STRUCTURAL TESTING AND REPAIR PROCEDURE OF FIBERGLASS COMPOSITE SECTIONS PRODUCED BY HAND LAYUP METHOD

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Abstract
In this contribution two objectives are in focus. On one hand, a research study on fiberglass composite sections including hand layup manufacturing and structural testing followed by repair procedures is done, and on the other hand, some experiments in respect to the studied cases were carried out and verified. In the experimental study, fiberglass composites specimens were manufactured by hand lay-up method in the lab to be able to carry out different tests such as tensile test, three point bend test and impact test. Having the results in hand different types of composite sections were compared together. Also we could compare our findings with results from similar tests on carbon fiber and hybrid composites. It is shown that the carbon fiber undergoes a high stress/low strain, while fiberglass takes less stress at a larger strain. Comparing the results, carbon fiber shows more strength and stiffness in compare to fiberglass.

1 Introduction
Composite material's applications are so wide that many specialists consider that after Stone Age and Metal, we are approaching an era that can be called as the Composites Age. The benefit of using composite can be include, very high specific strength and stiffness with low weight, great freedom of shape, good chemical resistance against acids as well as superior weather/water resistance, good impact characteristics and high thermal isolation characteristics along with good fatigue endurance with regard to number of load cycles. Mel M. Schwartz [1] has discussed the typical advantages and disadvantages of composite materials. Essentially weight reduction due to the high strength- or stiffness to weight ratio, longer life due to the no corrosion and lower manufacturing costs because of lower part count can be considered as some of the significant advantages of composites. However composites have some disadvantages such as cost of raw materials and fabrication, possible weakness of transverse properties and difficulty in attaching. Furthermore advantages and limitations of composite materials have been discussed by Isaac M. Daniel and Ori Ishai [2]. In essence on the scale of fiber dimensions, composite have the advantage of high stiffness and high-strength fibers. Also composites present the unique possibility of designing the material, the manufacturing procedure and the structure in one unified and concurrent process. Different fabrication methods suitable for a range of applications are available. On the negative side, composite fabrication is still dependent to some extent on skilled hand labour, with limited automation and standardization, which needs more stringent, extensive, and costly quality

control procedures. Daniel Gay and Suong V. Hoa[3] discussed the fabrication processes. Basically, in order to fabricate composite, it is necessary to combine fibre with a resin. However the mixture of reinforcement and resin does not really become a composite material until the matrix become hardened as the last stage of the fabrication. There are many methods for the composite manufacturing such as, Contact molding, compression molding, molding with vacuum, resin injection molding, etc. However wet layup is the simplest and most economical method of composite manufacturing. In this method resins are restricted to polyester, vinyl ester or epoxy which are compatible with room temperature, but fibers can be chosen from any of the available reinforcements. The best advantage of wet layup is to vacuum bag the uncured laminate. However Geoff Eckold[4] discussed disadvantage of vacuum bagging as it has a limitation in consolidation pressure. Moreover due to the enlargement of the bubbles trapped in the resin in regions of low pressure it may produce voided laminates. Layup sequence for vacuum bagging operation has been shown in figure 1.

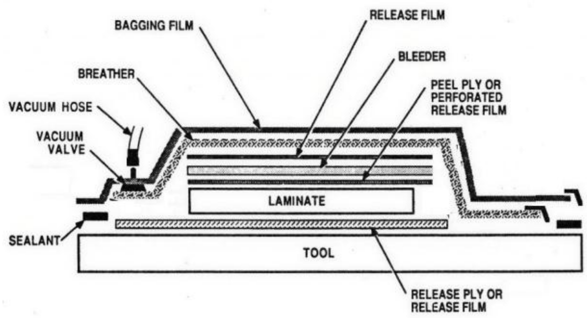

Figure 1. Layup sequence for bagging operation

In the other hand, the increasing usage of composite structures in variety of areas including aerospace industry will require the development of repair techniques and process for different types of composite structures. There are three possibilities. Firstly damage could be negligible which requires no work other than possible cosmetic surface refinishing. This could be included minor dents, scratches etc. which results no effects in structural performance and may be disregarded. The second type of damage has been classified as a serious but repairable damage and final classification is a serious damage and not repairable which the structure cannot be restored to the satisfactory condition whether because of economic reasons or technical limitations. This type of damage requires replacement of component. An ideal repair is required to permanently restore structural capability with a minimum increase in weight as well as a minimum reduction in functional capacity. There are different repair techniques for composite structures such as Cosmetic repair, Resin injection repair, Bolted external patch repairs as well as flush structural repairs. These have been described in details by Michael J. Hoke and his colleagues[5] as well as Alan Baker[6].

