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Effect of Altitude on E-glass/Epoxy Composite for Aircraft Parts

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The undersigned have examined the thesis entitled **“EFFECT OF ALTITUDE ON E-GLASS/EPOXY COMPOSITE FOR AIRCRAFT PARTS”** presented by **SAMSON WOLDU**, a candidate for the degree of **Master of Science** and hereby verify that it is worthy of acceptance.

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DECLARATION

I, undersigned and declare that this thesis titled **" effect of altitude on e-glass/epoxy composite for aircraft parts”** is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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ABSTRACT

This work focuses on analyzing in a fundamental way the effects of curing pressure during wet layup procedure. An experiment was conducted to expose effects of altitude on E-glass/Epoxy composite during fabrication or repair. Processing techniques of specimen preparation for an experimental observation are also presented.

E-glass/Epoxy laminates were obtained by a wet layup vacuum assisted technique as per the recommendation of Aircraft manufacturer. The composite laminates were prepared to meet ASTM standards and the basic properties are determined with the help of universal testing machine. Composite test samples were manufactured from plain woven E-glass and epoxy adhesive at bagging vacuum pressure of 19” Hg, 16” Hg and 13” Hg.

The effect of altitude on E-glass/epoxy composites is analyzed and presented. Engineering stress against engineering strain graphs are plotted and documented to indicate the effects of altitude at various curing pressures.

This paper has also examined the need for an alternate means of compliance to make sure the structural repair procedures adopted by Ethiopian airlines for aircraft repair are well-defined to shrink the effect on a structural integrity.

Keywords: Composite, Aircraft, Experiment, Altitude, Bagging Pressure, Curing Pressure, matrix, Strength, Effect, Fabrication, Repair

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NOMENCLATURE

ASTM	American Society for Testing and Materials
BMS	Boeing material Specification
FEM	Finite Element Method
FG	Fiber Glass
NDT	Non Destructive Test
PREPREG	Pre immigrated
SRM	Structural Repair Manual
UDF	Uni-Directional Fabric

Chapter -1

Introduction

1.1. Background

The world is as of now concentrating on alternate material sources that are environment agreeable and biodegradable in nature. Because of the expanding natural concerns, bio composite produced out of regular fiber and polymeric resin, is one of the late advancements in the business and constitutes the present extent of experimental work. The use of composite materials has grown significantly in aeronautic, automotive, naval, and civil construction sectors by substituting conventional materials such as steel, aluminium and other alloy materials. Because laminated Composite materials have of high strength to weight ratio. The use of composite materials field is increasing gradually in engineering. For example, in civil construction, high-speed boats and trains, automotive industries, and aerospace structures [1].

A composite consists of mainly two parts i.e. matrix and fiber. The accessibility of characteristic fiber and simplicity of assembling have enticed scientists worldwide to attempt by regional standards accessible inexpensive fiber and to learning their achievability of fortification determinations and to what degree they fulfil the obliged particulars of great strengthened polymer composite aimed at structural requisition. Fiber reinforced polymer composites has numerous preferences, for example, generally minimal effort of creation, simple to create and better quality contrast than perfect polymer. Due to this reason fiber strengthened polymer composite utilized within an assortment of provision as class of structure material. [2]

Early airplanes were composites, constructed of wood frames, wire bracing and fabric. Welded steel frames began to replace wood by the early 1920’s. Light aluminium structure came into use as load bearing structure in the early 1930’s. By the 1950’s, the transition to the full metal airplane had been completed. In the 1960’s, the use of composite structures started showing a resurgence, with the development of fiberglass, Kevlar and carbon composites.

The use of a few fiberglass reinforced plastic composite parts such as wing tips, radomes (Nose part of the Aircraft) and tail cones on the early Boeing 707 airplanes marked a return to the use of composite structure in airplane design. The success of these parts in service lead to the increased use of composites on each new model introduced since that time. The Boeing 747 has over 10,000 surface square feet of fiberglass composite structure [3].

The B777 marked Boeing's first use of composites in primary structure. The 777 used carbon composites for the empennage, floor beams and flaps. During the past few decades Boeing has invested billions of dollars in advanced composite research and development. This has allowed Boeing to use advanced composites as the primary structural material for the B787 Dream liner. For this reason, this work considers it essential to do subsequent mechanical tests against several parameters in order to come up with the best property while a pre-test has been done by the manufacturer. In line to that, this work tried to experimentally analyse the effect of altitude on a composite repair since various repairs are expected to be done in Ethiopia in the coming few years following the growing utilization of composite on aircraft structure. Now days, due to the appreciable mechanical performance and strength to weigh ratio of E-glass epoxy and carbon fiber reinforced plastics have been used on majority of aircraft structure.

