 105. Table 2 contains the properties of these resins (Dieter 2002). Four types of fiber/risen composite plates with six layers of fibers (CW/UP [0c, glass2]s, CW/EP $[0c,glass_2]_s$, C/UP, $[0,90,0]_s$ and C/EP, $[0,90,0]_s$) were manufactured using wet hand layup technique. Resin of (UP) type (TOPAZ-1110 TP) was mixed with (Methyl Ethyl Keton Peroxide, MEKP) hardener in weight ratio of 100:2. Whereas, epoxy matrix base was mixed with hardener in weight ratio of 3:1. Composite plates stacking procedure (shown in Fig. 2), is construct by placing the fibers ply one above other with mixed resin to spread between them using mold (300×200×20) mm as shown in Fig. 3 (a). The frame of the mould was manufactured from steel plate at the workshop in Babylon University, with two thicknesses; 4 mm for the base and 6 mm for the heavy weight cover as shown in Fig. 3 (b). At a constant fiber volume fraction of 30%, the process was repeated up to 6 layers for all types of the composite plates. The fiber volume fraction (v_f) can be determined experimentally by weighing a lamina, then removing the matrix and weighing the fibers according to the ASTM D2584 (Abdalla 2008). Since, the experimental procedure is destructive, an analytical procedure is preferred. In determining the fiber volume fraction analytically, the fiber arrangement in the lamina and the form of the fiber reinforcement in the lamina must be known. The volume fraction of fibers can be calculated from the equation as follows (Abdalla 2008):

$$v_f = \frac{1}{1 + \left(\frac{1-\varphi}{\varphi}\right)\frac{\rho_f}{\rho_m}} \tag{1}$$

Where: ρ_f : is the Density of fiber in g/cm^3.

ρ_m : is the Density of matrix in g/cm^3.

φ: is the Fiber weight fraction

Covering the inside wall, using nylon paper to prevent the adhesion between specimen and mold wall. Steel cover plate was applied to removing air bubbles and prevent shrinkage during curing process. At room temperature the curing process was done and completed within 24 hours. Laminate product was left 3 hours at 70ºC in oven to achieve a sufficient curing. A tipped cutter was used to cut the plate into the appropriate dimensions, to produce the test samples.

Mechanical properties:

1.Tensile Test

The tensile tests specimens were prepared in accordance with ASTM D3039 standard (Hodgkinson 2000). The dimensions of tensile test specimens are shown in Fig. 4. This test was performed at (30^{o}C, 0^{o}C, and -30^{o}C) temperatures by cooling the specimens in a special refrigerating device shown in Fig. 5, then tested in these temperatures in 200KN WDW – 200 E III hydraulic test machine, with constant strain rate of 2 mm/min. The test temperature was controlled by touch thermometer. The tests results are listed in Table 3.

2. Charpy Impact Test

The Charpy impact test is one of the most common tests for characterizing mechanical properties behavior of materials. The principal advantages of the test are the ease of preparation of the specimen, accomplish of the test proper, speed, and low cost (Marc 2009). A Charpy test at only one temperature is not sufficient, because the energy absorbed in fracture drops with decreasing test temperature. So this test is performed according to ISO-179 (ASTM 1989), at (30^{o}C, 0^{o}C, and -30^{o}C) temperature by cooling the specimens in a special refrigerating device as shown in Fig. 5, then tested in these temperatures in impact test machine. The test temperature was controlled by touch thermometer. Fig. 6 shows a standard specimen for impact test.

Fatigue test:

Fatigue is the failure or decay of mechanical properties after repeated applications of cyclic stress lower than ultimate tensile stress of material (Rajendran 2004). The specimens of the fatigue test were prepared according to the Machine's Manual (HSM20), as shown in Fig. 7. Seven specimens composite plate were cut and tested to generate the S-N curve for each laminated by an alternating bending specification of Fatigue test machine HSM20 as shown in Fig. 8, 1400rpm, spanning voltage 230V, frequency 20 Hz, normal power 0.4 KW, and performed at room temperature and a stress ratio of R = -1 (tension-compression). A series of experiments were performed on each set of specimens (seven specimens) by changing the applied moments each time and recording the number of cycles to failure. The applied stress is calculated from the applied moment. The bending stress can be estimated from the simple theory of a cantilever beam (HSM20):

$$\sigma = \frac{1.5EB\delta}{l^2} \tag{2}$$

The format of the regression trend, which is typical for composite fatigue data, has been explored. So, the relationship between stress and number of cycles can be expressed in power law regression as the following equation (Daniel 1999):

$$\sigma = a\,N^b \tag{3}$$

Where σ is the applied stress, and (a), (b) are the fitting parameters.

The coefficient (a) related to static bending strength, while the coefficient (b) related to the fatigue degradation and describes the fatigue sensitivity. A correlation coefficient (R^2) was used to verify whether the experimental data are well explained by power formula, it is useful to measure the strength of this relationship. The regression constants (a & b) and the correlation coefficient (R^2), that represent the fatigue trends results are given in Table 4.

