Advanced Materials
Manufacturing & Characterization

journal home page: www.ijammc-griet.com

Characterization of Epoxy based Composites for Light Weight and High Strength Applications for Air-Frame Structures

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A R T I C L E   I N F O

Article history:
Received 14 Oct 2012
Accepted 26 Dec 2012

Keywords:
Carbon, epoxy,
mechanical properties,
fiber volume fraction.

A B S T R A C T

Metals are not suitable materials for aerospace applications due to their high density and therefore composite materials are used as substitute due to their light weight and high strength characteristics. Composite materials especially carbon-epoxy composites are especially strength bearing materials useful in aero space applications used as airframe structures . Filament winding process, tape wound process, and molding processes are used for fabrication of air frame structures, which are capable to mechanical loads when compared to other materials. Bi-directional carbon-epoxy composites are representative materials to filament tape wound components of air frame structure. This study is tried to analyse the fiber volume fraction of the composites with effective consolidation (low thickness) of layers by applying vacuum and pressure during curing of the laminate. Mechanical properties like tensile, flexural and inter laminar shear strength for carbon-epoxy (LY556+HT972),bi-directional composites with different process parameters to fiber volume fraction with low thickness. The results from the study have demonstrated that the composites cured with vacuum and pressure is exhibiting improvement in tensile strength, flexural strength due to high fiber volume fraction.

Introduction

Material have been classified into four categories based on their applications to achieve particular physical, mechanical and therm al characteristics. 1Metals, 2.Organicmaterials(polymers), 3.Cera micmaterials, 4.Composite materials. A composite is commonly defined as a combination of two or more distinct material search of which retains its own distinctive properties, to create a new material. The two distinct materials. Composites are the mixture of two materials, which in combination, offer superior properties to the materials alone. Structural composites usually refer to the use of fibers which are embedded in a plastic. These composites offer high strength with very little weight.. The two distinct materials are one is matrix and another is reinforcement embedded in the plastic. Matrix surrounds the reinforcement and protects the reinforcements impart their special mechanical and physical properties to enhance the matrix properties. A synergism produces material properties unavailable from the individual constituent materials. The matrix material can be introduced to the reinforcement before or after the reinforcement material is placed into the mold cavity allows the designer of the product or structure to choose an optimum combination**.** Composites are having the following advantages in terms of light weight , weight distribution, high strength to weight ratio, directional strength and stiffness, corrosion resistance, weather resistance, low thermal conductivity, low coefficient of thermal expansion, high dielectric strength, non-magnetic and radar transparency.

Epoxy resin:

Epoxy or poly epoxide is a thermosetting polymer formed from reaction of an epoxide "resin" with polyamine "hardener". Epoxy term refers to a chemical group consisting of an oxygen atom bonded to two carbon atoms that are already bonded in some way. The resin consists of monomers or short chain polymers with an epoxide group at either end. The

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- Doi: http://dx.doi.org/10.11127/ijammc.2013.02.065

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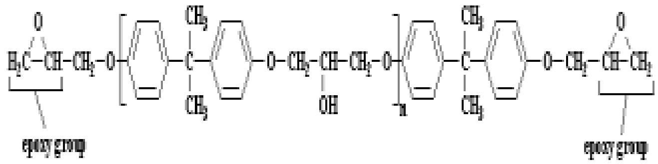
structure of molecule is shown in the figure below.



Epoxies generally out-perform most other resin types in terms of mechanical properties and resistance to environmental degradation, which leads to their almost exclusive use in aircraft components.

Carbon fiber :

There are wide varieties of reinforcements are available like carbon fiber,. Glass fiber ,Boron fiber. For this study Carbon fiber is selected, because Carbon has the highest strength .Carbon fibers exhibit substantially better strength and stiffness values than all the others, outstanding temperature performance, high electrical and low thermal conductivity. Impact or damage tolerance of pure carbon composite products can be from relatively low to very poor, and greatly depends on processing method.

Carbon-Epoxy Composites :

The carbon fibers are first placed in the mould and then semi-liquid epoxy resins are sprayed or pumped in to form the object. Pressure may be applied to force out any air bubbles, and the mould is then heated to make the matrix set solid. Carbon epoxy resins have an infinite service lifetime when protected from the sun, but, unlike steel alloys, have no endurance limit when exposed to cyclic loading.