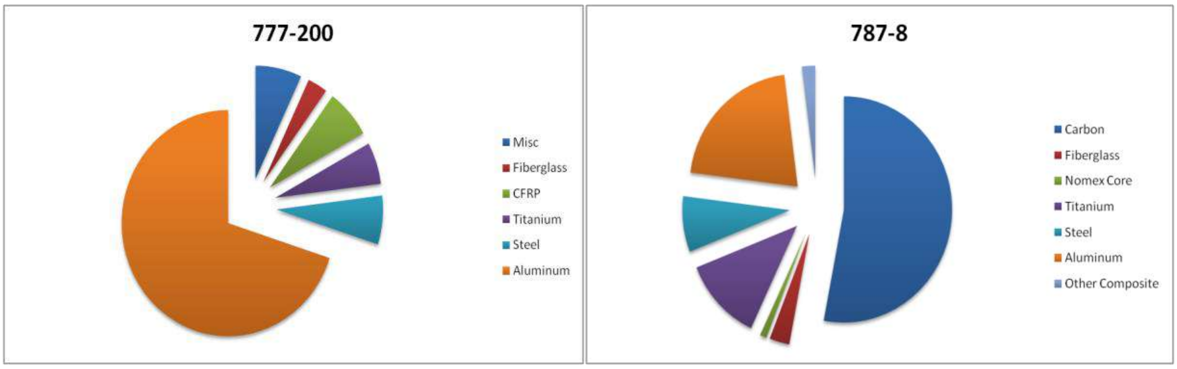

Figure 1.1: Structural Material Weight Percentage on B777 Vs 787[5]

To understand the characteristic of composite repairs under various loading conditions, studying the mechanical and physical properties becomes vital. Despite the fact aircraft manufactures took various repair conditions under consideration for the pre-flight design, the effect of altitude on structural repairs performed at comparatively very high altitude need more precision and a second eye as evidence on such regard is handed to Ethiopian Airlines structural engineering section. Besides, it is recalled that since, Ethiopian Airlines repair facility is located at around 7600ft (2317m) from sea level, it is challenging to achieve the minimum curing pressure of 22-inch Hg which is usually followed by a recommendation from the manufacturer side to try an alternate method which is not part of the approved repair manuals.

1.2. Statement of the Problem

Aviation industry in Ethiopia is emerging and is now taking the curtsy to repair state of the art aircraft (B787-8 and A350-900) composite structures. One of the industries on a global site which perform composite repair is Ethiopian Airlines structure repair shop. Commercial Aircraft composite parts are fully manufactured at this time. Composite Repair shops in Ethiopian airlines premises are capable of performing non-destructive inspection as per the manufacturers structure repair manual (SRM) recommendation. However, destructive tests are not widely adopted to examine aircraft composite repair strength and stiffness properties. The required repair strength is initially determined by the manufacturer and operators are recommended to strictly follow the repair procedures to fall within the safe operational safety.

For a composite aircraft structure repair, the manufacturer (Boeing) recommend 26 to 22 inches of Hg curing pressure during wet layup procedure. However, as Ethiopian Airlines is located at a very high altitude which is 7600Ft from sea level, it is quite difficult to achieve the recommended curing vacuum pressure. Meanwhile, by strictly following manufacturers recommendations and avoiding leak in between sealants during wet layup manufacturing process, the maximum curing pressure that could be attained with in Ethiopian Airlines premised is 19 inches of Hg.

This is incurring a lot of cost to since, damaged structural parts are sent for foreign repair following structural damage as it is seldom to attain the minimum curing pressure recommended by the manufacturer. This, is therefore, inspired the researcher to investigate the effect of altitude on a composite repair. Moreover, the researcher emphasised the need for studying physical and mechanical properties of composite as mandatory for the reason composite properties are prone to different conditions like working environment, manufacturing processes and operating conditions.

Therefore, this work has intended to bridge the gap between qualities of repair performed in Ethiopia (located at High altitude) and standard repair procedures set by the manufacturer. This work also clearly portrays the effect of altitude/curing pressure on composite structural integrity, by experimentally characterising tensile and compressive properties of the test samples. The tests are performed according to American Society for Testing and Materials (ASTM). However, the effect of curing pressure during specimen preparation has been taken in to consideration in accordance with recommended fabrication/repair process by the manufacturer. In addition, this paper presents the way a specimen is prepared and processing technique with an attention given to the way experiments are conducted and recorded.

1.3. Objective of the Study

1.3.1. General Objective

The objective of this paper is to experimentally investigate the effects of altitude/curing pressure on the mechanical property of E-glass/Epoxy composite for aircraft structural part.

1.3.2. Specific Objective

- Conduct tensile and compression experimental test on e-glass/epoxy test samples.
- Compare the results obtained with results of similar experimental research outlets

1.4. Limitation

As a developing country, it is quite challenging to find organisations furnished with the compulsory facility to perform mechanical test on composite test specimens. Moreover, the under listed are limitations I encounter during my work.