Dynamic response:

Using eight bolts, composite plate of (200×200 mm^2) was fixed from all sides. An accelerometer was glued at sheet center in the back side. Using a suitable structure to fix a metal pipe over the plate. Using the pipe as a guide to drop the steel ball from a height of 1m on the center of the plate. The structure setup is shown in Fig. 9. Spherical steel ball of 23g weight and 18.9 mm radius was freely dropped on composite plate top side. Strain is digitized and then transferred to vibration data collector device type (TVC 200). The (TVC 200) connect to computer for data transferred. To represent the deflection of the tested plates, the data analyzed using utilizing MCM3 software program.

To achieve the test conditions required at (0^oC, and -30^oC) temperatures, a special refrigerator was designed and manufactured. Structure was set inside the refrigerating device and the temperature was controlled by a thermometer type (TM 914C) as shown in Fig. 10. Then the procedure of the dropped weight mentioned above is repeated at (0^oC, and -30^oC) temperatures, where the steel ball was freely falling through a hole in the refrigerator top side.

RESULTS AND DISCUSSION

Mechanical properties test results that done at (30)ºC, 0ºC and (-30)ºC temperature are listed in Table 3. The results show that, with using carbon fiber reinforced the mechanical properties increased rather than that of using CW, because the carbon fiber has higher tensile strength and modulus of elasticity than E-glass fiber. This makes the composite need more forces to reach failure, leading to increase the strength of the composite materials. Also, the orientation of the fibers plays an important role in increasing the modulus of elasticity and tensile strength of the laminated composites. The use of EP resin gets greater mechanical properties than that of using UP, because the EP has better adhesive properties and superior mechanical properties than UP. The elastic modulus and tensile strength improved with the temperature decrease from 30ºC to 0ºC and (-30) ºC due to the shrinking occurred, while the fracture toughness decreased. The elastic modulus and the tensile strength of C/EP composite plate increased by 13% and 10% respectively as shown in Fig. 11, while the fracture toughness decreased by 11% as the test temperature decreases from 30ºC to (-30)ºC.

In fatigue tests, the specimens are investigated to estimate the basic S-N Curve as shown in Fig. 11. The fatigue limit of the tested materials is taken at number of cycles of 10^6. Since beyond that, fatigue life becomes infinite (Mallick 2008 and Varadharajan 2005). In general the fatigue limit (strength) of the materials is proportional to its tensile strength; hence, materials with higher ultimate tensile strength possess higher fatigue limit. In the first instance, for all the laminated composites, the fatigue strength decreases in different percentages with increasing No. of cycles to failure. It decreases rapidly during the first hundred thousand cycles. This is first region in which the fatigue life initiates the first damages. Most of these damages are a transverse crack that takes place in the composite structure. As cycles increase the decrease in the stress takes new pattern and the decrease is less sharp than the first hundred thousand and starts to take linear decreasing and could be seen as a slope between two points to the final failure at the end of the 10^6 cycles. This behavior can be explained as that the damage in the first few thousand cycles due to the transverse crack and then it starts to grow in the composite and starts to produce the fiber matrix debonding, and then a delaminations area which is noticeable and after that a final failure or breakage of fiber happens. The (C/EP) gives higher fatigue limit than other composites due to high elastic modulus, tensile strength and high fracture toughness. The fatigue limit of C/EP is greater than that of CW/EP by 63.8%. Also the laminated composite made from EP matrix have higher fatigue limit than the composite made from UP with maximum increment of 40%.

In the dynamic response test, in the z-direction deflection was measured at the center of plate back side. Figs. 12, 13, 14 and 15 represent the deflection behavior of the composite plates. The deflections behaviors measured for the first 390 msec just after the impact. The results showed that all the laminated plates have the same deflection behavior but differ in magnitude. The C/EP composite plate has less deflection value than other composite plates as shown in the Figs. 12, 13 and 14, because the mechanical properties, fracture toughness, and fiber-matrix bonding have a remarkable effect on increasing the absorbed energy and decreasing the deflection at impact. At 30ºC, Fig. 12 the deflection of C/EP is less than the deflection of CW/EP and C/UP by 14.2% and 22.5% respectively. As the temperature test decrease from 30ºC to (-30)ºC the central deflection decreases as shown in Fig. 15; the deflection of C/EP and C/UP composite plates decrease by 11% and 21% respectively. This is attributed to the changing material properties and this will affect on stiffness, stress components, fracture toughness, absorbed energy, and damping, thus will effect on the deflections of the laminated composite materials. When the temperature decreases, the stiffness will increase due to shrinking. The laminated composite constituents become more brittle and stiffer at low temperatures, the strain will decrease, and the compressive stress increase. And thus, the material's ability to absorb energy is higher which make the deflection decreases.

CONCLUSIONS :

The following conclusions can be drawn:

1. The C/EP composite plate has a higher mechanical property, fracture toughness and fatigue limit than other composite plates.
2. The elastic modulus and the tensile strength of C/EP composite plate increased by 13% and 10% respectively while the fracture toughness decreased by 11% as the test temperature decreases from 30ºC to (-30)ºC.
3. The composite plate made from EP matrix have higher fatigue limit than the composite made from UP with maximum increment of 40%.
4. The C/EP composite plate has lower deflection value at impact test than other composite plates.
5. The deflection of C/EP and C/UP composite plates decrease by 11% and 21% respectively as the test temperature decreases from 30ºC to (-30)ºC.