Experiments:

The present experimental work has been categorized in to Preparation of laminates by varying the process parameters.
Determination of physical properties by chemical methods
Specimen Preparation and mechanical testing of samples
Testing for mechanical properties
5.1. Raw materials used in the present study
In the present study Epoxy resin(LY556) and hardener (HT 972) is used as matrix which is purchased from M/s. Ecmas Corporation, Hyderabad, Carbon fabric is used as reinforcing agent, purchased from M/s. NikunjEximp Enterprises, Mumbai (Toray make) with 12k roving or in the form of bi- directional fabric. The fibers/ fabric is fabricated from Poly Acrylo Nitrile (PAN) precursor
5.2. Preparation of laminates by varying the process parameters
5.2.1.Laminate preparation
Epoxy resin (LY556) and Hardener (HT972) are mixed in the 100:27 ratio by weight and the solution is applied on the bi-direction carbon fabric and 320x320x2mm thickness of the layers have been developed by stacking 10 layers in the mould.

Carbon fabric layers of size 320mm x 320mm are taken from fabric role by cutting with the help of template of size 320x320 mm. Epoxy resin (LY 556) is mixed with hardener (HT972) in the weight ratio 100:27 in a beaker. The moulds are cleaned with acetone and then wax is applied to the moulds for easy removal of the cured laminate. Resin impregnated carbon fabric layers are placed in the mould by hand lay up technique.

The laminate preparation sequence is shown in Fig.5. Three laminates are prepared to be cured by different process parameters. i). No vacuum and pressure ii).With vacuum iii).With vacuum and pressure. The corresponding cure cycles, vacuum levels and pressure application steps are given as cure cycle-1, curecycle-2 and cure cycle-3.

Laminate -1

sample (LY 556 + HT972)	ILSS, MPa	Flex Str, MPa	Flex Mod, GPa	Tensile Str, MPa	Tensile Mod, GPa
1	32.43	530.45	42.64	510.94	62.55
2	31.39	527.11	44.06	686.46	60.12
3	33.60	424.41	42.69	723.77	59.61
4	30.79	493.73	41.57	598.26	64.24
5	32.13	486.08	35.89	621.30	61.85
6	34.47	497.98	38.04	651.20	64.25
Average	32.46	493.29	40.81	631.988	62.103
Standard deviation	1.14	38.40	3.15	74.383	1.97

Fig.5.1. Laminate-1 properties

Lamianate -2

sample (LY 556 + HY5200)	ILSS, MPa	Flex Str, MPa	Flex Mod, GPa	Tensile Str, MPa	Tensile Mod, GPa
1	26.26	477.78	36.49	661.01	62.35
2	31.25	499.14	38.49	727.03	59.39
3	30.47	508.58	43.17	685.91	60.64
4	30.93	527.68	42.97	766.85	64.80
5	28.40	527.29	42.51	714.66	61.18
6	30.35	532.31	43.55	684.50	61.09
Average	29.61	512.13	41.19	706.66	61.57
Standard deviation	1.918	21.16	2.95	37.70	1.84

Fig.5.2. Laminate-2 properties

In this study, it is decided to carry out the test by varying the process parameters). With vacuum and pressure(by varying rate of application of pressure-1), ii). With vacuum and pressure(by varying rate of application of pressure-2), iii). No vacuum and pressure and was designated as cure cycles. The corresponding cure cycles, vacuum levels and pressure application steps are given as below.

Cure cycle-1.

i). Keep component temperature at 140^0C for 4 hours
ii). Vacuum= - 960mbar
iii). Pressure = At 140^0C, 1 bar up to 2 hours, 2.0 bar up to 4 hours.
Cure cycle-2
i). Keep component temperature at 140^0C for 4 hours
ii). Vacuum= - 960mbar
iii). Pressure = At 140^0C, 0.5 bar up to1 hour, 1.0 bar up to 2 hours, 1.5 bar up to 3 hours and 2 bar up to 4 hours.
Cure cycle-3
i). Keep component temperature at 140^0C for 4 hours
ii). Vacuum= NIL
iii). Pressure = NIL
The prepared laminates are designated as per cure cycle -1 as Laminate-1, as per cure cycle-2 as Laminate-2 and as per cure cycle-3 as Laminate-3. The prepared laminates are tested for mechanical properties.

Determination of physical properties by chemical methods

The material properties are standardized based on the epoxy resin content, fiber volume fraction and void content of the samples. Density, resin content and fiber volume fractions are determined by acid digestion and Archimedes principles and the values are tabulated in Table.5.4.

Specimen preparation and mechanical testing of samples diamond wheel cutting machine.

The samples are tested for tensile, flexural and inter laminar The specimens are cut in the required dimensions as per the ASTM standards using a shear strength properties using universal testing machine (UTM) as per the ASTM standards ASTM 3039, ASTM7264 and ASTM D2344 respectively. The specimen samples are shown in . For each test 6 samples are tested and the average value of the test results is considered as the material properties. Table.5.1-5.3 shows the mechanical properties of the laminates, cured under different cure cycles.