- Finding universal testing machine for composite test specimens with the desired cross head speed and jaws with proper grip was challenging. Most of the universal test machine specifications available are for metals and are not compatible with this work.
- Getting related research outlets conducted on similar objective was demanding, as only few airline operators are located at reasonably high altitude.
- Experimental set ups to test composite test specimens were not complete.
- Financial Burdon to afford fabric and related kit costs

1.5. Organization of the Thesis

This paper is organized in to five basic chapters. The first chapter of this paper focuses on introducing the pre-studies or background; problem of the statement; objectives and research limitations. The second chapter reviews various investigations and researches approaches and result conducted on composite materials specifically to E glass/Epoxy. The third chapter deals with the experimental methods and conditions conducted on E-glass/epoxy fabricated at various set of curing altitude/pressures. The fourth chapter presents experimental test results and discussion. The last chapter discourses to give conclusions, recommendations and future works.

Chapter -2

Literature Review

2.1. Introduction to composite materials

Composite materials in the context of high performance materials for structural applications have been used increasingly since the early 1960‟s; although materials such as glass fiber reinforced polymers were already being studied 20 years earlier. Initially conventional test methods originally developed for determining the physical and mechanical properties of metals and other homogenous and isotropic construction materials were used [6].

According to [2], generally composite materials are classified based on the type of matrix material, the form of reinforcement. Based on the matrix material we can classify as Polymer, Metal, ceramic matrix composite and based on the form of reinforcement [2,4]

Composite materials are also becoming more important in the construction of aerospace structures. Aircraft parts made from composite materials, such as fairings, spoilers, and flight controls, were developed during the 1960s for their weight savings over aluminium parts. New generation large aircraft are designed with all composite fuselage and wing structures and the repair of these advanced composite materials requires an in-depth knowledge of composite structures, materials, and tooling. The primary advantages of composite materials are their high strength, relatively low weight, and corrosion resistance [5]

Application of composites on Aircraft include:

- ✈ Fairing
- ✈ Flight control surfaces
- ✈ Landing gear doors
- ✈ Leading and trailing edge panels on the wing and stabilizer
- ✈ Interior components floor beam and floor boards
- ✈ Vertical and horizontal stabilizer primary structure on wide body aircraft
- ✈ Primary wing and fuselage structure on new generation aircraft
- ✈ Turbine engine fan blades
- ✈ Propellers

2.1.1. Laminated Structure

In materials science, a composite laminate is an assembly of layers of fibrous composite materials which can be joined to provide required engineering properties, including in-plane stiffness, bending stiffness, strength, and coefficient of thermal expansion [5].

Laminates are made by stacking layers (also called plies or lamina) in a specified sequence. The layers are often in the form of prepreg“ (fibers pre- impregnated with partly cured resin) which are consolidated in an autoclave. A laminate may have more than 4 layers and the fibre orientation changes from layer to layer in a regular manner through the thickness of the laminate. The figure shown below describes how the laminate is formed from the ply or lamina [2]

2.1.2. Major Components of a Laminate

An isotropic material has uniform properties in all directions. The measured properties of an isotropic material are independent of the axis of testing. Metals such as aluminium and titanium are examples of isotropic materials. A fiber is the primary load carrying element of the composite material. The composite material is only strong and stiff in the direction of the fibers. Unidirectional composites have predominant mechanical properties in one direction and are said to be anisotropic, having mechanical and/or physical properties that vary with direction relative to natural reference axes inherent in the material. Components made from fiber reinforced composites can be designed so that the fiber orientation produces optimum mechanical properties, but they can only approach the true isotropic nature of metals, such as aluminium and titanium.

A matrix supports the fibers and bonds them together in the composite material. The matrix transfers any applied loads to the fibers, keeps the fibers in their position and chosen orientation, gives the composite environmental resistance, and determines the maximum service temperature of a composite [5]

2.1.3. Strength Characteristics

The reinforcement/fiber is usually much stronger than the matrix/resin, and it gives the composite its good properties, transfer the strength to matrix and load carrying application. The matrix/resin holds the reinforcement in an orderly pattern and also helps to transfer load among the reinforcement. [2]

Structural properties, such as stiffness, dimensional stability, and strength of a composite laminate, depend on the stacking sequence of the plies. The stacking sequence describes the distribution of ply orientations through the laminate thickness.

As the number of plies with chosen orientations increases, more stacking sequences are possible. For example, a symmetric eight-ply laminate with four different ply orientations has 24 different stacking sequences. [5]

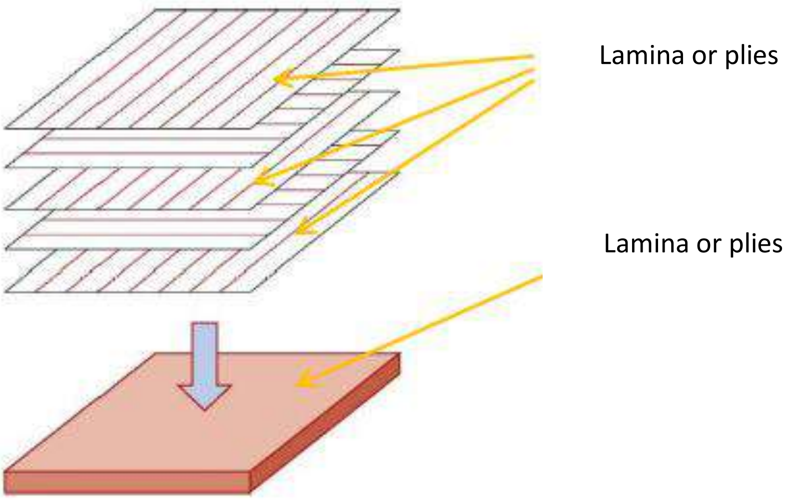

Figure 2.1: Composite Laminate [2]