Table 1. Properties of the resins and fibers used in this work (Sinoma and Abdalla 2008).

Materials	Density (g/cm3)	Modulus of Elasticity (GPa)	Strength (MPa)	Poisson's Ratio
E-glass	2.58	72	3450	0.22
Carbon	1.79	230	3900	0.2

Table 2. Properties of the resins used in this work (Dieter 2002).

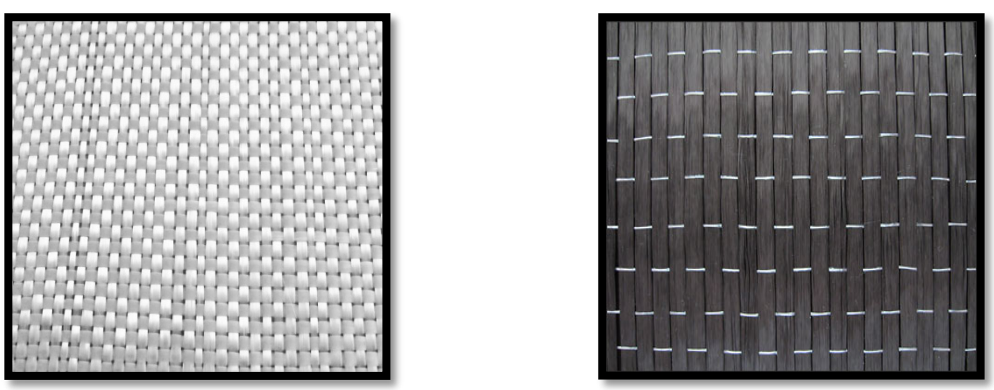
Materials	Density (g/cm^3)	Modulus of Elasticity (GPa)	Strength (MPa)	Poisson's Ratio
Polyester	1.1-1.4	2.1-3.4	34.5-103	0.37-0.4
Epoxy	1.1	4.667	≥ 25	0.35

Table 3. Tensile test and Charpy test results

Material	Elastic modulus (GPa)			Tensile strength (MPa)			Fracture toughness (MPa√m)		
	30ºC	0ºC	-30ºC	30ºC	0ºC	-30ºC	30ºC	0ºC	-30ºC
CW/UP	15.66	16.80	17.91	425.37	470.32	515.47	33.505	31.146	29.324
C/UP	26.85	27.54	28.64	644.84	702.76	748.62	43.507	41.607	39.765
CW/EP	17.4	18.53	19.31	455.02	492.05	538.71	39.633	37.503	34.304
C/EP	30.7	32.8	34.8	701.84	772.65	832.65	50.696	47.61	44.744

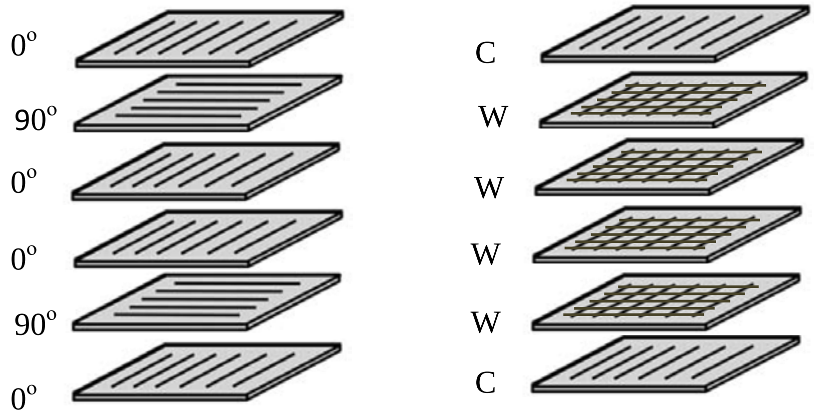
Table 4. Regression parameters of fatigue data.

Material	a	b	R2
CW/UP	233.032	-0.1401	0.9966
CW/EP	197.306	-0.1125	0.9903
C/UP	181.584	-0.0965	0.9938
C/EP	161.930	-0.0617	0.9724



