The Effects of Different Environmental Conditions on the Characteristics of Fiber Reinforced Plates

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Abstract

The failure of polymer matrix composite upon exposure to the environment conditions has been assessed in the present study. Glass fabrics and unsaturated polyester resin were selected to fabricate 8-layer laminates cross ply [(0/90)8] arranged in symmetric and antisymmetric stacking sequence. Environmental conditioning using Sea and Tap water with humidity exposure and Ultraviolet radiation was conducted to investigate the vibrations characteristics of symmetric and antisymmetric composite samples. After exposure time to the conditions above for 500, 1000 and 2000 hr, laminates were subjected to three point bending testing, in order to study their flexural properties (stiffness and strength) before and after these exposures. Then a finite element analysis using the package program *ANSYS* (version 10) was used for the analysis of free vibration characteristics. The object was to obtain the natural frequency for each case of environmental conditions at different exposure times. The results showed that natural frequencies of cantilever laminate plates decreased with the increased exposure time for the different environmental conditions.

Keywords: Durability, Environmental degradation, Frequency

تاثيرات الظروف البيئة المختلفة على خواص الصفائح المقواة بالياف الفابير

الخلاصة

تم في الدراسة الحالية تقييم الفشل لمصفوفة البوليمر المركب نتيجة التعرض الى الضروف البيئية. وتم أختيار الليف الزجاجي وراتنج البوليستر الغير مشبع لتصنيع ثمان طبقات متقاطعه (0\90) رتبت بشكل متماثل وغير المتماثل. الظروف البيئية المستخدمة هي ماء البحر ، ماء الحنفية ، التعرض للرطوبة والاشعة الفوق بنفسجية وذلك لتحري خواص الاهتزاز للعينات المتماثلة والغير متماثلة. تم اخضاع العينات لاختبار الانحناء الثلاثي بعد زمن التعرض للظروف (500-1000-2000) ساعة وذلك لدراسة خواص الانحناء (الصلابة والقوة) قبل وبعد التعرض. ثم استخدم تحليل العناصر المحددة باستخدام برنامج الانسز (أصدار 10) لتحليل خواص الاهتزاز الحر والحصول على التردد الطبيعي لكل حالة من الظروف البيئية ولمختلف أزمان التعرض. أضهرت النتائج أن التردد الطبيعي للصفائح الكابولية يقل مع زيادة زمن التعرض ولمختلف الظروف البيئية.