2.2. Composite Repair Processing

Composite materials nowadays are used in a wide range of applications in aerospace, marine, automotive, surface transport and sports equipment markets. Damage to composite components is not always visible to the naked eye and the extent of damage is best determined for structural components by suitable Non Destructive Test (NDT) methods. The concept for composite repair of composite or metallic structures is simple. The bonded repair reduces stresses in the damaged region and keeps the cracks from opening and therefore from growing. Characteristics of composite failure is difficult to determine and accordingly the repair procedures are quite detail and require great deal of attention. Modern composite repairs also demand modern facility with controlled environmental temperature monitoring system and safety devices during handling repairs and products.

2.2.1. Processing Materials

Processing materials are the materials that are used when a composite is fabricated / repaired. These materials do not become part of the repair.
The following materials are common processing materials:

- Perforated parting film
- Bleeder material
- Solid parting film
- Caul plate
- Breather material
- Vacuum bag material
- Vacuum bag sealing Tape
- Marking pens and pencil
- Bagging Bag
- Hot bonder
- Thermocouple
- Vacuum pump
- Weighing scale
- Mixing spatula
- Scissor
- Lay out Ruler
- Masking tape
- Set square
- Cleaning Agent

These materials are categorized as contact and non-contact. Contact materials are those materials that can touch the repair. For example, the marking pens and pencils are contact materials.
Non contact materials are those materials that do not touch the repair. For example, vacuum bag materials do not touch the repair. composite processing materials used for composite fabrication shall be stored in a place where no contaminant or foreign objects easily affect its character. Moreover, the materials that are used for aircraft composite repair shall be approved for use in the fabrication/repair process by concerned regulatory body before further application.

2.2.2. Processing Material Use

Each one of the materials listed above has a specific use. Perforated parting film is used to allow air and volatiles out of the repair. It also prevents the bleeder ply from sticking to the repair. The bleeder ply gives an air path for the air and volatiles to escape from the repair. Solid parting film is used to prevent the resins from bleeding through and damaging the heat blanket or caul plate. The caul plate is used to make the repair smooth, prevent thermocouple marks and to help make the temperature over the repair uniform. The breather material is used to provide a path for air to get out of the vacuum bag. The breather must contact the bleeder. The vacuum bag materials provide a tough layer between the repair and the atmosphere. The preferred material is 3mil (0.003 inch) thick nylon. Vacuum bag sealing material seals the vacuum bag to the part, tool or to more vacuum bag material (envelope bag method). Marking pens and pencils are used to lay out the repair plies. Approved markers can be used to mark on the plies or part.

2.2.3. Hand Lay-up

Though different layup procedures were available, specimens for this work were prepared using the wet layup method. The table surface was cleaned and one coat of mixture of resin and hardener was applied in the above-mentioned ratio. Then, the fabrics were wetted one by one. Afterwards, the perforated parts film was applied over the final lamina. This perforated parts film carries many minute holes through with the excess resin escapes and also offers a smooth surface finish to laminate. Finally, a breeder and bleeder ply were applied so as to absorb the excess resin in course of vacuum bagging [8]

Figure 2.2 hand lay-up process

2.2.4. Vacuum Bagging process

This is basically an extension of the wet lay-up process described above, where pressure is applied to the laminate once laid-up in order to improve its consolidation. This is achieved by sealing a plastic film over the wet laid-up laminate and on to the tool. The air under the bag is extracted by a vacuum pump and thus up to one atmosphere of pressure can be applied to the laminate to consolidate it [2,4]. The applied vacuum pressure during bagging process is a function of highly atmospheric pressure altitude where the composite is fabricated. The maximum pressure applied in order to squeeze the laminates together and remove inter ply volatilities out is directly proportional to the atmospheric pressure. The higher the altitude the lesser curing pressure applied and vice versa. In line to that, the intent of this work is to experimentally investigate the effect of curing pressure on the final mechanical property of a composite.