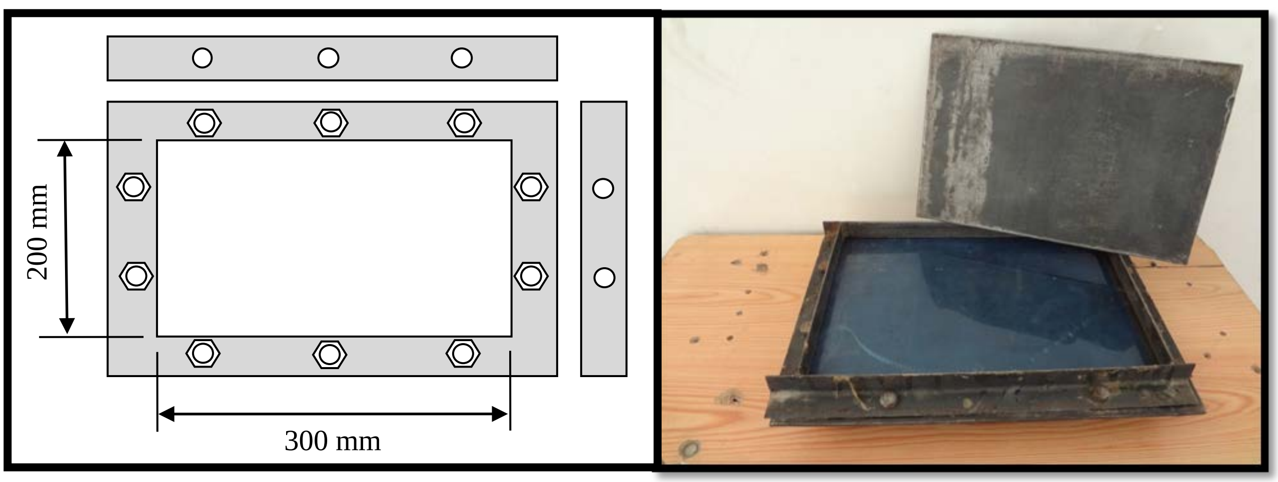
a- E-glass woven roving fiber. **b-** Unidirectional woven carbon fiber

Fig. 1 Fiber reinforcement materials used in this work.



a- $[0,90,0]_s$ **b-** $[0^c,glass_2]_s$

Fig. 2 The stacking procedure of composite plates.



(a) (b)

Fig. 3: **(a)** Top view of schematic frame,

(b) Manufactured frame.

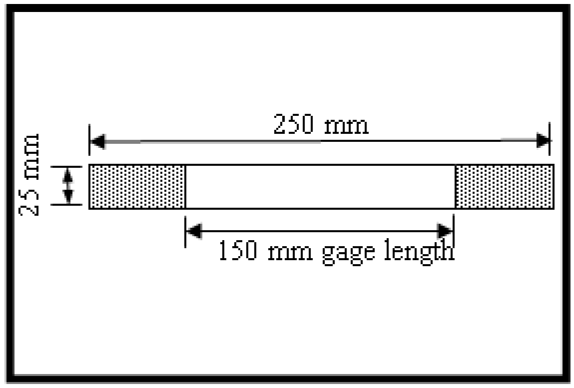


Fig. 4: Schematic specimen of tensile test.

Fig. 5 Special refrigerating device.

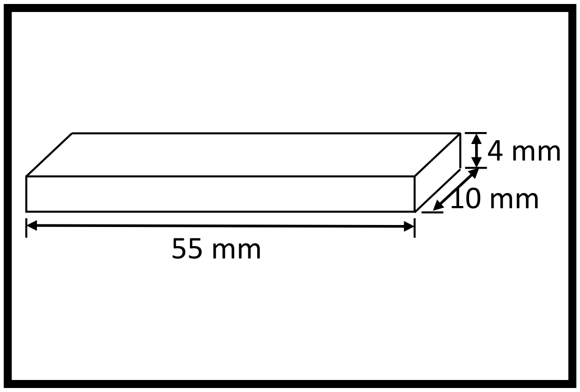


Fig. 6 Schematic Specimen (ISO-179).

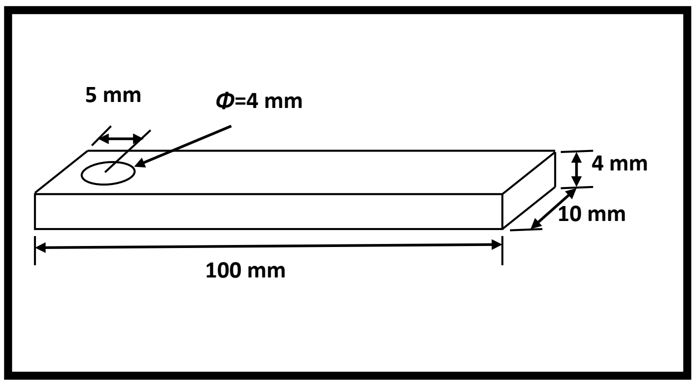


Fig. 7 Schematic specimens of fatigue test.

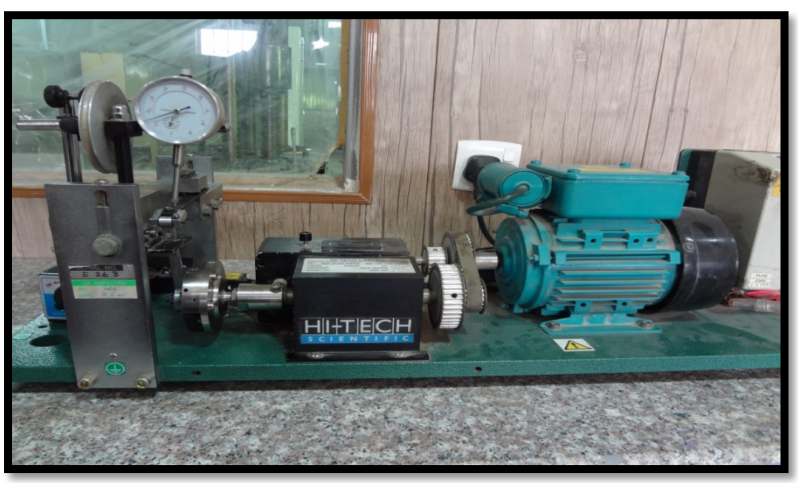


Fig. 8 Fatigue test machine.

