Experimental and Numerical Investigation of Hyper Composite Plate Structure Under Thermal and Mechanical Loadings

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ABSTRACT

In this study eleven models of the rocket fins were made of hyper composite material with different values of volume fraction of components (70%, 60%,50% for polyester, 40%, 30%,25%,20%,10% for fibers and 0%, 5%, 10%, 20%, 30%,40%for powder) to produce an isotropic composite plate structure. The reinforcement of the matrix is done by mixing of the polyester resin with the carbon fiber and carbon powder. Mechanical and thermal properties were evaluated by conducting several tests. A concentrated load was applied on these models the effect of adding the carbon powder on the maximum deflection and the effect of temperature on this deflection were studied and discussed. The temperature range was suggested according to the matrix ability and applications. The experimental results were verified numerically using ANSYS finite element program. The results showed that the addition of carbon powder to the composite material composed of polyester and glass fiber leads to increase the value of Young 's Modulus (maximum value 6.36 GPa) and decrease the amount of maximum deflection. The maximum deflection was increased with the increasing of temperature. The lowest value of maximum deflection was occurred in the model composed of (50% polyester,30%glass fiber and 20% powder) which reached to 1.56 mm. The comparison between experimental and numerical results showed a good agreement between them.

Key words: rocket fins, hyper composite material, maximum deflection, thermal and mechanical loads.

دراسة عملية وعددية للصفائح المركبة الهجينة تحت تأثيرالاحمال الميكانيكية والحرارية

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الخلاصة

في هذا البحث تم تصنيع احد عشر نموذج من زعانف الصاروخ صنعت من مادة مركبة هجينة ذات كسور حجمية مختلفة (70% 60%,50% للبوليستر و 40%, 30%,25%,20%,10% للالياف و 0%, 5%, 10%, 20%, 30%,40% للباودر)لأنتاج صفيحة من مادة متماثلة الخواص. ان المادة الاساس قويت باستخدام الياف الزجاج مع باودر الكاربون. درست الخواص الميكانيكية والحرارية من خلال اجراء عدة اختبارات. سلط حمل متمركز على هذه النماذج وتم حساب اقصى انحراف لها مع دراسة تأثير درجة الحرارة على ذلك الانحراف. ان مدى درجات الحرارة كان بالاعتماد على قدرة المواد المستخدمة والتطبيقات العملية. تم التحقق من النتائج العملية عدديا باستخدام برنامج انسز. أظهرت النتائج أن إضافة مسحوق الكاربون للمادة المركبة المكونة من مادة البوليستر والألياف الزجاجية يؤدي إلى زيادة معامل المرونة حيث وصل الى 6.36 GPa وخفض الحد الأقصى للانحراف. ازدادت قيمة الحد الأقصى للانحراف بزيادة قيم درجات الحرارة المسلطة على النموذج. ووجد ان أقل قيمة للأنحراف الأقصى ظهرت في النموذج المكون من (50% بوليستر و30% الياف زجاج و20% باودر كاربون) حيث بلغت (1.56 mm). ان المقارنة بين الدراسة العملية والعددية بينت ان هناك اتفاقا جيدا بينهما.

الكلمات الرئيسية: زعانف الصاروخ، مواد مركبة هجينة، أقصى انحراف، احمال حرارية وميكانيكية

1. INTRODUCTION

1.1 Hyper Composite Material

Hyper composite material is more advanced composite as compared to established fiber-reinforced polymer (FRP). Hyper composite material can have more advanced than single reinforcing phase with a single matrix phase or multiple matrix phases with single reinforcing phase or multiple matrix phases with multiple reinforcing phase. It is possible to obtain the advantage of the various fibers while coincidental mitigating their undesirable qualities by combining two or more kinds of fibers, **Mutsuyoshil** and **Aravinthan**,**2010.**
There are three kinds of hyper composites: matrix hyper, fiber hyper and interfacial hyper. The matrix hyper means combining of two or more type of resin in one composite. The fiber hyper means different fibers using in one textile while interfacial hyper means combining of two or more type of fiber bundles with various surface treatments. The mechanical properties of these hyper composites (high specific strength, high specific stiffness, energy absorption, low density and corrosive resistance) variegated according to changing volume ratio and stacking succession of different plies **Mohammed**, **2013.**
Ibrahim, 2011, studied the influence of reinforcing polymer with graphite and glass particles. The results showed that the hyper composite material (20% glass, 30% graphite, 50% epoxy) has higher flexural strength than polymer matrix material. **Smait** and **Mohammed, 2012,** studied experimentally the effect of graphite filler on the mechanical behavior of glass – polyester composite material at (30% volume fraction). The results showed that the mechanical properties were improved with the increasing of the graphite filler to (7.5%) and it was regressed above this content. **Sakthivel** and **Ragendran, 2014,** fabricated hyper composite material using natural and glass fiber. The results showed that the hyper composite material has higher mechanical properties in the tensile, impact and flexural tests**. Basim et.al, 2014,** prepared hyper composite material using epoxy resin and glass fiber with volume fraction of 6% and calcium carbonate as powder with volume fraction 3% and 6%. The results showed that the increasing in hardness and flexural strength is shown with the increasing of powder volume fraction and smaller particles size.