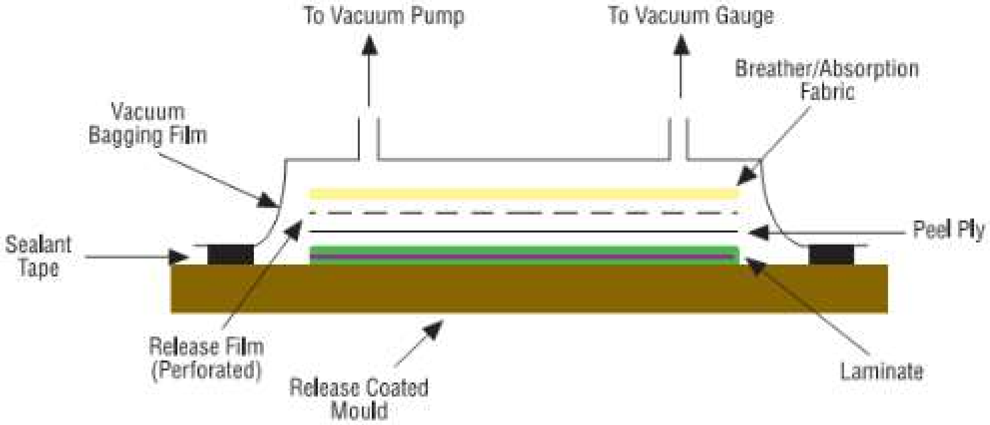

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Figure 2.3 Vacuum bagging processes [2]

2.3. Previous Works

2.3.1. Composite Materials

The work of Ermias Gebrekidan [4] experimentally characterized the mechanical properties of E-glass/Epoxy & E-glass /Polyester composite. His objective was to present processing techniques of specimen preparation, conduct experiment to obtain mechanical properties and also conduct experimental observation using Scanning Electron Microscopy (SEM) to know inhomogeneity, porosity and fracture behaviour. He investigated and presented the effect of strain rate on E-glass/epoxy and E-glass/polyester. He obtained E-glass/polyester laminates by compression moldeing process and E-glass/epoxy laminate by hand lay-up vacuum assisted technique. To obtain the ASTM standard he cut the laminates.

In contrast to Ermias's work, this paper has a different objective. Though, Ermis did compare properties of E-glass/Epoxy & E-glass /Polyester composite, the effect of altitude/pressure has not been considered. This work conducts an experiment to reveal the effects of altitude on E-glass epoxy repair by varying the strain rate. On top of Ermias's work, this paper has presented the effects of altitude/pressure on E-glass/epoxy composites repairs performed at various level of altitudes. Mechanical properties of E-glass/Epoxy repairs under various altitudes have been investigated with an experimental test of tensile, compression, and flexural strength using universal testing machine.

Further to Ermias's excellent contribution in composite property specially on E-glass/Epoxy & E-glass /Polyester Giovanni Belingardi and Ermias Gebrekidan Koricho [6] analysed the possibility of replacement of the engine support frame, which at present is made of steel and in some advanced cases in lightweight metals, with a new component made of Carbon/Epoxy composite material to point out and solve the existing major constraints with respect to the use of composite structures such as the effect of variation of stacking sequence and ply angles of sub-laminate on load carrying capacity and stiffness of engine sub-frame. In addition to his proposed analysis of replacing steel engine support with Carbon/Epoxy composite, he compares the Results with the structural performance (with particular attention to the equivalent stiffness) of the new proposed solution based on composite material with lightweight metal one.

Giovanni Belingardi and Ermias Gebrekidan Koricho [6] have further, optimized simplified design concept of engine support sub-frame and proposed the one that is suitable for manufacturing process and ultimately reduces the production cost. Having, clear understanding on the intent of comparing composites for the sake of optimized usage by both Ermias and Giovanni, this work intended to look further on its application and investigate the role and effect of altitude on a composite repairs manufactured to restore original strength and contour of structural damages on aircraft. Moreover, this work is also interested to present processing techniques of specimen preparation and conduct experiment to obtain mechanical properties.

In addition to the excellent contribution made by Ermias and Giovani altogether to the newly developing era of composite, this work is also curious to investigate and justify the proposed solutions given by manufacturer for repairs made at high altitude and contribute to review modification procedures followed to repair structural damages. Likewise, standard of repairs on its stiffness and loading capacity of E-glass/Epoxy for composites fabricated at high altitude will be investigated.

On the search for composite with understandably good mechanical properties E. Zaretsky, and G. deBotton, M. Perl [7] have prepared Glass fibers reinforced polymer composites by various manufacturing technology and used for various applications. The researcher presented mechanical, tribological, thermal, water absorption and vibrational properties of various glass fiber reinforced polymer composites. Similarly, this paper has also presented glass fiber reinforced impregnated with an epoxy resin. However, the interest of this paper is not to identify the properties of e-glass epoxy fiber instead reveal the effect on structural properties of E-glass epoxy fabricated at high altitude. Unlike E.Zaretsky's investigation, this work presents E-glass/epoxy composite preparation/fabrication and also investigated repairs done on high altitude environment. The effect of altitude on a composite repair, performed in high altitude repair shops like Ethiopia airlines has been investigated and presented.

Four scholars M. Gopalakrishnan, S. Muthu, R. Subramanian, R. Santhanakrishnan, and L.M.Karthigeyan [8] took the concept of optimum usage of composite material that could be applied at the initial design stage or when repairing damaged composite structures for various industries like aerospace, automotive and marine. Their paper described preliminary work towards the optimum usage of π/4 quasi-isotropic E-glass/epoxy laminate repair practices, and it demonstrates the procedure followed to determine their tensile properties.