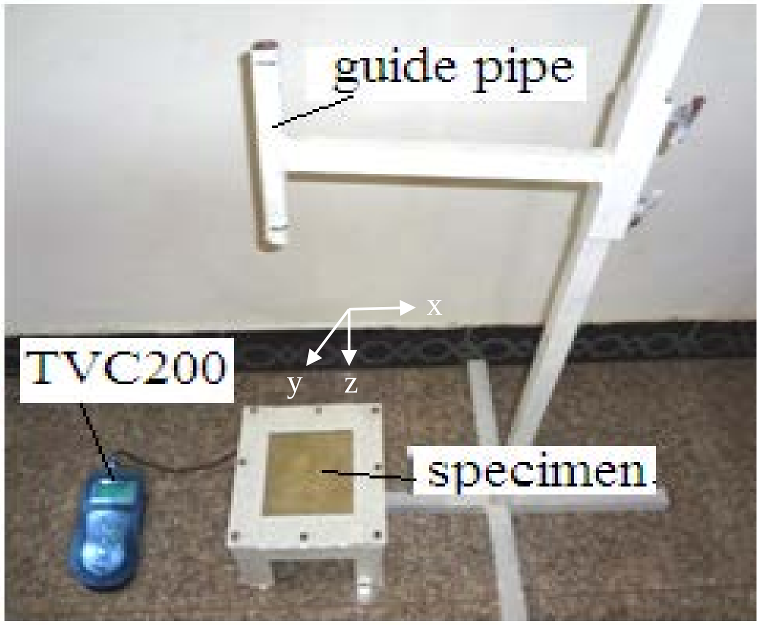


Fig. 9: The structural setup of the dynamic response test.

Fig. 10 : Fixed Support frame inside the refrigerating device.

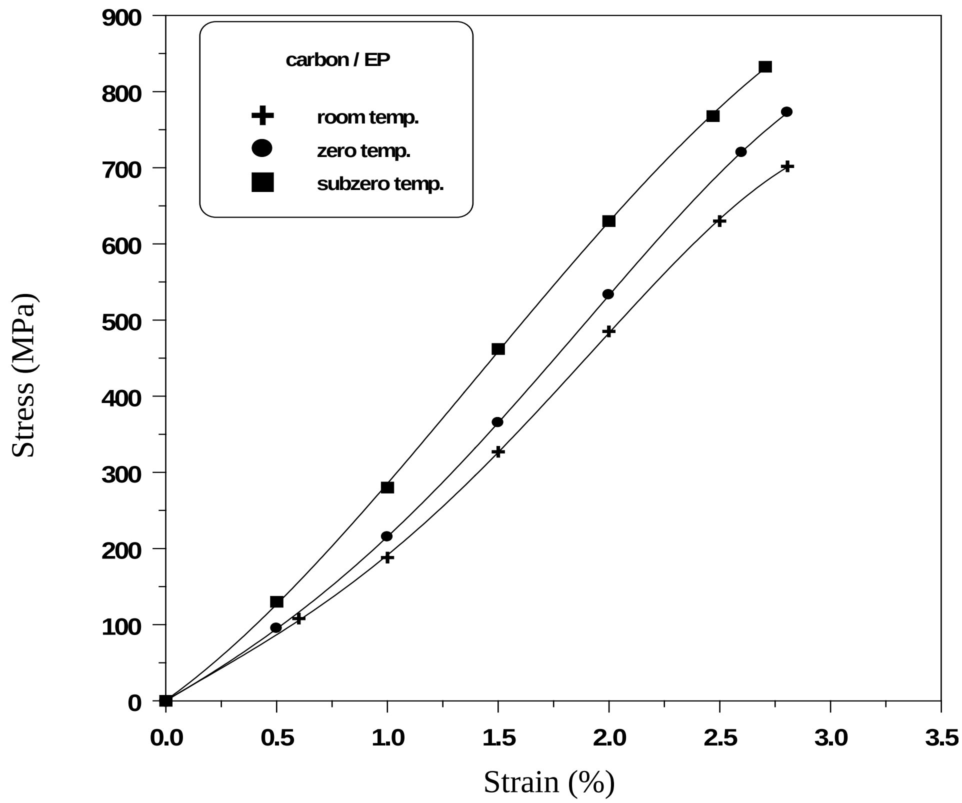


Fig.11 Experimental stress-strain curve obtained for C/EP for different temperatures.