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1-Introduction

The rapidly expanding application of composite materials in recent years have provided much optimism for future engineering design and technology which for last few decades have become more and more prevalent in engineering application .The desire for lightweight and stronger materials spurred the development of high strength and low ductility material such as fiber-reinforced matrix composites .Fiber-reinforced composite materials consist of fibers of high strength and modulus embedded in or bonded to a matrix material with distinct interfaces (boundaries) between them . In this form , both the fibers and the matrix retain their physical and chemical identities ,yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone [1] .Components made of fiber reinforced have been used in this fields of mechanical , aeronautical, aerospace and marine (canoes, fishing trawlers, patrol boats, sonar dome ,masts of sub marine, air craft structures, all types of cars body work, naval mine hunting ships ,non-pressure hull casing) .In general fibers are the principal load- carrying members, while the surrounding matrix keeps them in the desired location and orientation , act as load transfer medium between fibers, and protects them from environmental damage . Many fibers reinforced composite materials offer a combination of strength and modulus that are either comparable to or better than many of the traditional metallic materials [2]. Free vibration of thick ,isotropic and laminated composite rectangular with central point supported by the finite layer method has been analyzed. The one dimensional linear or quadratic shape function are adopted to describe the variation in the displacements through the thickness layer. The governing eigen value equation of plate is derived via the conventional displacement method .The eigen frequencies of simply supported rectangular plates with central point support are studied considering aspect ratio ,side to thickness ratio , properties of material, number of laminates and stacking sequences .The results were compared with Mindlin plate solution to verify applicability and accuracy of proposed method [3] .The application of differential quadrature method was presented to study the free vibration of moderately thick composite plate with edges elastically restrained against translation rotation . The governing equation is based on the first order shear deformation theory .Angle- ply and cross-ply laminates with different aspect ratio, thickness to length ratio are examined .Comparisons are made with results for thin and moderately thick angle-ply and cross-ply laminated plates [4] . The effect of seawater absorption was investigated on fatigue damage accumulation in glass fiber reinforced polyester laminate of the type widely used in the marine and offshore industries , using four point bending flexural loading to ensure peak strain in the outer layers of the material most subjected to seawater absorption . Acoustic emission was used to characterize damage accumulation. The results were found to correlate well with independent measurements of changing bending stiffness and with micro structural observations of the damage sections [5]. The effectiveness of using U V curing resin to fast repair laminated beams damaged by low velocity impact was investigated experimentally . A total of 45 effective specimens were prepared, damaged, repaired, conditioned, and tested. A finite element analysis was conducted to understand the failure modes of the repaired samples [6]. Three different unidirectional polymer-glass composite systems involving phenolic and polyester resins aged for six and eleven weeks in tap water were tested in the mode I double cantilever beam test .The results showed a dramatic increase in water absorption and a decrease in fracture toughness for phenolic/glass systems [7] .The effect of seawater immersion on the durability of glass and carbon fiber reinforced polymer composites was investigated experimentally, the materials used were glass/polyester, carbon/polyester and glass/vinyl ester and carbon/vinyl ester composite. The samples were immersed in seawater at a temperature of 30 °C for two years. The composites experienced significant moisture absorption and suffered chemical degradation of the resin matrix and fiber/matrix inter phase region which degraded the flexural modulus and strength of the composites and only mode I inter laminar fracture toughness was affected by the immersion [8]. A moisture absorption test was performed on unidirectional glass/polymer composite materials. The composites were exposed to a moist environment of relative humidity of 80% at 50 °C. Also finite element techniques were used to study numerically the effect on the composites Significant differences in the moisture absorption properties of composite specimens were found indicating that the effect of moisture on the mechanical and electrical properties of material depends on the type of composite used [9].The capability and effectiveness of E-glass fiber-reinforced UV cured vinyl ester composites to repair damage RC beams were investigated, then the repaired beams were again subjected to a four bending test, this time until failure ,then the effectiveness of UV curing FRP on the fast repairing damage of RC beams were evaluated based on the tested results [10].The failure of polymer matrix composites upon exposure to the combined action of temperature ,humidity and UV radiation were studied .The dynamic mechanical analysis, for a range of temperatures and frequencies under tensile and three point bending loadings, revealed that the aged materials gained stiffness ,whereas a small deterioration in strength was found. [11].Experimentally the effect of seawater on the bearing strength behavior of the woven glass fiber composite was investigated. The ratio of edge distance and width of specimen to pin diameter were systematically varied during experiments. The specimens were tied to a ship making voyage in the Sea of Marmara to provide real environmental conditions. The specimens were exposed to the seawater of 2.2 percent of salt at 22-26 °C surface temperature for a period of one, two and four months. The results showed that specimen bearing values obtained for the four months specimens decrease considerably with respect to that of one and two months. But, the failure modes for all configurations are in the same mode. Failure distance of the pin displacement increases with the increase of the immersing period owing to softening of the specimen[12].

As the laminated beam, plates or shells become more and more important in all industries and in modern engineering applications, so wide attention has been paid on the experimental, theoretical and numerical analysis for static and dynamic problems of such Structure in recent years [13]. And as a result, there have been important objective reasons for studying and investigating the environmental effects ranging from UV exposure to moisture absorption on the mechanical properties and vibration characteristic of eight layer cross ply arranged in symmetrical and antisymmetrical orientation [0/90/0/90].This was done through studying the effect of time exposure on the natural frequencies and mode shapes for each case of environment.