Their work used unidirectional fiber (UDF) laminae and UDF laminate specimens to understand the tensile properties of UDF E-glass/epoxy laminate. They chose to investigate the property of unidirectional e-glass epoxy π/4 quasi-isotropic laminates is with the intension where usage of UDF (Uni-Directional Fiber) reinforced laminates would offer better strength in the direction of the fibers than in the transverse direction.

Their paper work considered that it is important to have composite laminate that offers isotropic properties at least in-plane. It would enable the designer to have better control over delamination and crack propagation issues. Their work provides a unique comparison between experimental results of UDF laminae and UDF laminate level. They have tested π/4 quasi-isotropic laminates to understand the tensile properties. They have put that the derived properties obtained could be suitably used for future work on quasi-isotropic E-glass/ epoxy composite laminate repair practices. Conversely, on this work, tensile, plane laminate repair unlike unidirectional E-glass/epoxy has been investigated using a conventional testing machine to determine effects of altitude on a repair for repairs fabricated at high altitude or low pressure environment. A number of specimens have been considered to clearly identify the effects and observation results are recorded.

Referring to the materials selected and contributions provided on a composite field of study Keshavamurthy Y C, Dr. Nanjundaradhya N V ,Dr. Ramesh S Sharma, and Dr. R S Kulkarni C.,2012 [9] have Investigated tensile properties of fiber reinforced E-glass/epoxy angle ply laminated composites. They conducted experiments on E-glass/Epoxy laminate composite specimens with varying fiber orientation to evaluate the tensile properties with different stacking sequences, i.e., [0/0], [90/0], and [±45]. They have prepared a specimen using vacuum bag technique. Their specimens were prepared for testing as per ASTM standards to estimate the tensile properties. After having the test, they come up with a conclusion that E-Glass/Epoxy with [0/0] fiber orientation yields high strength when compare to 00 & ±45 for the same load, size & shape. Relatively, on this work e-glass epoxy has been chosen for investigation with a plain or zero degree fiber orientation. Their paper has put all the focus and observed the effects of fiber orientation against strength but this work further investigated the effect of altitude/pressure on a repair performed from E-glass fiber reinforced with epoxy resin.

In the year 2004 a scholar George C. Jacob, 2004 [10] presents a detailed review of strain rate effects on the mechanical properties of polymer composite materials. An attempt was made to present and summarize much of the published work relating to the effect of strain rate studies done in the past on the tensile, shear, compressive, and flexural properties of composite materials to better understand the strain rate effects on these mechanical properties of fiber-reinforced polymer composite materials. George's work has also been further consolidated by Ermias work [4] to identify the strain rate effect, while this paper summarizes the effect of environmental pressure or altitude on a composite repair for aircraft.

In addition to George C. Jacob, 2004 [10] and Ermias's [4] work, effect of strain rate on the tensile properties of a glass/epoxy composite was investigated by Okoli and Smith [11]. Tensile tests were performed on a glass epoxy laminate at different rates (1.7 x10-2 -2000 mm/s). The tensile strength of the composite was found to increase with strain rate. Moreover, in other studies, the effects of strain rate on the tensile, shear, and flexural properties of glass/epoxy laminate was investigated by Okoli and Smith [10].

2.3.2. Methodology

For the preparation of this work and defining the methodology to be used, various research papers and journals have been studied and investigated. On this regard, A. F. Hamed, M. M. Hamdan, B. B. Sahari and S. M. Sapuan, [12] have presented the results from a series of tensile tests on the mechanical properties of composite materials. Specimens cut from pipes made from composite materials under internal pressure loadings have been tested using a series of ASTM S test methods for mechanical properties. Since, this product is to test tensile, compression and flexural properties on plain E-glass/Epoxy composite, it has been identified that testing methodologies would be different. likewise, this work has also employed standard set by ASTM to prepare and as well test specimens.

The results obtained from their series of tests have been presented and compared with results from analytical equations. Good agreement was achieved between the experimental results and analytical results. Conversely, this work investigates the effect of altitude/pressure on E- glass composite for aircraft part application. The paper will focus on presentation of processing techniques of specimen preparation, conducting experiments and recording strength and stiffness data. All the test methods will be presented based on the American Society for Testing and

Materials (ASTM). Unlike comparing test results with analytical equations result obtained from this work will be applied in the repair procedures of composite at high altitude for different loading conditions

Studding further to applied methodologies worldwide, the researcher came up with idea of studying researches developed for automobiles as it has similarity in application. Experimental Analysis of E-Glass /Epoxy & E-Glass /polyester Composites [13], in this Paper Experimental characterization of the mechanical properties of E-glass/Epoxy & E- glass/Polyester composite was conducted. The objectives of this paper is to present processing techniques of specimen preparation, conducting experiment to obtain mechanical properties and conduct experimental observation using Scanning Electron Microscopy (SEM) to know inhomogeneity, porosity and fracture behaviour. E-glass/polyester laminates were obtained by compression molding process and E-glass/epoxy laminate by hand lay-up vacuum assisted technique. However, a wet lay wet layup procedure has been used to prepare the test specimens and vacuum assisted instead of molding for high accuracy.