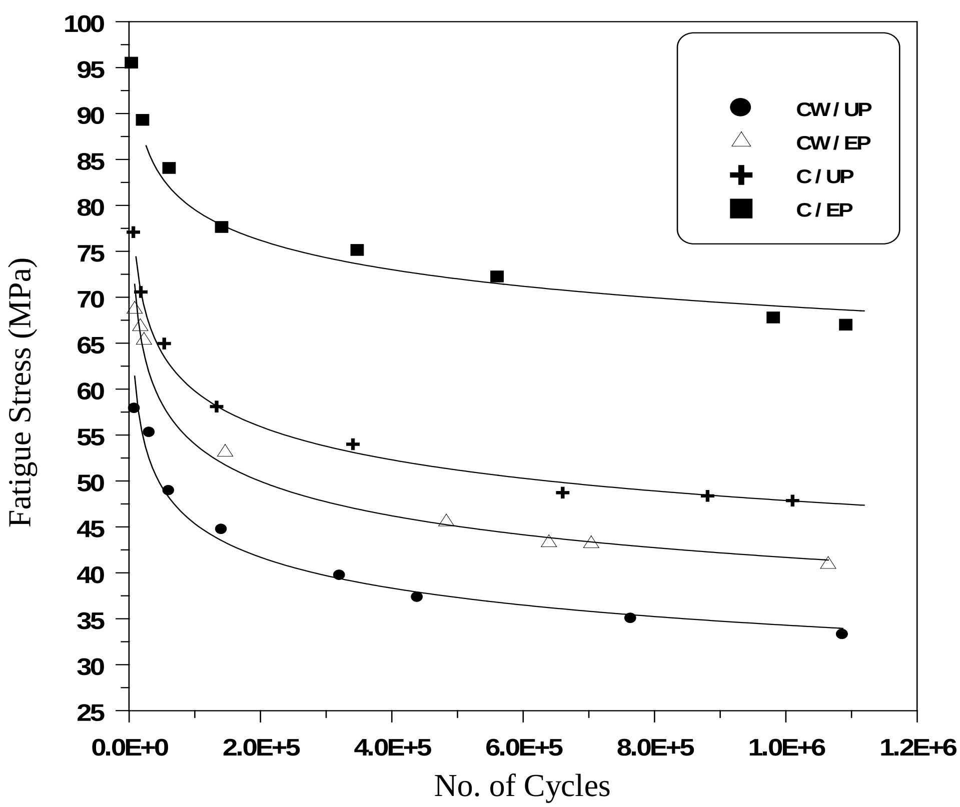


Fig. 12: S-N Curve of the composite plates.

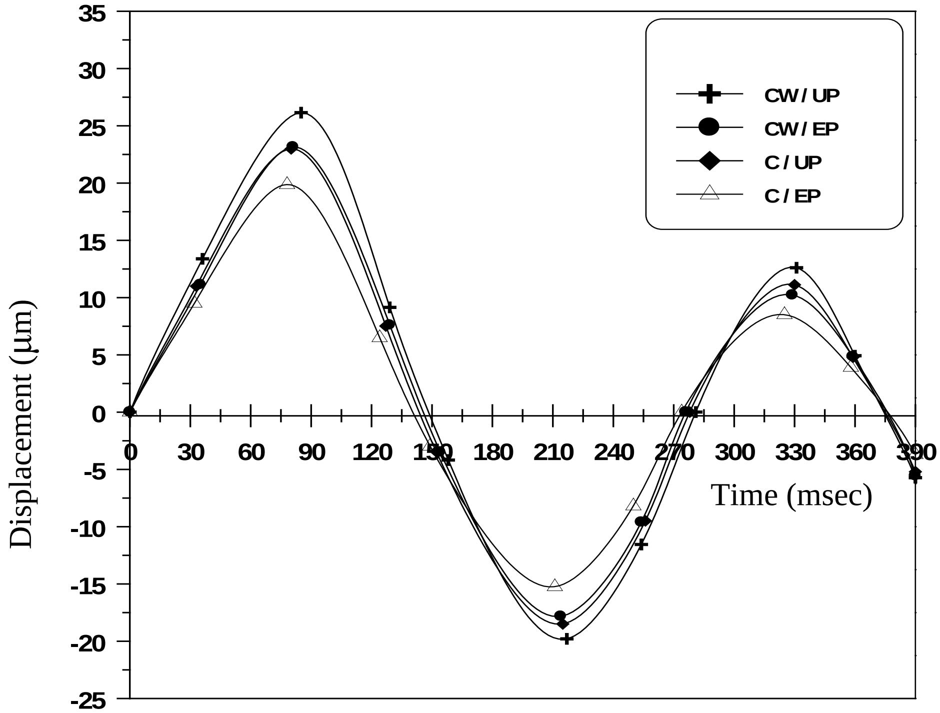


Fig. 13: Deflection behaviors of different composite plates at 30ºC temperature test.