2- Sample Preparation:

It is well known that the laminated composites consist of layers of at least two different materials that are bonded together. Lamination is used to combine the best aspects of the constituent layers in order to achieve more useful material. This definition quite fits with the class of laminated fibrous composites (composed of fibers in a matrix) in which the final composite product results from the layer stacking. The method that is used in the present work for manufacturing the laminated composite plates is hand lay-up which is the oldest method that was used to get the composite materials as shown in Figure (1) [14].In this study, E-glass fibers and polyester resin matrix were used for the preparation of the laminated plates. Table 1 shows the mechanical properties of E-glass and polyester materials.

2-1 Determination of fiber volume fraction, Vf

The relative quantity of the various constituents in a composite is known as the volume fraction and is normally expressed as the ratio of volume of reinforcement and the total volume of the composite. Experimentally, it is easier to determine the fiber weight fraction *Wf* from which the fiber volume fraction can be calculated using the following equation [15]:

$$V_f = \frac{1}{\left[1 + \frac{\rho f}{\rho m}\left(\frac{1}{Wf} - 1\right)\right]} \quad .... (1)$$

Where V_f is the fiber volume fraction, W_f is the fiber weight fraction, ρm is the matrix density (g/cm3) and ρf is the fiber density (g/cm3). The fiber weight fraction can be experimentally determined by ignition loss method. This was used for the polymeric matrix composites containing fibers that do not lose weight at high temperature, such as E-glass fibers. In this method, cured resin is burned off a small test sample at 565 °C in a muffle furnace.

Based on the above method, the values for the fiber and matrix volume fractions are V_f = 41.59%, V_m = 58.41% for the symmetric and V_f = 43.46%, V_m = 56.54% for the anti-symmetric samples. Table 2 shows the values of elastic and shear modules and the ratios for the symmetric and antisymmetric samples.

3. Test Environments

For Tap and Sea environment procedures, two 600 X 600 X 260 mm glass boxes as shown in Figure 2 were designed as conditioning chambers, and divided into two sections, one for symmetric specimens and the other for anti-symmetric specimens. The sea water was then taken from the Arabian Gulf of constituents shown in Table 3; the tap water was taken from the tap of United Arab Emirates University. With regards to Humidity environments, a glass box 600x600x20 mm was designed as the conditioning chamber which was divided into two sections; The first section is for symmetric specimens while the second was for anti-symmetric specimens. The environmental conditioning chamber placed in special room designed to simulate the humidity impact in the civil engineering department in United Arab Emirates University. Finally, when considering Ultraviolet chamber, a Special wood chamber designed and built with dimensions (70 X 70 X 70) cm. The UV effect was studied using , a 300 Watt R40 *OSRAM SUN LAMP* - E27 BASE - 230 Volts - HIGH UV LIGHT BULB, 1000 hr virtual age. UV lamp was used as the UV radiation and specimens (symmetric and anti symmetric) put inside the chamber to simulate the ultraviolet environment. The distance between UV lamp and the samples surface was about 60 cm [6], UV lump and chamber shown in Figure 3 a & b.

4. Experimental Results

The three points bending testing method has received a wide acceptance in the composite material industry [16]. This method was utilized in order to investigate the changes in flexural stiffness due to environmental exposure at different exposure time (500-1000-2000) hrs. The bending tests were performed according to ASTM standard D 790-02 [17], using a universal tensile testing machine MTS (20/MH). A supported span-to-depth ratio of 16:1 was maintained for all tested samples as shown in Figure 4. Table 4 shows the change in flexural strength and modulus before and after exposure to different environmental conditions and times.

5- Theoretical Results*:*

Finite element procedures are very widely used in engineering analysis, and their applications are expected to increase significantly in the coming years. These procedures are employed extensively in the analysis of solid structures, heat transfer and fluids. Moreover, finite element methods are becoming more and more useful in virtually every field of engineering analysis [18].

Finite element method analysis ANSYS (version 10) is used to study the dynamic behavior by taking the experimental parameters obtained in previous section to obtain the natural frequencies and mode shapes for different environmental conditions for cantilever plate as shown in Figure 5.