In the experimental study, fiberglass composites specimens were manufactured by hand lay-up method in the lab to be able to carry out different tests such as tensile test, three point bend test and impact test. Having the results in hand different types of composite sections were compared together. Also we could compare our findings with results from similar tests on carbon fiber and hybrid composites.

2 Structural testing methods

Different tests such as tensile test, three point bend test and impact test have been carried out. Firstly; three point bend test has been done using Universal Testing Machine (UTM) and the speed of machine has been set to run at 50 mm/min. In the next step the specimen has been carefully placed in the correct position. Then by using the control panel the machine has been run until the metal plate rested very lightly on the specimen. Subsequently the machine's load cell has been set to zero. After that the machine has been started again, and data have been recorded by the computer. It has been used to get variables like maximum stress, maximum load, and modulus of elasticity.

Tensile testing is one of the most common mechanical stress-strain tests are performed in tension. Several mechanical properties of materials that are important in design can be find out using tensile test results. During the experiment the tensile test has been carried out on each fiberglass specimens and produced a load against extension graph. The Universal Testing Machine (UTM) has been set up and the speed has been set in order to perform a new test. The tensile specimen has been mounted by its ends into the holding grips of the tensile machine. The machine has been designed to elongate the specimen at a constant rate and at the same time the instantaneous applied load and elongations have been measured using a load cell and extensometer.

Finally Impact test has been done for each laminate. Each sample was cut to pre-set size with four holes so the sample could be clamped into the rig. Then in order to do the first test specimen clamped into the rig and the drop intender was dropped from specific height and the damage to the specimen has been checked. This procedure has been continued until the first test piece fractures and the height was noted. Afterward the actual test specimen was clamped in the rig for the actual results and the data obtained during the first test has been used to calculate an appropriate scale for the second specimen by subtract one inch from the recorded height for the first specimen. Finally the specimen has been removed from the rig and a micrometer has been used to measure the depth and width of indent on the tested specimen.

3 Results and Discussions

3.1 Tensile test

The tensile test has been carried out on three different composite materials, including two eight ply fibreglass and six ply carbon fiber laminates. In general the load against deformation graphs shows that the paths of the curves are visibly jump, where the tensile test generally should come with a straight line up to the maximum load which represent the elastic region. It must be taken to the account that these cracking on the graphs show the de-bonding of fibers and matrix and the strain energy have been used in order to create these new surfaces within the material in micro structural size. As a result if the load is suddenly removed from the laminate before reaching the maximum load, the damaged parts of fibers and matrix will be remain in the composite structure and this might not be visible without using special equipment's. Moreover the following graph shows the stress/strain gradient at fracture for three different composite materials

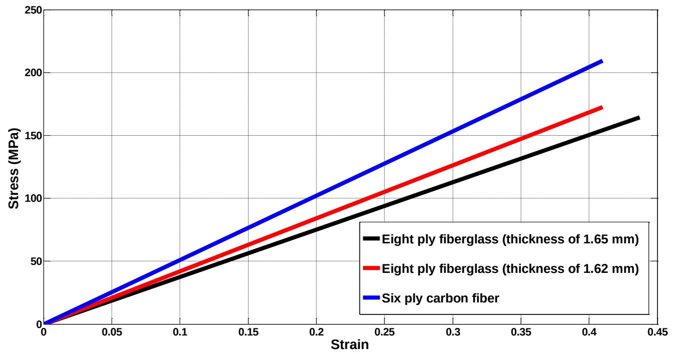

Figure 2. Stress/Strain gradient at fracture for different composite materials at tensile test

During the study of the results it has found that the fiberglass takes less stress at a larger strain while the carbon fiber undergoes a high stress/low strain. It shows that carbon fiber is stronger and stiffer in compare with the fiberglass composites. However they have their own benefits such as heat, fire and chemical resistance properties and their usage totally depends to their applications.

3.2 Three point bend test

The three point bend test has been done on four different composite materials, including two fibreglass laminate as well as carbon fiber and hybrid composite with layers of carbon–glass–carbon. In general the obtained load against deformation graphs during the experiment shows that the elongation is small, consequently the area under the curve is small and the required strain energy to break the composite is relatively low in compare with the other types of materials. Moreover the test has shown that composites are commonly brittle. The following graph (figure 3) shows the stress/strain gradient at fracture for four different composite materials