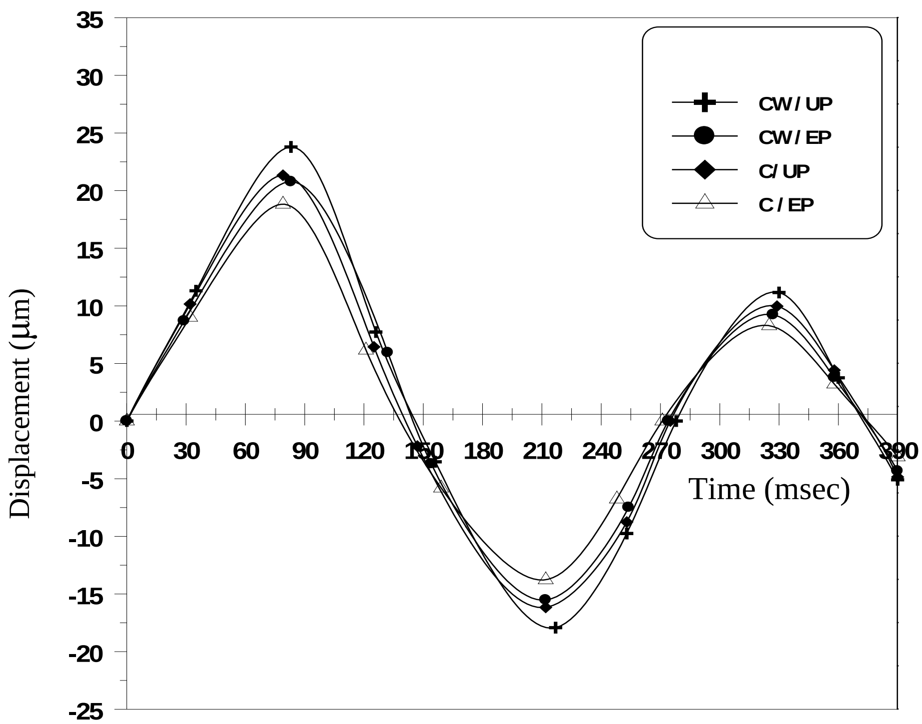


Fig. 14: Deflection behaviors of different composite plates at zero temperature test.

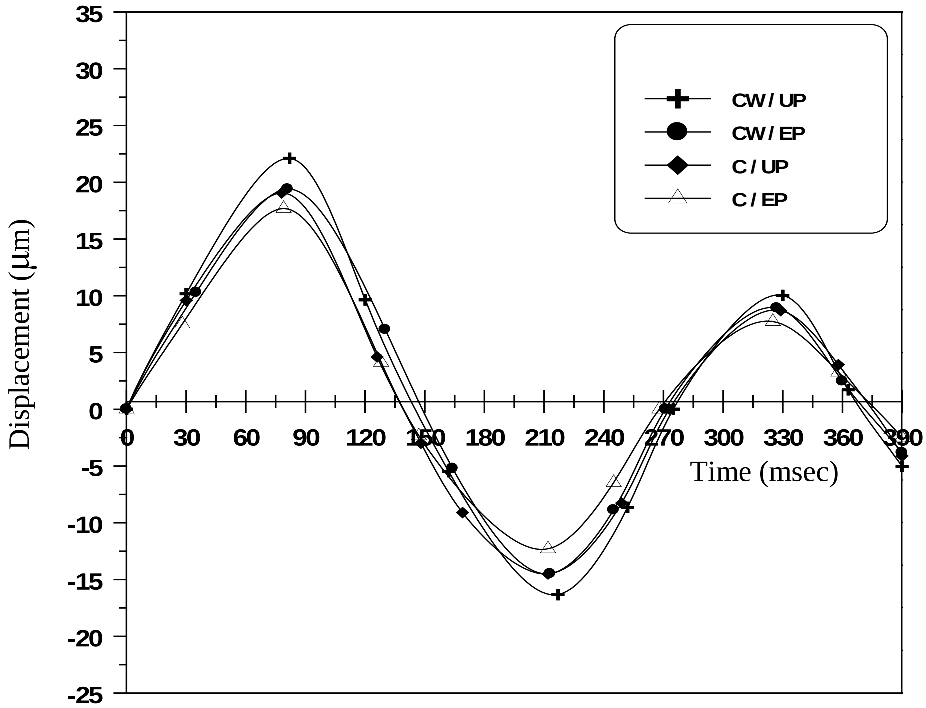


Fig. 15: Deflection behaviors of different composite plates at (-30) ºC temperature test.