In addition to experimental Analysis, Progressive Damage Analysis of E-Glass Epoxy Composite with finite element method is presented by Laminates Adil Ahmed. S1, Dr. N. S. PrasannaRao2 and Dr. P. L. Srinivas Murthy3, Manu. N4 [14]. As per the study of this work it has been predicted that damage behaviour of composite laminates finds more importance and is a challenging task for researchers in present days. Progressive damage analysis of e-glass epoxy fibers is outlined in this paper. FEM analysis of e-glass fiber reinforced composite is performed. Tsai-hill failure theory has been considered in the methodology for progressive failure analysis. Here e-glass fibers are woven and hand layup technique is used for the preparation of plates. Experimental and finite element analysis is performed. It has been found that the results obtained via the progressive failure analysis correlate reasonably well with the experimental results. In regard to this, further experimental analysis has been performed in this work to investigate effect of high altitude but finite element method of analysis was left for further study. On the contrary of the previous work this paper considered a wet layup composite preparation.

This work by Vasileios M. Drakonakis,1,2 James C. Seferis,1 [23] focuses on analysing in a fundamental way the application of pressure and temperature separately for prepreg composite with newly designed controlled pressure vessel. However, application of such manufacturing methodology is limited to small prepreg composites which is different from the intent of this work.

Prashanth Banaker,H.K.Shivananda and H.b.Niranjan [20] The objective of their research is to gain a better understanding of tensile properties of epoxy resin composites reinforced with glass fiber. The effect of fiber orientation & thickness of laminates has been investigated & experimentation was performed to determine property data for material specifications, the laminates were obtained by hand layup process. The effect of fiber orientation and thickness were investigated in detain on this work however, this work has not taken in to consideration the effects of altitude or pressure on e-glass epoxy repair. On this work property data for material specifications and laminates were obtained by wet layup process. All the test methods will be presented based on the American Society for Testing and Materials (ASTM). This investigation deals with the testing of tensile, compression, flexural strength on a universal testing machine.

2.3.3. Composite Application

Esmael Adem [2] Addis Ababa University, have experimentally characterized the mechanical properties of E-glass/Epoxy & E- glass/Polyester composite. His work presented processing techniques of specimen preparation, conducting experiment to obtain mechanical properties of composite structure and conduct experimental observation using Scanning Electron Microscopy (SEM) to know inhomogeneity, porosity and fracture behaviour. The effect of strain rate on E-glass/epoxy and E-glass/polyester has been investigated & experimentation was performed for an automobile body. However, this work summarizes the effect of high altitude repair on E-glass/Epoxy repair. The effect of altitude on E-glass/epoxy composite repair has been investigated & experimentation was performed for an aircraft application.

The use of composite materials has grown significantly in aeronautic, automotive, naval, and civil construction sectors by substituting conventional materials such as steel, aluminium and other alloy materials. On this regard Giovanni Belingardi, Ermias Gebrekidan Koricho, [6] have summarized the possibility of replacement of the engine support frame, which at present is made of steel and in some advanced cases in lightweight metals, with a new component made of Carbon/Epoxy composite material. A methodology is developed that helps to point out and solve the existing major constraints with respect to the use of composite structures such as the effect of variation of stacking sequence and ply angles of sub-laminate on load carrying capacity and stiffness of engine sub-frame. Unlike Giovanni’s work engine support frame for light wet vehicles this work compare the structural performance of repairs performed at different altitudes for the application of Aircraft parts.

Taking composite material application into account, this paper analyses the mechanical property of E-glass epoxy composite fabricated at different vacuum pressures. The effect of altitude (curing Pressure) on a property of E-glass epoxy composite has been investigated.

Chapter -3

Experimental Methods & Conditions

3.1. Materials

General

Mechanical testing of materials is an initial condition in the design and fabrication process of structural parts in order to obtain stiffness and strength under varying loading conditions. The mechanical testing of composite structures to obtain parameters such as strength and stuffiness is a time consuming and often difficult process. It is, however, an essential process, and can be somewhat simplified by the testing of simple structures. The test methods outlined in this section merely represent a small selection available for aircraft structural composites and the result will be used to determine the best composite repair procedure for a particular application on aircraft structure for any induced damage.

3.1.1. E-Glass Fiber

The raw materials used in this work are typically used for Aircraft structural construction and are: E-glass fibers, Epoxy resin with its hardener, that is obtained from Ethiopian Airlines Aviation Academy, Ethiopian.

E-glass is often used for secondary structure on aircraft, such as fairings, radomes, and wing tips. E-glass fiber is also used for helicopter rotor blades. There are several types of E-glass used in the aviation industry like Electrical and Structure glass. E-glass is identified as such for electrical applications. It has high resistance to current flow. E-glass is made from borosilicate glass. S-glass and S2-glass identify structural fiberglass that have a higher strength than E-glass. S-glass is produced from magnesia-alumina-silicate. Advantages of E-glasses are lower cost than other composite materials, chemical or galvanic corrosion resistance, and electrical properties (an E-glass fiber does not conduct electricity).