1.2 Thermal Effect on Composite Material

The environmental conditions have a significant effect on the physical and mechanical properties of engineering materials, which is one of the basic things that should be taken into consideration. In view of the properties of the composite material such as high strength to density ratio and high thermal and electrical insulation and the urgent need to be used in a lot of military and engineering fields such as aircraft, ships, rocket, hydrofoils and space vehicle which are subjected to change in the ambient temperature. This changes in the temperature incite the researchers to study the effect of temperature on the properties of these materials, **Thanon, 2013.**
Putic et.al, 2006, studied the effect of low and high temperature on the impact properties of glass-epoxy composite. The impact strength was presented at three temperature levels. They showed that the impact properties were higher at the elevated temperature and they were the smallest in low temperature. **Abbas, 2007,** studied the influence of temperature on the young modulus, flexural

strength, impact strength and thermal conductivity of hyper composite material manufactured from epoxy with glass fiber and carbon fiber at different temperature (23, 40 and 60) °C with volume fraction of 30%. The results showed that young modulus is decreased with the increasing of the temperature, but, the flexural strength, the impact strength and the thermal conductivity were increased with the increasing of the temperature.**AL-alkawi, et al, 2012,** studied the effect of temperature on the value of the ultimate tensile strength of composite material manufactured of polyester as resin and E-glass woven fiber. The results showed that when the temperature was increased the ultimate tensile strength was increased.

The goal of this research is to manufacture eleven model of Hybrid composite plate (rocket fin) and study the mechanical and thermal properties of these models and then applying a concentrated load to obtain the maximum deflection. In the other hand the thermal effect on this deflection is to be investigated. These models were made of unsaturated polyester with different values of volume fraction of fiber glass and carbon powder.

2. EXPERIMANTAL WORK

2.1 Materials

Unsaturated polyester was used as a matrix. It is viscous liquid, transparent and thermosetting polymer type. It is converted to a solid state by mixing with the hardener (2% of polyester weight). The type of fiber used is E-glass (chopped) and the type of powder is carbon powder (Avg. Diameter:109.86 nm, Purity 99.997%).

2.2 Preparation of Mold and Manufacturing of Tensile Test Samples and Fins

The mold is manufactured of wood and glass so as to make the samples with the desired dimensions [25 cm x 25 cm x 0.3 cm]. And then prepare the mold using wax to insure the clean and smooth facing and also to easy the process of sample removal. **Fig.1.**

There are several methods to manufacture a composite structure. There are advantages and disadvantages for each one of them. It has been using the hand lay out method to prepare the models and samples because it is the simplest procedure to use and the way by which to obtain the samples in different shapes and sizes. The models of rocket fin which have been manufactured in this research are shown in the **Fig. 2.**

2.3 Tensile Test

According to ASTM D638-03 the samples were cut up from the manufacturing plate; 165 mm length, 19 mm width, 3mm thickness [three sample for each sample] as shown in **Fig. 3-a** This test is done in Materials Engineering Department / University of Technology. The tensile test machine is shown in **Fig. 3-b**. The specimen was put in this machine and then pulled hydraulically with strain rate (0.5 mm/min). **Fig. 4** shows the manufactured tensile test specimens before the test and after the failed.

2.4 Thermo-Mechanical Analyzer (TMA) Test

TMA is a technique used to measure the change in the dimensions of sample (length or volume) as a function of temperature. There is widely application for this technique to various material such as polymers, metal, ceramic, glass and fiber etc. It was used in this research to evaluate the Young Modulus and coefficient of thermal expansion as a function of temperature. The device, the dimensions of sample and the manufacturing sample are shown in **Fig. 5**. This test was achieved in polymer department of Ministry of Science and Technology.

2.5 Thermal Conductivity Analyzer (TCI)

TCI is a device used to measure the thermal conductivity and effusively of materials. It can be used for various materials such as powder, liquid, solid and pastes and gives the result in a short time, when compared with other devices. The device, the dimensions of sample and the manufactured sample are shown in **Fig. 6**. This test was achieved in polymer department of Ministry of Science and Technology.

2.6 Bending Test

The aim of this test is to identify the linear behavior of the material under the influence of the applied load vertically to the surface plane of it. The bending test includes the determining of the value of the deflection that occurs by the effect of applying the force. The bending structure rig is consisting of the following parts as shown in **Fig. 7.**

1. Metal vise is used to fix the models of the rocket fins as a cantilever plate
2. Dial indicator is an instrument used to measure the deflection in the tip of the fin due to loading. It was fixed by the holder
3. Load cell is a sensor used to create an electrical signal which it's magnitude is proportional to the applied load.
4. Load cell indicator is used to convert the signal coming back from the load cell into force signal. The type used in this research displays force in kg unit.
5. Power supply is to provide the device with electric power.
6. Electric stove used to heat the models.
7. Thermos-reader with thermocouple is used to measure the temperature of the samples during the test.

All instrument used in this test were calibrated in Central Organization for Standardization and Quality Control. The concentrated force is applied by rotating the screw which is existing on load cell.