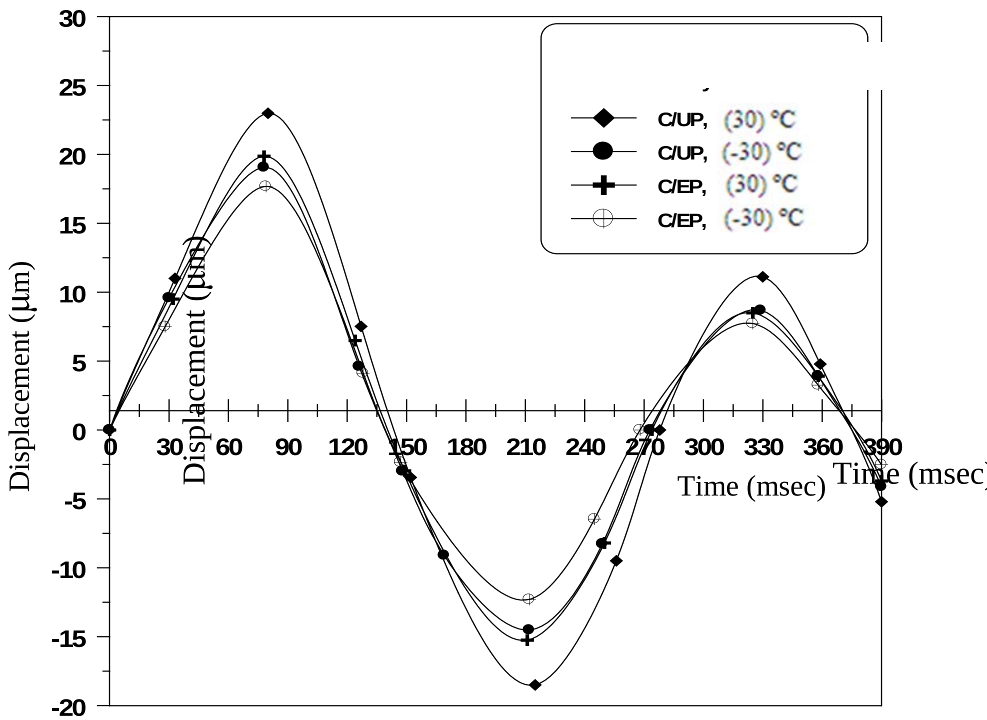


Fig. 16: Effect of resin and temperature on the deflection behavior of carbon fiber composite plates.

REFERENCES :

Abdalla F. H., et al, "Determination of Volume Fraction Values of Filament Wound Glass and Carbon Fiber Reinforced Composites", ARPN Journal of Engineering and Applied Sciences, ISSN 1819-6608, VOL. 3, NO.4, 2008.

Ahmed N., M. Farag and B. Mustafa "Effect of fiber-reinforced type on the dynamic behavior of composite plate", International Journal of Scientific & Engineering Research, Volume 4, Issue 9, September-2013.

Akin C., and M. Senel, "An Experimental Study of Low Velocity Impact Response for Composite Laminated Plates ", DPU Fen Bilimleri Enstitüsü Dergisi, Sayi 21, ISSN-1302-3055, Nisan, 2010.

HSM20, Alternating Bending Fatigue Machine Instruction Manual HSM20.

ASTM, "Annual Book of ASTM Standard", Section 8, Plastics (I), Vol. (08-01), Easton, M. V. S. A., 1989.

Daniel David Samborsky, "Fatigue of E-Glass Fiber Reinforced Composite Materials and Substructures", Civil Engineering Department, Montana State University, Bozeman, Montana, 1999.

Dieter Urban and Koichi Takamura, "Polymer Dispersions and Their Industrial Applications", Wiley-VCH Verlag GmbH & Co. KGaA, 2002.

Ebtihal Abbas Sadiq, "Dynamic Response of Composite Plates Under Cryogenic Enviroment", Ph.D thesis, College of Engineering, Mechanical Engineering Department, University of Baghdad, Baghdad, Iraq, 2009.

Heimbs S., S. Heller, P. Middendorf, "Simulation of Low Velocity Impact on Composite Plates with Compressive Preload", Material II-Composites, 7. LS-DYNA Anwenderforum, Bamberg, 2008, 11-24.

Hodgkinson J. M., " Mechanical Testing of Advanced Fiber Composites", Woodhead Publishing Limited, Abington Hall, Abington, Cambridge CB1 6AH, England, 2000.

Jaafer H. J., "Effects of Fibers on Damping Behavior of Composites Materials", M.Sc. Thesis, University of Technology, Department of Applied Scinces, Iraq. 2010.

Mallick P., "Fiber reinforced Composites Materials, Manufacturing, and design", Taylor and Francis Group, LLC, third edition, 2008.

Marc Andr´e Meyers, and Krishan Kumar Chawla, "Mechanical Behavior of Materials", Second Edition, Cambridge University Press, 2009.

Namik K. Alpaydin and Halit S. Turkmen, "The Dynamic Response of the Sandwich Panel Subjected to the Impact Load", IEEE Xplore, 2009, 176-180.

Rajendran V., "Materials since", Tata McGraw-Hill Publishing limited, chapter 21, 2004.

Sinan Zuhair, "Improvement of polymer matrix composite material behavior using optimum additive percentage of graphite and aluminum under low velocity impact", MSc. Thesis, AL-Mustansiriya University, Baghdad-Iraq, 2013.

Sinoma Jinjing, Product Data Sheet Fiber Glass Co. , Ltd. http://www.ppgfiberglass.com

Varadharajan b. R., W. N. P. Hung and H – J. Sue, "Fatigue of Epoxy α Zirconium Phosphate Nanocomposites", Proceeding of the ASEE Gulph-Southwest Annual Conference Texas A&M University-Corpus Christi, 2005 .