ANSYS used in this study element (Shell 99) (this element used for layered application of structural shell model up to 100 different material layers are permitted, 8 nodes and has six degree of freedom at each node, translation in the nodal x, y and z direction and rotations about the x, y and z axes (Ux, Uy, Uz, qx, qy, qz).With regards to the variation in natural frequencies, this was shown in Table 5 and 6. Specimens for free vibration of laminated plate symmetric and anti-symmetric for zero hour exposure for different modes shapes have been illustrated .Also it can be seen the effect of environmental conditions (Tap water, Sea water, Humidity and Ultraviolet radiations) on the fundamental natural frequencies for different orientations (cross-ply) of eight layers Symmetry (0/90/0/90/90/0/90/0) and anti-symmetric (0/90/0/90/0/90/0/90). With exposure time to the Tap water for symmetric and antisymmetric composite plate, the natural frequencies for symmetric plate decreases about 25% during the first 500 hrs, and 30% during time (500-2000) hrs. While for antisymmetric the natural frequencies decrease 5% at the first 500 hrs and after 1000 hrs it decreases in steady state to value 13%. Variation in natural frequencies with exposure time to Seawater . Symmetric laminates decrease about 27% of their natural frequencies during the first 500 hr of exposure time and after that it keep they decreasing but at a very slow rate. Similarly antisymmetric laminates decrease about 9% of their natural frequencies during the first 500 hrs of exposure time, they lose more than the symmetric samples during the next 500 hrs and they keep decreasing but at a slow rate after 1000 hrs. Overall, the symmetric laminates lose approximately 30% of natural frequencies and the antisymmetric lose approximately 15% of the natural frequencies after 2000 hrs of exposure time. Also the effect of humidity exposure on the natural frequencies of the symmetric and antisymmetric laminates as shown. After 2000 hrs of exposure time, symmetric laminates lose about 32% of natural frequencies of which 24% were lost during the first 500 hrs of exposure time. Antisymmetric samples lose about 14% of the natural frequencies, in which 6% were lost after 500 hrs of exposure time. Finally the table shows the relation between the natural frequencies with exposure time to ultraviolet radiation; within the first time at 500 hrs the symmetric laminate loses 25% up to 40% after 2000 hrs, antisymmetric lose 5% up to 19% after 2000 hrs. Figure(6),shows the comparisons of natural frequencies for different environmental conditions for the first, second and third mode shapes of free vibration for the symmetric and antisymmetric laminate plates. Finally when considering Mode shape ,Figure 7 represents the modes of free vibration of cantilever plates for the (1^{st}), (2^{nd}), (3^{rd}), (4^{th}) and (5^{th}) mode shapes of vibration. It can be observed that the 1^{st}, 3^{rd}, 5^{th}modes are very much pure bending while the 2^{nd}, 4^{th} have a combined action bending and torsion these five modes are for the free vibration without any impact of the environmental on it.

6-Conclusions

The natural frequencies of cantilever laminate plates decrease with increased exposure time for the different environmental conditions. This is because that mass of the structure increases in magnitude which in case of tap water, sea water exposure the specimens absorption reaches saturation state as time change, so it will be lower in tap water while it is lowest in case of sea water due to the increase in mass because of the extra mass of salt, also can observe that the case of UV radiation value is nearer to the case of tap water exposed samples. Also the reduction is because of the structure stiffness magnitude reduces which causes the natural frequencies especially in case of sea water which is lower than tap water and humidity and UV exposure. Also the fiber orientation has a great effect on the magnitudes of frequencies as exposed to tap water, sea water, humidity and UV radiation but the frequencies in the antisymmetric are a little bit higher than symmetric case this is because the stiffness magnitude will be definitely larger so that high frequencies will happen.