3. NUMERICAL ANALYSIS

The analytical solution of the plate bending is depending on the condition of the plate (geometry, boundary condition and load configuration). If these conditions are so complicated, the analytical solution becomes also complicated. In case a complex structure the numerical solution is used to verify the experimental results. The finite element method is a muscular computational technique in order to obtain the solution of integral and different equations that increasing in most fields of science and engineering, **Timoshenko, 1959.**

The deflection of models of fins is analyzed using finite element method by employment ANSYS program (version 15). The element type used in this research is shell 281 and its geometry is shown in **Fig. 8**. ANSYS recommends against using element in triangle form, zero-area elements are not allowed, zero-thickness elements are not allowed and no slippage is assumed between the element layers' shear deflections are included in the element; however, normal to the center plane before deformation are assumed to remain straight after deformation. Mechanical and thermal properties were defined to create the numerical model, then meshing the model with appropriate mesh, applying boundary condition, applying concentrated load, solving and finally plot the deflection for each model.

4. RESULTS AND DISCUSSION

The results of hyper composite models of rocket fin included the experimental results of mechanical and thermal properties of these models composed of chopped glass fiber; carbon powder and polyester resin with different volume fraction are listed in **Table 1**. Young modulus experimentally determined from the slope of the stress – strain curve created during tensile test conducted on a sample of material, the unit of it is (Pa or N/m^2). In addition to evaluate the effect of added carbon powder on the maximum deflection of these models and, study the effect of temperature on this deflection; the maximum deflection of isotropic hyper composite models of rocket fins is evaluated experimentally and numerically. A comparison between experimental and numerical results is done.

The mechanical and thermal properties of the fins studied are also shown in **Table 1. Fig. 9** shows the effect of adding powder on the maximum deflection of the fins consist of 30% glass fiber. It is clear that the addition of powder to the composite structure decreases the maximum deflection as a result of an increase in the Young 's Modulus. The same behavior was occurred for the models that consist of 20% glass fiber as shown in **Fig. 10** but in models consist of 10% volume fraction of glass fiber; the maximum deflection is increased then decreased as shown in **Fig. 11**. The effect of replacing of glass fiber with powder is shown in **Fig. 12, 13** and **14** for the models consist of (70, 60 and 50) % of polyester, respectively. These behaviors are happened because of the carbon powder has high value of tensile strength and flexibility if compared with the glass fiber، as well as randomly distributed in the polyester material and ease of penetration of matrix material in these powder and fiber creates a complete interface between the matrix and reinforcement material. But when the value of volume fraction of powder is increased, it leads to increase the maximum deflection due to the reduction in the value of Young's Modulus because of the difficulty of penetration of matrix material in powder and fiber which leads to the weakening of the interrelationship between matrix and fiber, thus reducing the efficiency of carrying the applied load on the composite plate. The same behavior was occurred in the **ref. (12).**

For all models of rocket fins the smallest maximum deflection was occurred in the model no.9 which consist of 50% polyster,30%fiber glass and 20% carbon powder. See **Table 1.**

The effect of temperature on that maximum deflection is shown in **Fig. 15** It is clear that the maximum deflection was increased in all models when the temperature increasing from room temperature to 60 °C because the temperature increase leads to a weak bonding strength between matrix and reinforcing materials thus it becomes soft and it happens a great strain. The minimum effect of temperature was happened in model no. 8 (40% fiber glass,10% carbon powder and 50% polyester

5. CONCLUSION

The most important conclusions that have been reached by this study are:

1. The addition of powder to the composite structure composed of polyester and glass fiber leads to the increasing of Young's Modulus (maximum value 6.36 GPa) and decreasing maximum deflection.
2. The comparison between experimental and numerical investigations showed a good agreement between the results.
3. Increasing of the value of the maximum deflection is happened due to temperature increase.
4. The minimum effect of temperature was happened in model no. 8 (40% fiber glass,10% carbon powder and 50% polyester)
5. the smallest maximum deflection was occurred in the model no.9 which consist of 50% polyster,30%fiber glass and 20% carbon powder.

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Table 1. mechanical and thermal properties of the models**.**

Model no.	Volume fraction of polyester %	Volume fraction of fiber %	Volume fraction of powder %	E (GPa)	K (W/m.C)	α (10^{-6})/C	Maximum Deflection (mm)
1	70	30	-	3.7	0.296	17.23	2.7
2	70	25	5	4.65	0.341	18	2.12
3	70	20	10	4.187	0.293	21.89	2.36
4	70	10	20	2.55	0.463	22	3.94
5	60	30	10	5.26	0.396	23.45	1.87
6	60	20	20	3.25	0.586	26.65	3
7	60	10	30	1.73	0.433	27.1	6.04
8	50	40	10	5.53	0.442	12.84	1.84
9	50	30	20	6.36	0.491	16.35	1.56
10	50	20	30	3.06	0.677	19.34	3.15
11	50	10	40	2.6	0.616	21.32	4