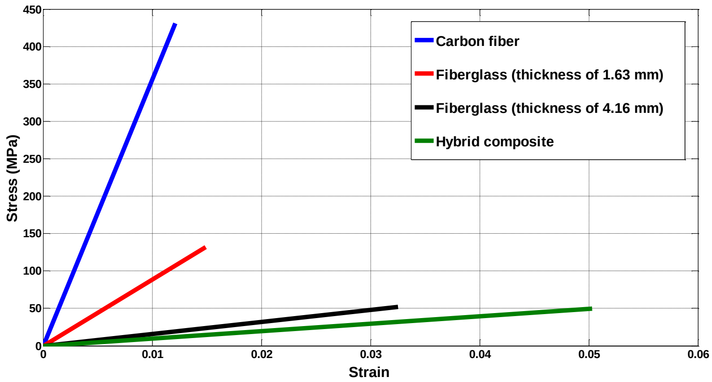

Figure 3. Stress/Strain gradient at fracture for different composite materials at three point bend test

The results find that the carbon fiber undergoes a high stress/low strain, while fiberglass takes less stress at a larger strain. It shows that carbon fiber is stronger and stiffer in compare with the fiberglass composites. However fiberglass composites have their inorganic characteristic they are heat, fire and chemical resistance with excellent resistance to most chemicals and resistant to fungal, bacterial or insect attack. Moreover fiberglass does not absorb water. In addition due to its low coefficient of thermal linear expansion and high coefficient of thermal conductivity, fiberglass composites have been shown perfect performance in thermal environments. Furthermore fiberglass can be ideal option for electrical insulation due to its no conductivity.

In the other hand, comparison of calculated results between two different fiberglass with two different thickness shows (illustrated in table 1) shows that; there is more flexural stress and less flexural strain in the fiberglass laminate made from thinner layers in compare with the eight ply fiberglass laminate made from thicker layers. Therefore the flexural modules are higher in the fiberglass made by the thinner layers, in compare with the laminate which has been made from the thicker layers. As a consequence it means where the two fiberglass laminates made from same amount of layers; the one which makes from the thicker layers has more resists to bending and also more brittle in compare with the fiberglass laminates made from thinner layers. It must also take to the account that one of the disadvantages of the fiberglass laminates which made from thicker plies is the weight issue.

Thickness [mm]	Deflection [mm]	Gradient	Flexural Stress [N/mm^2]	Flexural Strain	Module of Elasticity [N/mm^2]
1.63	8.16	1.86	132.016	0.0149	2039.71
4.16	6.97	4.33	52.049	0.0325	291.29

Table 1. Calculated three point bend test result for eight ply fiberglass laminate with two different thickness

3.2 Three point bend test

The Impact test has been performed on seven different composite materials, using a free-fall drop dart machine with no energy storage device. The tested laminates were included four eight ply fibreglass laminates with the thickness of 1.63mm and 4.16mm as well as three ply carbon fiber with the thickness of 1.05mm and six ply carbon fiber composite by the thickness of 1.4mm along with the hybrid composite with layers of carbon–glass–carbon and the thickness of 1.63 mm. The calculated results for fiberglass specimens have been illustrated in the table 2 as follow:

Thickness [mm]	Dropped Height [mm]	Mass of Indenter [kg]	Potential Energy [J]	Velocity [m/s]	Kinetic Energy [J]
1.63	0.55	0.9448	5.098	3.285	5.098
1.63	0.6	0.9448	5.561	3.431	5.561
4.16	1.8	1.793	31.661	5.943	31.661
4.16	1.9	1.793	33.420	6.106	33.420

Table 2. Impact test results for fiberglass with eight ply

Comparison shows that during the impact test, fiberglass laminates made from thicker layers with the thickness of 4.16 mm absorbs more kinetic energy and obviously indenter has more potential energy in order to damage the specimen. Furthermore impact test has been carried out on the three ply and six ply carbon fiber laminates. The obtained data during the experiment shows that three ply carbon fiber laminate with the thickness of 1.05mm absorbed kinetic energy of 2.592 J where the six ply carbon fiber with the thickness of 1.4 mm illustrates the kinetic energy of 5.5663 J. In addition results of impact test for hybrid composite laminate with the layers of carbon–glass–carbon and thickness of 1.63 mm have been reviewed. The experimental results have been shows that speed of 3.668 m/s for indenter as well as absorbed kinetic energy of 6.362 J. A Study and comparison on the obtained results for the different type of composite materials shows that the carbon fiber is more brittle and fiberglass is much tougher. It is also found that an increase in the thickness of a carbon fiber laminate noticeably changes its reaction to dynamic loads.

4 Future works

The mechanical properties for composite materials can be significantly reduced by impact damage and will result in the premature failure for the component, so cost effective and reliable damage detection is critical for utilization of composite materials. Our ongoing project is damage detection in composite materials using piezoelectric sensor/actuator.

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