7. References

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Table (1) Mechanical properties of E-glass and polyester

Materials	Density (g/cm3)	Young's Modulus (GPa)	Tensile strength (MPa)	Failure strain (%)
Polyester	1.2-1.5	2.0-4.5	40-47	2.2
E-glass	2.56	76	2000	2.6

Table (2) Calculated mechanical properties for the samples prepared in this study

Mechanical properties	Expression	Results	
		Symmetric Vf=41.59 Vm=58.41	Antisymmetric Vf=43.46 Vm=56.54
E_1(Gpa)	$E_1 = E_f V_f + E_m V_m$	32.77	34.16
E_2(Gpa)	$E_2 = \frac{E_f E_m}{V_m E_f + V_f E_m}$	3.36	3.467
ν_{12}	$\nu_{12} = \nu_f V_f + \nu_m V_m$	0.272	0.27
ν_{21}	$\nu_{21} = \nu_{12}\, {}^{E2}\!/_{E1}$	0.0278	0.0273
$G12$(Gpa)	$G_{12} = \frac{G_f G_m}{G_f V_m + G_m V_f}$	1.283	1.32

Table (3) Analysis of seawater from Abu Dhabi coast (Arabian Gulf)

Constituent	
CL	16702(Mg/1)
So_4	2211(Mg/1)
Mg	1509(Mg/1)
Ca	438(Mg/1)
PH	8.20
Conductivity	48600(uS/cm)

Table (4) Flexural properties before and after exposure to environmental conditions

conditions	Exposure time hr	Flexural stress *MPa*		Flexural modulus *GPa*	
		Symmetric	Antisymmetric	Symmetric	Antisymmetric
Original	Zero	391	459.6	26.22	22.43
Tap water	500	310	438	14.9	20.4
	1000	306.5	433	14.1	17.5
	2000	298	409	12.6	16.8
Sea water	500	368	431	14	18.4
	1000	353	421	13.2	16.7
	2000	330	419	13	16.3
Humidity	500	370	453	15.24	19.8
	1000	370	428	13.43	17.77
	2000	318	427	12	16.44
UV radiation	500	383	456	14.88	20.11
	1000	376	441	11.14	16.45
	2000	355	437.4	9.3	14.74

Table (5) Values of the natural frequencies at exposure time zero hour for cantilever laminate plate.

Natural frequencies (Hz) at time = 0					
Mode No.	First freq.	Second freq.	Third freq.	Fourth freq.	Fifth freq.
Sequence					
Symmetric	57.335	176.477	354.552	601.925	719.088
antisymmetric	52.653	162.064	325.597	552.767	660.361

Table (6) Variation in the natural frequencies for different environmental conditions for five mode shapes of vibration, using FEM (ANSYS-10)

Conditions		Natural frequencies (Hz) at exposure time (hr)					
		500		1000		2000	
Mode No.		Sym.	Antisym.	Sym.	Antisym.	Sym.	Antisym.
Tap water	Mod1	43.221	50.213	42.045	46.508	39.746	45.568
	Mod2	133.034	154.557	129.414	143.15	122.337	140.258
	Mod3	267.274	310.513	260	287.597	245.781	281.786
	Mod4	453.753	527.16	441.404	488.255	417.265	478.39
	Mod5	542.074	629.77	527.321	583.292	498.484	571.507
Sea water	Mod1	41.896	47.689	40.681	45.432	40.372	44.885
	Mod2	128.954	146.785	125.215	139.84	124.263	138.155
	Mod3	259.076	294.9	251.565	280.946	249.652	277.561
	Mod4	439.836	500.653	427.084	476.964	423.836	471.218
	Mod5	525.448	598.103	510.214	569.804	506.334	562.938
Humidity	Mod1	43.712	49.47	41.034	46.865	38.788	45.077
	Mod2	134.544	152.267	126.302	144.25	119.388	138.747
	Mod3	270.306	305.913	253.748	289.807	239.858	278.751
	Mod4	458.901	519.35	430.789	492.007	407.209	473.237
	Mod5	548.224	620.44	514.64	587.774	486.47	565.351
Ultraviolet	Mod1	43.192	49.855	37.372	45.091	34.146	42.683
	Mod2	132.945	153.454	115.031	138.789	105.102	131.378
	Mod3	267.095	308.298	231.103	278.836	211.157	263.945
	Mod4	453.448	523.4	392.346	473.381	358.482	448.102
	Mod5	541.71	625.278	468.714	565.523	428.26	535.323