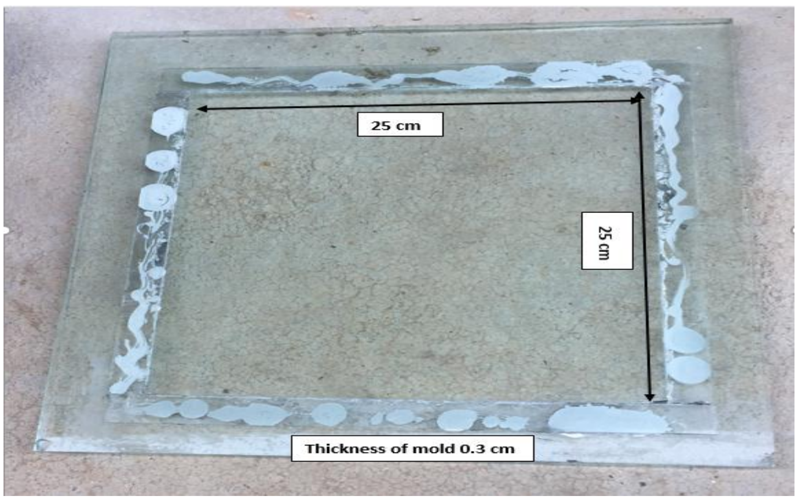


Figure 1. The mold**.**

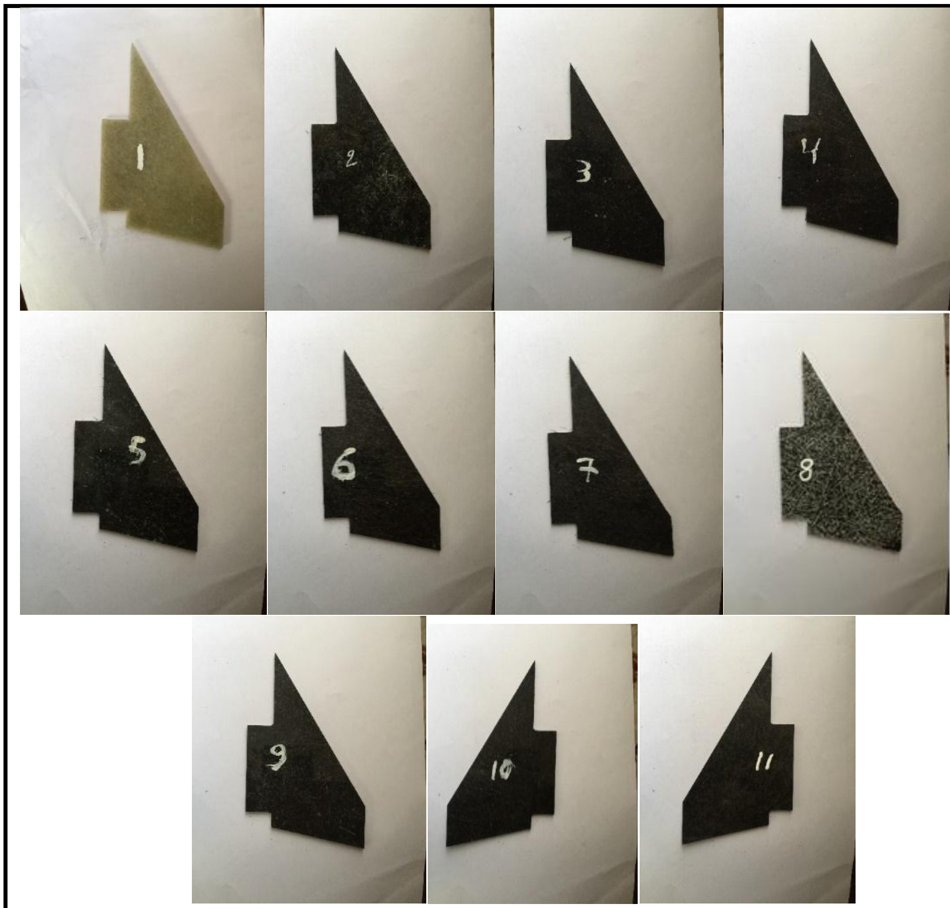
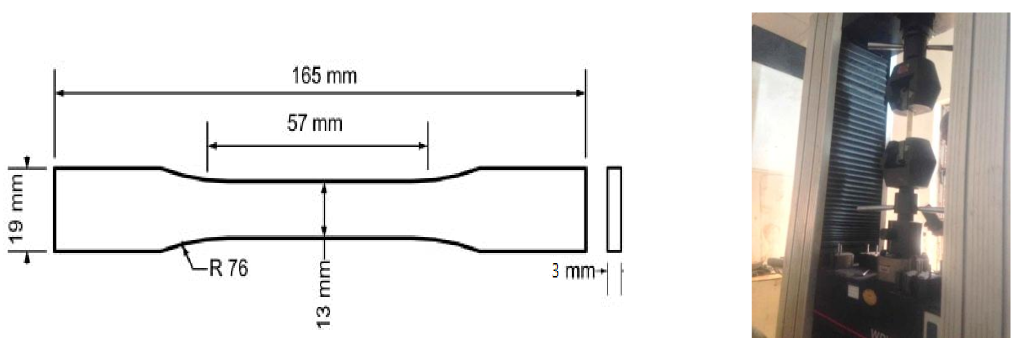
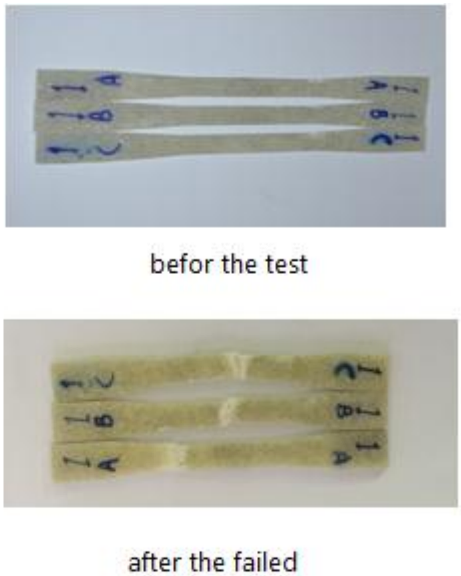