Laminate-3

sample (LY 556 + HY5200)	ILSS, MPa	Flex Str, MPa	Flex Mod, GPa	Tensile Str, MPa	Tensile Mod, GPa
1	31.36	581.66	46.49	782.30	59.84
2	32.84	557.05	44.96	797.69	60.42
3	33.46	575.16	49.73	781.89	60.49
4	32.65	595.61	47.60	721.49	65.84
5	33.71	580.42	46.59	768.44	60.11
6	31.87	583.56	46.80	750.64	59.57
Average	32.64	578.91	47.02	767.05	61.04
Standard deviation	0.90	12.66	1.57	27.34	1.01

Fig.5.3. Laminate-3 properties

Discussion

Effect of fiber volume fraction on Mechanical properties

All mechanical properties were compared in with respect to consolidation thickness, density and fiber volume fraction. From table it is obvious that the laminate-3 cured at vacuum condition only is exhibiting improvement in tensile strength, flexural strength due to high fiber volume fraction. The effect on ILSS properties is marginal because it is resin dependent property. ILSS value depends on the interfacial strength among the fabric layers only.

Effect of resin content on the mechanical properties

If the resin content is more, the strength of the composite will be lower because strength depends on the fiber volume fraction. Hence Laminate-1 cured with vacuum and pressure condition is having high resin content due to vacuum suction and pressure application. Therefore it exhibits good interfacial strength due to high resin content. Therefore it is exhibiting high ILSS value.

Effect of void content on the process parameters

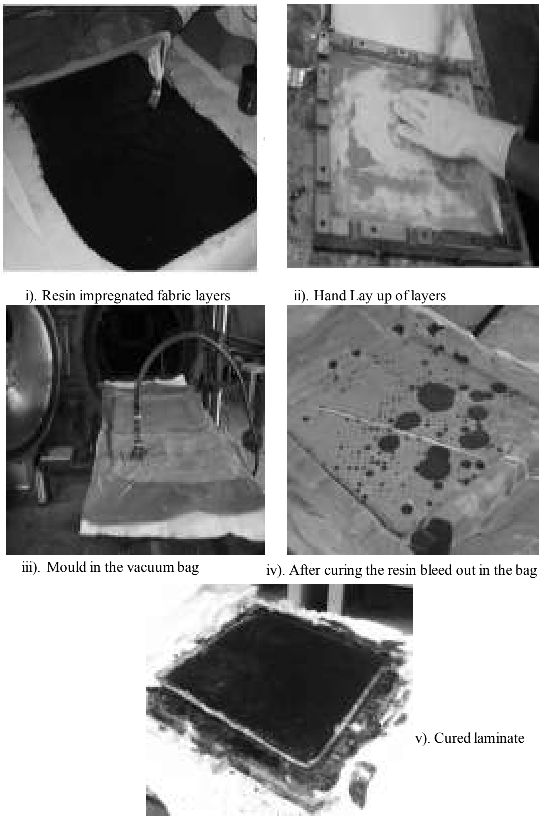
Vacuum phenomenon during process is removing the volatile gases hence the trapping of gases in the component is minimum in laminate-3. Hence the voids formed in the component are low. If the component is having low void content, it exhibit high tensile, flexural and ILSS values. Pressure application may cause trapping of volatiles between the fabric layers. Hence high void content is observed in the laminate-1.

Laminate-1	Resin content(wt %)	Fiber volume fraction (vol%)	Density (gm/cc)	Void content(%)
1	24.95		1.5053	
2	25.49		1.5052	
3	24.91			
Average	25.11	63.9	1.5052	

Laminate-2	Resin content(wt %)	Fiber volume fraction (vol%)	Density (gm/cc)	Void content(%)
1	27.08		1.4660	
2	26.81		14617	
3	26.79			
Average	26.89	65.15	1.4638	

Laminate-3	Resin content(wt %)	Fiber volume fraction (vol%)	Density (gm/cc)	Void content(%)
1	28.44		1.4658	
2	26.72		1.4503	
3	28.65			
Average	27.83	67.23	1.4580	

Table.5. Physical properties of laminates



i). Resin impregnated fabric layers ii). Hand Lay up of layers

iii). Mould in the vacuum bag iv). After curing the resin bleed out in the bag

v). Cured laminate

Fig.5. laminate preparation sequence

Conclusion

High fiber volume fraction is achieved in the laminate-3 with only vacuum curing process of the laminate.2. High fiber volume fraction in Laminate-3 is exhibiting improved tensile and flexural strength of the laminate. 3. The effect of vacuum and pressure application on ILSS properties is marginal.4. Low void content in the laminate-3 is attributed to vacuum suction phenomenon, it in turn improves the tensile and flexural properties. Finally it is concluded that to minimize the weight of the structure, fiber volume fraction should be high and which reduces the final component thickness due to good tensile and flexural

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