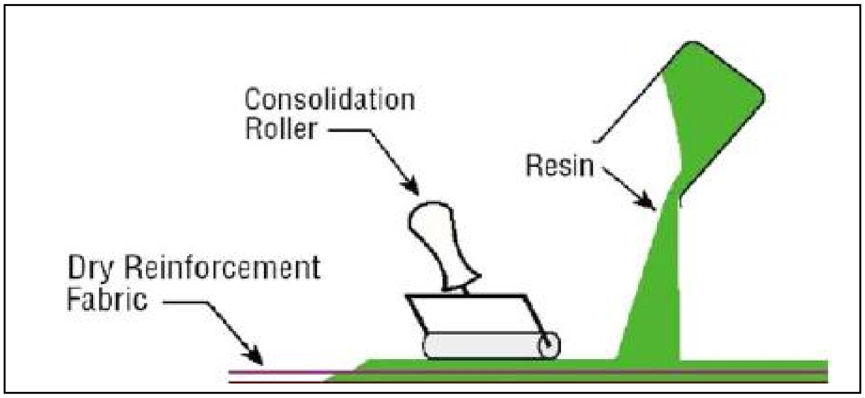


Figure (1) Hand lay-up technique [13]

Figure (2) Seawater and tap water chambers

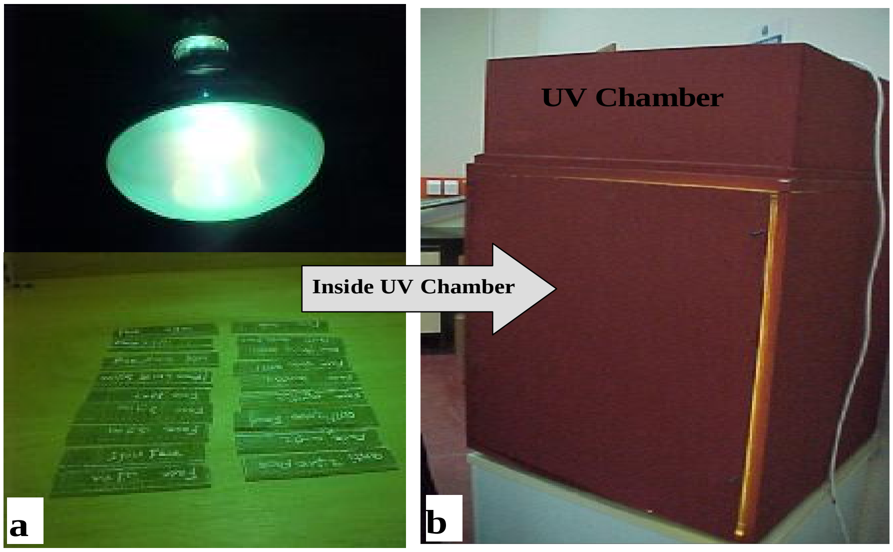


Figure (3) a- UV lump and specimens b- UV Chamber