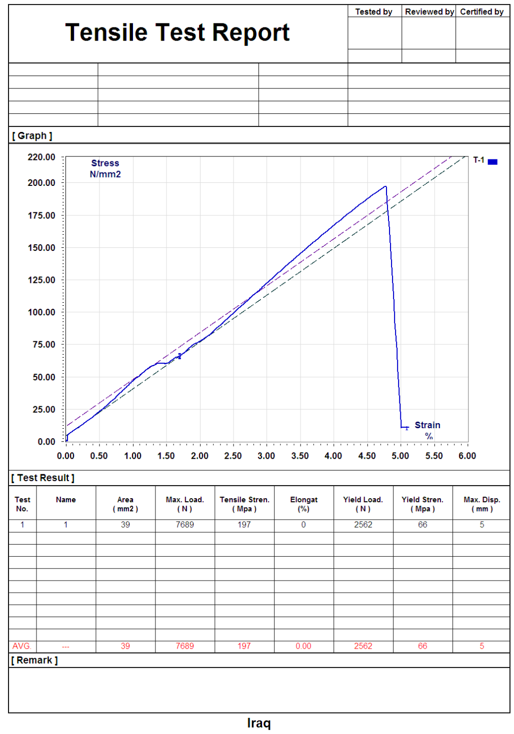
Figure 2. Models of rocket fins.



a **b**

Figure 3. (a) dimensions of tensile test specimen (ASTM D 638-03). (b) tensile test machine.

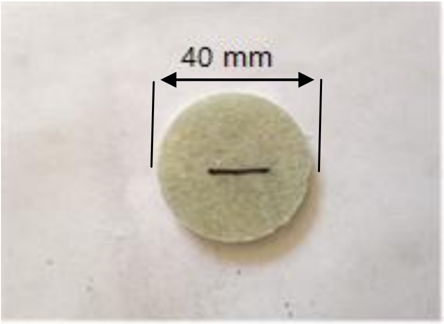




Test No.	Name	Area (mm2)	Max. Load. (N)	Tensile Stren. (Mpa)	Elongat (%)	Yield Load. (N)	Yield Stren. (Mpa)	Max. Disp. (mm)
1	1	39	7689	197	0	2562	66	5
AVG.	---	39	7689	197	0.00	2562	66	5

Figure 4. a. Tensile test specimens before the test and after the failed and the tensile test result.

Figure 5. Thermo-mechanical Analyzer (TMA).



Thickness 3mm

TCI device.

Figure 6. Thermo-conductivity Analyzer test (TCI).

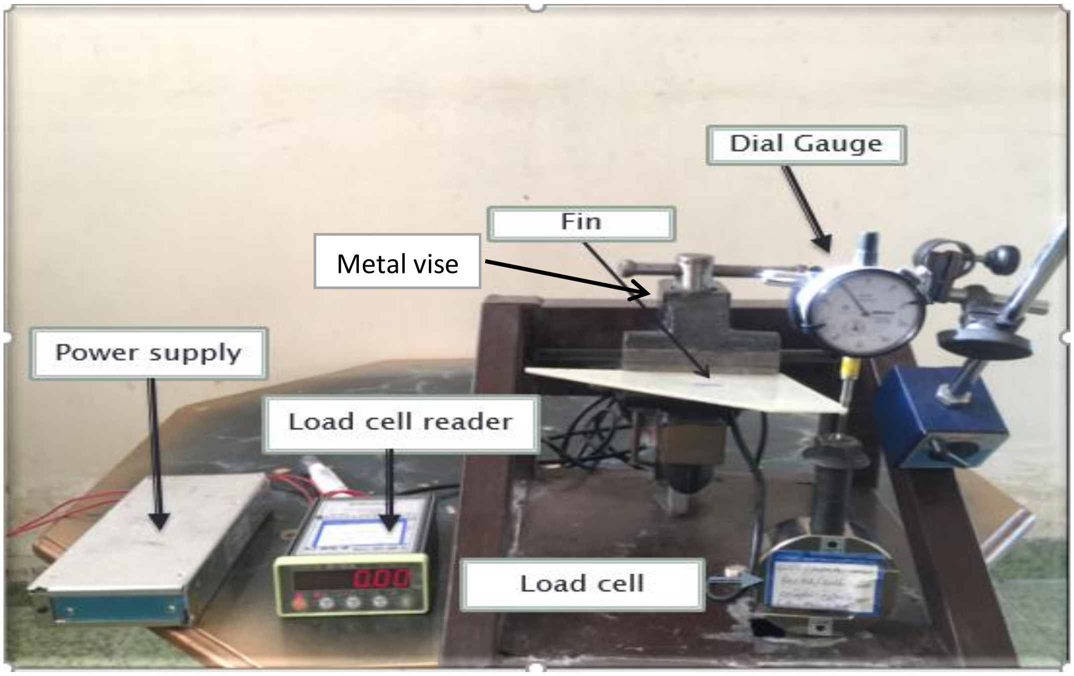


Figure 7. The test rig of bending test.

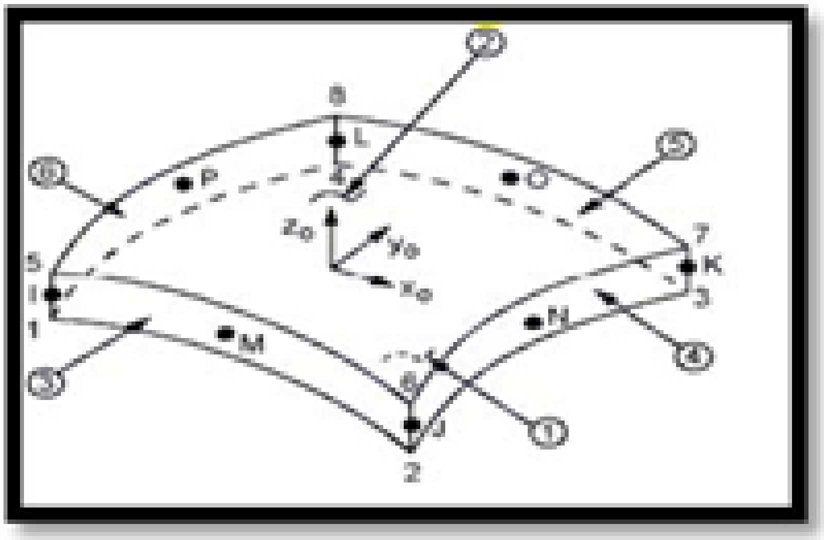


Figure 8. Shell 281 element.

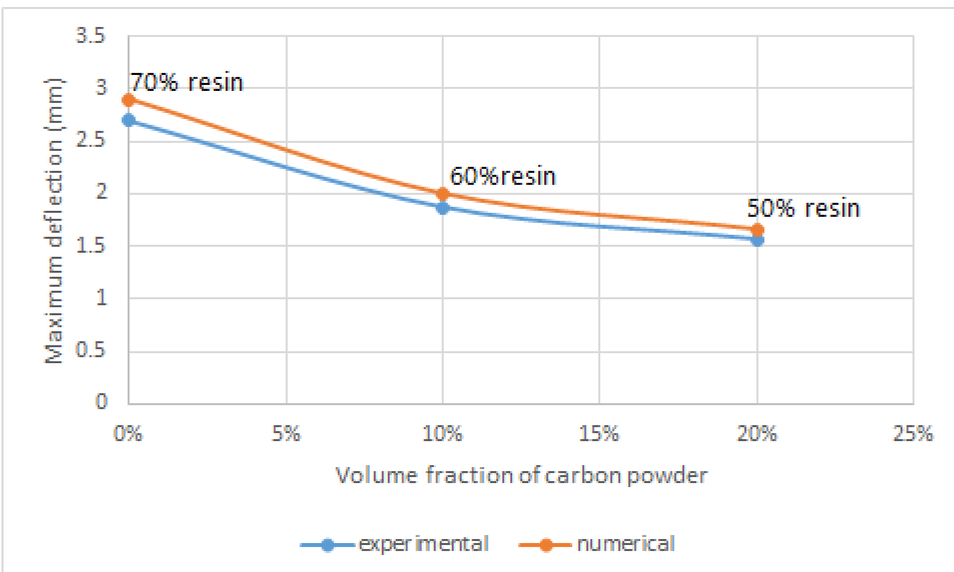


Figure 9. The effect of adding carbon powder on the maximum deflection of the models consist of 30% glass fiber.

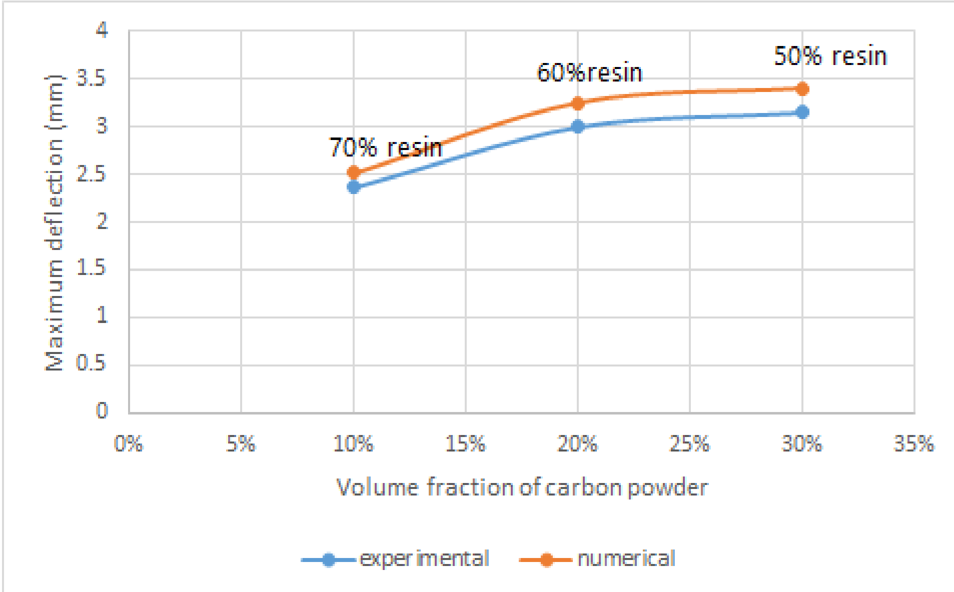


Figure 10. The effect of adding carbon powder on the maximum deflection of the models consist of 20% glass fiber.