Figure (4) Three point bending testing machine

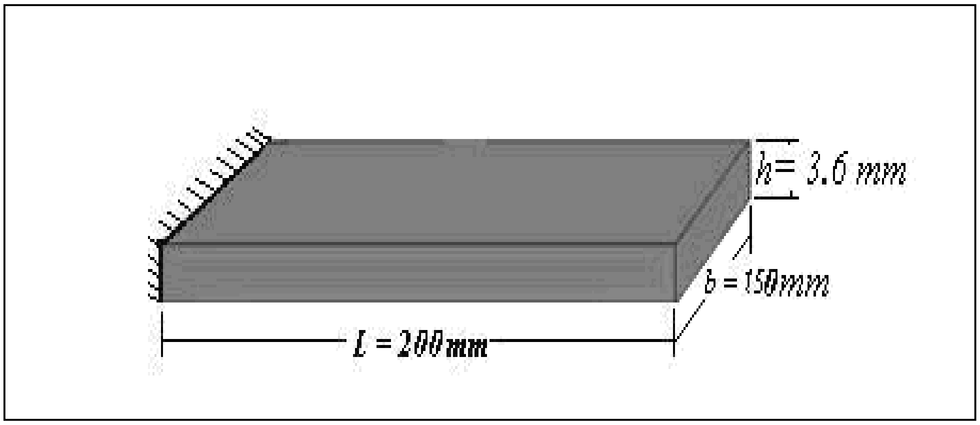


Figure (5) Cantilever laminate plate

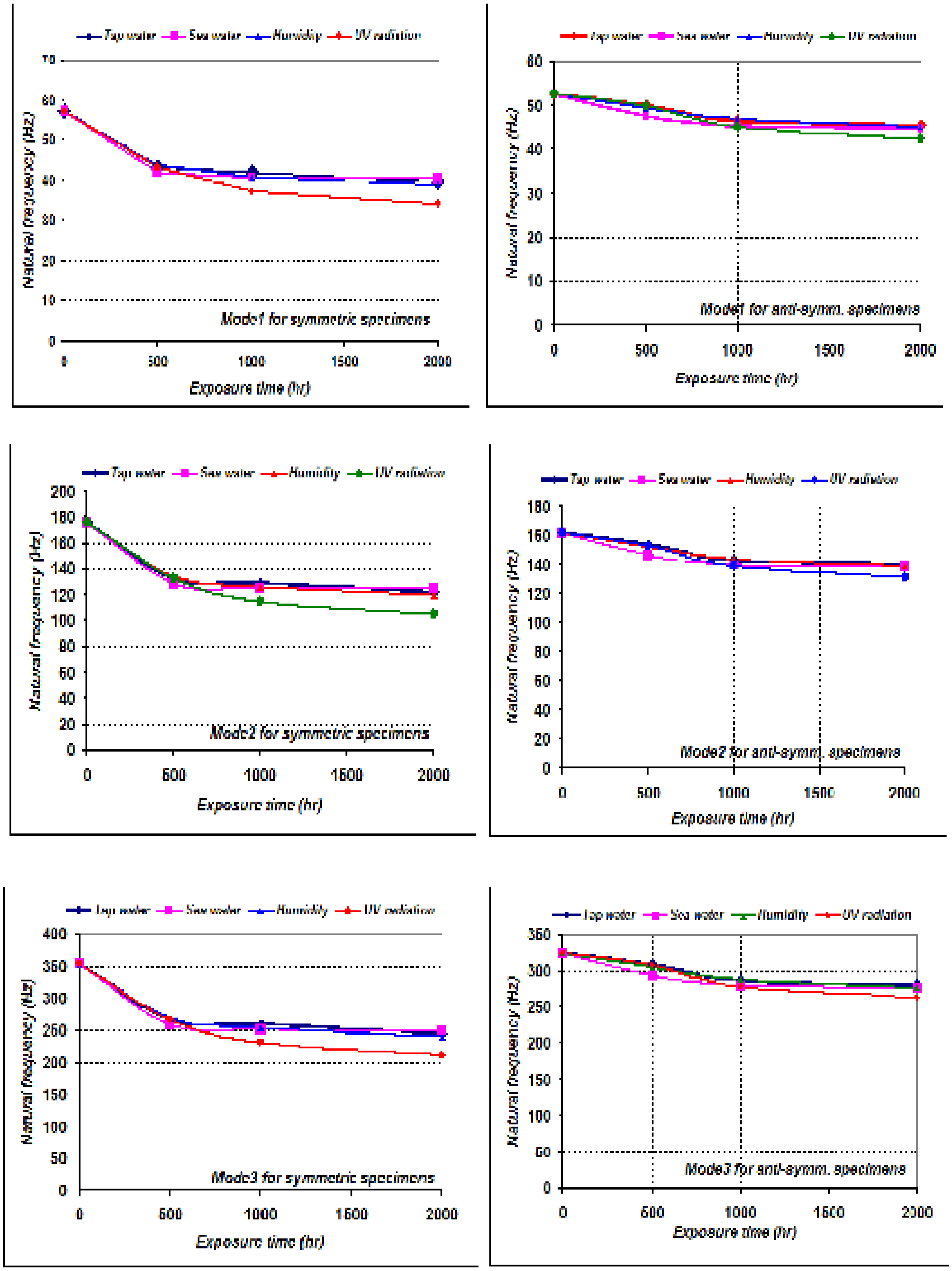
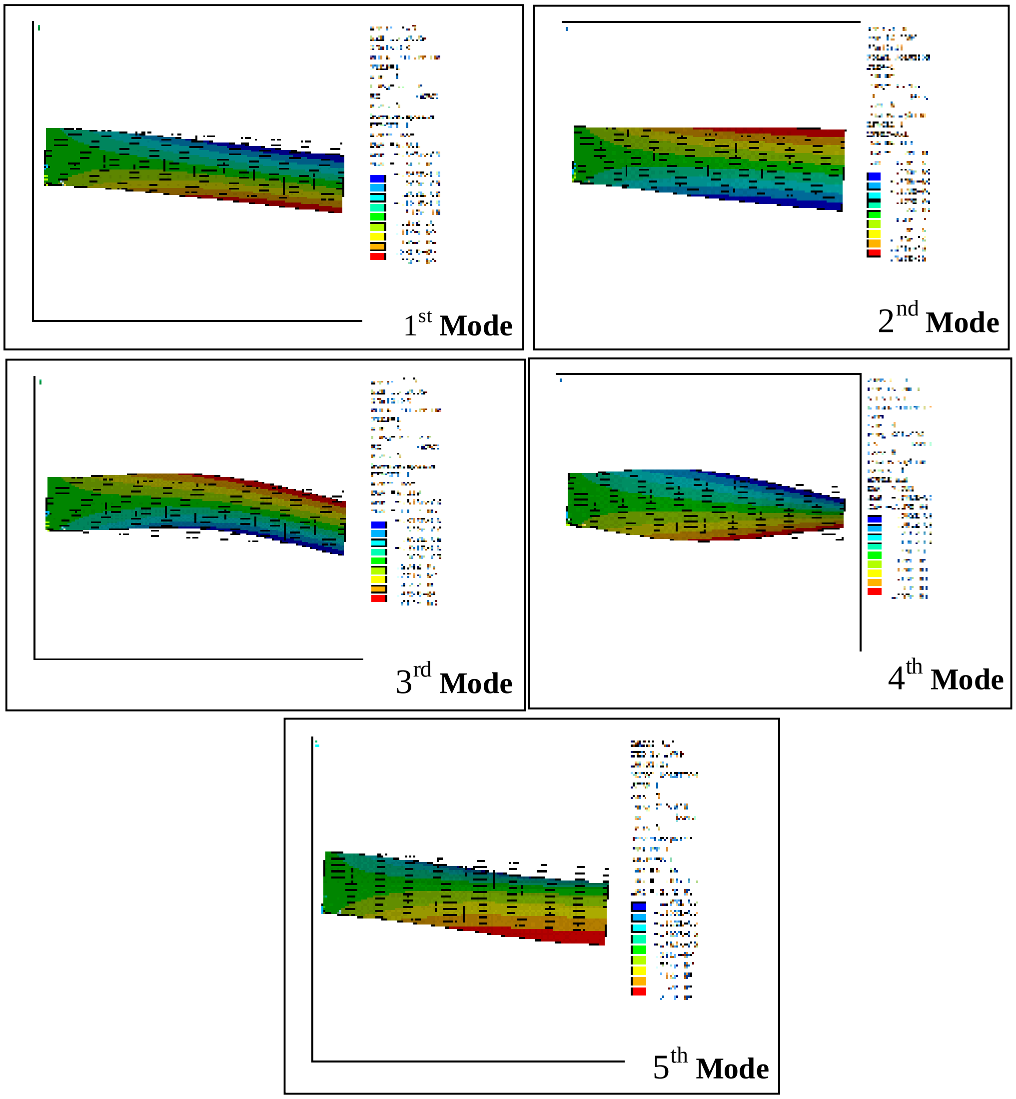


Figure (6) Comparison of the natural frequencies for different environmental



1st **Mode**

2nd **Mode**

3rd **Mode**

4th **Mode**

5th **Mode**

Figure (7) 1st, 2nd, 3rd, 4th, 5th mode shapes of symmetric cantilever plate.