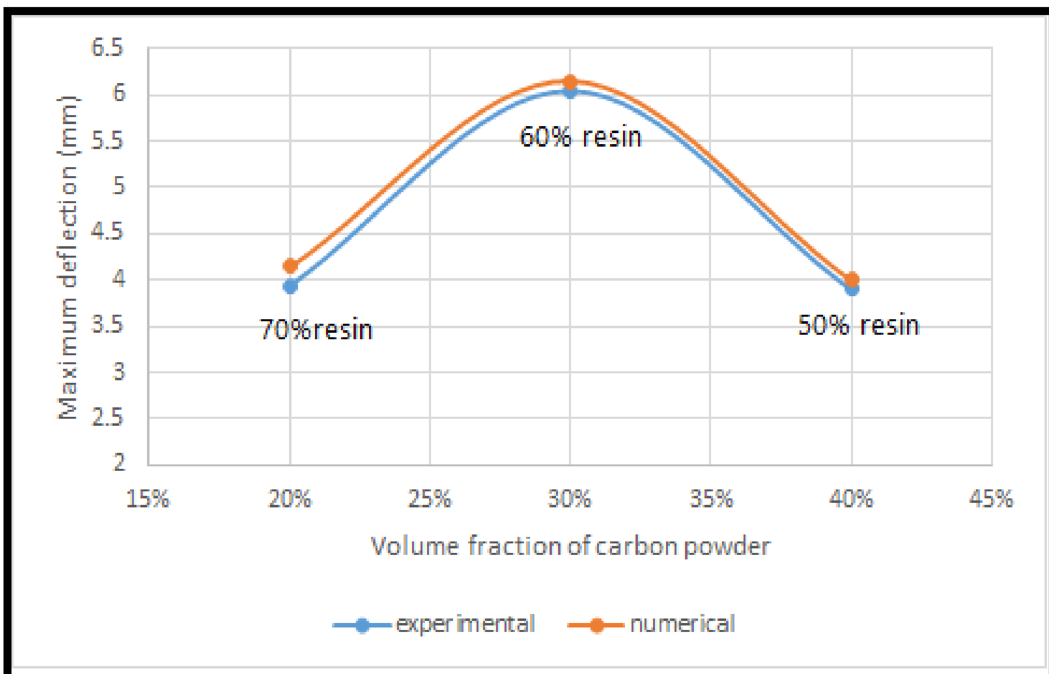


Figure 11. The effect of adding carbon powder on the maximum deflection of the models consist of 10% glass fiber.

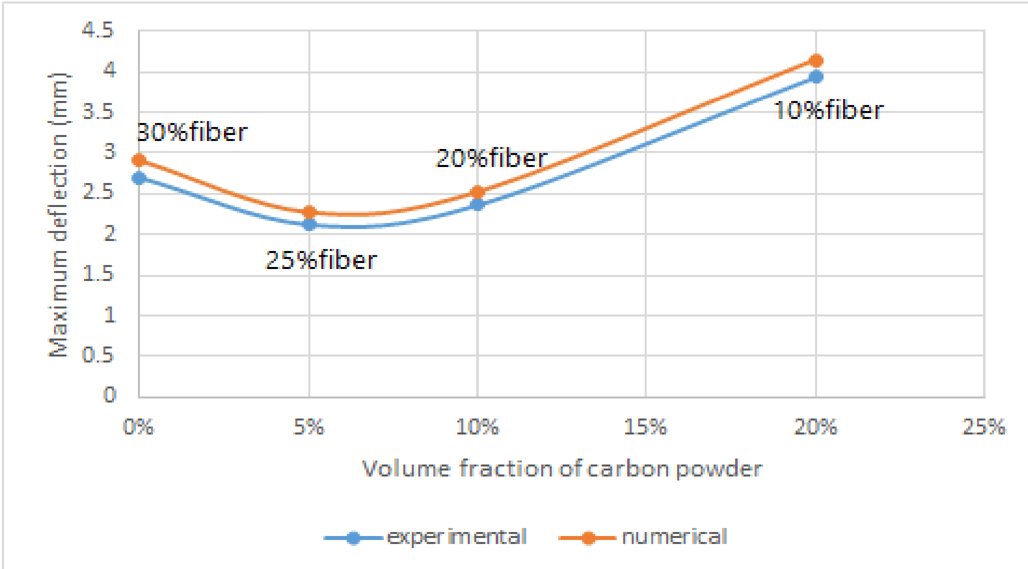


Figure 12. The effect of replace the glass fiber with carbon powder on the maximum deflection of the models consist of 70% polyester.

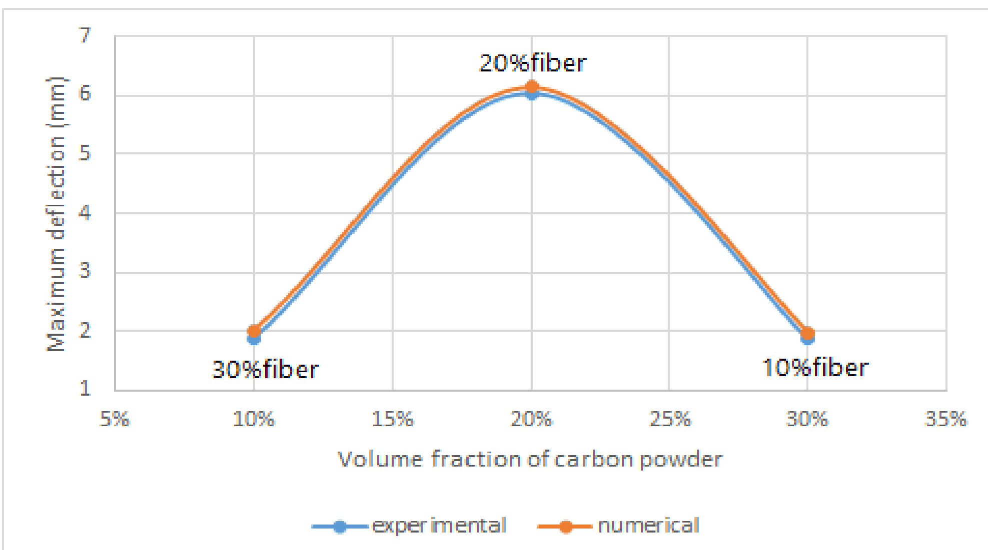


Figure 13. The effect of replacing fiber with powder on the maximum deflection of the models consist of 60% polyester**.**

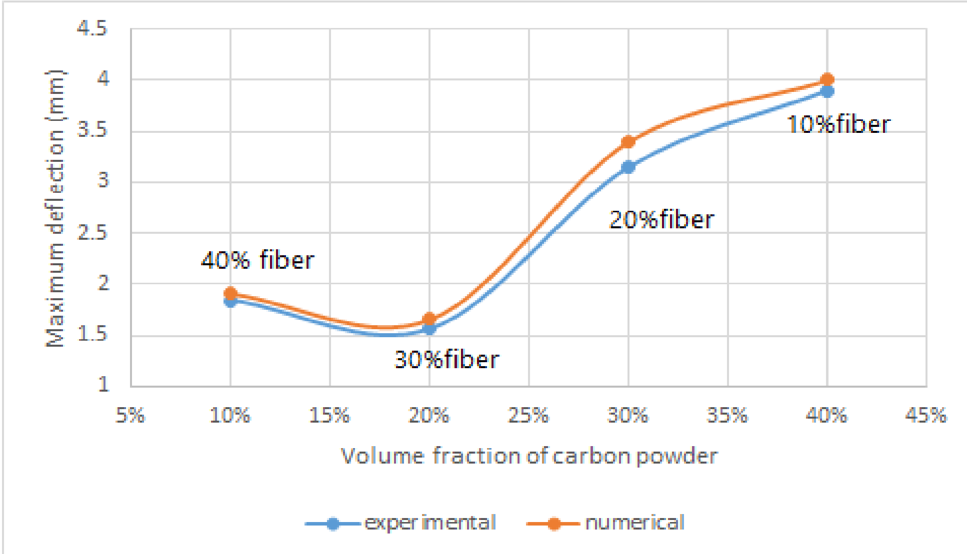


Figure 14. The effect of replace fiber with powder on the maximum deflection of the models consist of 50% polyester**.**

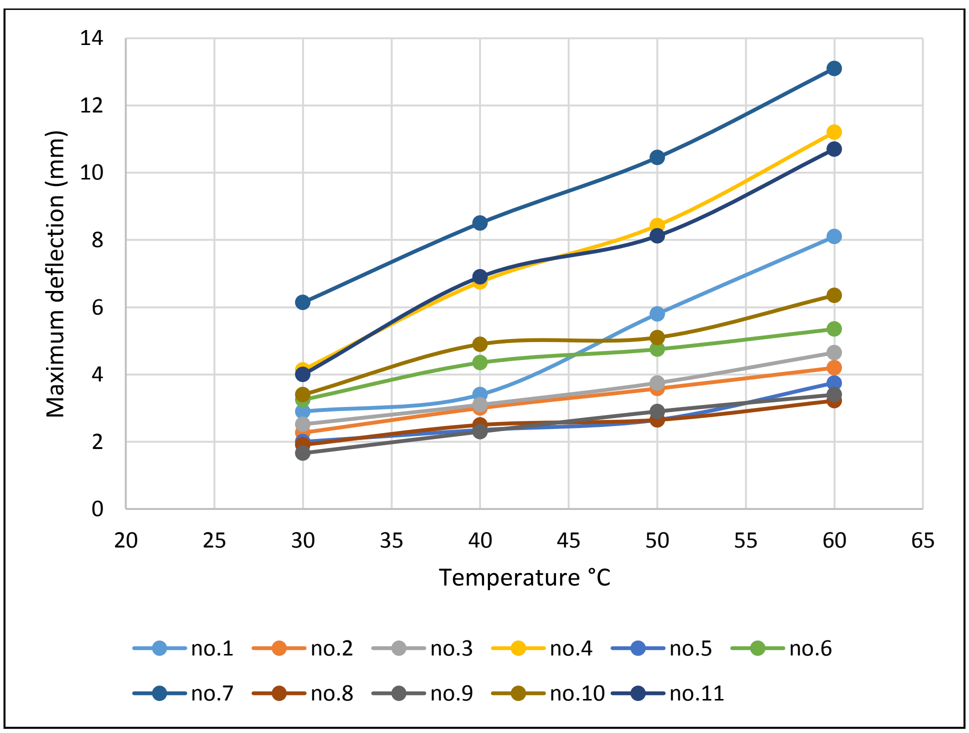


Figure 15. The effect of the temperature on the maximum deflection for all models**.**