E-glass has a white color and is available as a dry fiber fabric or prepreg material Laminates are sheet constructions which are made by stacking layers (also called plies or lamina) in a specified sequence.

The layers are often in the form of prepreg (fibers pre- impregnated with partly cured resin) which are consolidated in an autoclave. A laminate may have more than four layers and the fiber orientation changes from layer to layer in a regular [5]

These fibers are high-performance reinforcement widely used in wet/hand lay-up of Aircraft, boats, vessels and automotive parts. It is relatively low cost, the most common form of reinforcing fiber used in polymer matrix composites. “E” glass produced fibers are considered as predominant reinforcement for polymer matrix composites due to their high electrical insulating properties,

- low susceptibility to moisture,
- high mechanical properties, and
- Low cost

Owing to the upper-mentioned favourable characteristic and is widely adopted in Ethiopian Airlines, E-glass fiber has been taken as strengthening for this work. The type of E-glass fiber which is used in this study is woven roving. This fiber type has good mechanical properties as compared to chopped mat and it is used when higher strength part is required especially for aircraft structural construction. The typical picture of plain woven E-glass fiber is shown below.

(a) (b)

Figure: 3.1 E-glass fibers Woven Fabrics E-glass fiber (a) Rolled Woven Fabrics (b)

E-Glass Fabric Construction Properties

According to good mechanical property and a wider application on aircraft, Class I E-glass fiber has been selected for the intended work. The typical Mechanical properties of woven E-glass is depicted below. BMS 9-3 is a part name given by Boeing and the chemical manufacturer (JPS Composite Material Corp.) identify the E-glass fabric as JPS164-112.

Type	Class	Part No.	Thickness, mm	Weave	Actual Thickness, mm	Weight kg/m3	Style	Dry Tensile Strength Kg/mm^3
G	1	BMS9-3	0.3683-0.4445	Plain	0.381	0.41	164	21.795

Table 3.1.E-glass manufacturer specifications [29]

Fabric style

Fabrics are usually plain or harness weave. Plain weave fabric has each warp direction tow or yarn interlaced with each fill direction tow or yarn. Harness weave fabric has each warp direction interlaced under several fill direction tows or yarns. Only the most common weave styles are used by aircraft manufacturers like Boeing and among those a plain weave style has a wider application. Considering force and area of E-glass epoxy application on aircraft a plain wave has been selected for the intended work.

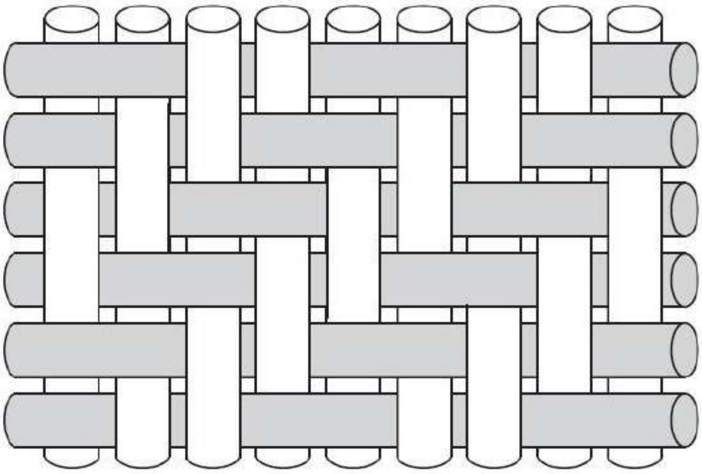


Figure: 3.2 Fabric style [29]

3.1.2. Epoxy Resin and its hardener

Epoxy

Epoxies are polymerizable thermosetting resins and are available in a variety of viscosities from liquid to solid. There are many different types of epoxy, and the manufacture recommendation should be referred to select the correct type for a specific repair. Epoxies are used widely in resins for pre-preg materials and structural adhesives [3]. The advantages of epoxies are high strength and modulus, low levels of volatiles, excellent adhesion, low shrinkage, good chemical resistance, and ease of processing [3].

Their major disadvantages are brittleness and the reduction of properties in the presence of moisture [3]. The processing or curing of epoxies is slower than polyester resins [3]. Processing techniques include vacuum bagging. Curing temperatures for aircraft structural application vary from room temperature to approximately 350 °F (180 °C). The most common cure temperatures range is between 302 °F (150°C) and 350 °F (180 °C). [5]

Epoxy Resin Requirements

Appearance

- Each component of the resin is homogeneous material.

Figure: 3.3. Epoxy Resin

Blending

- This work has furnished information on the proper blending proportions of Parts A and B. Parts A and B readily blend to produce a uniform product, with 2 to 3 minutes of hand mixing at room temperature. The amount of hardener (Part B) is expressed in terms of one hundred parts by weight of base material (Part A) as specified in the specification data sheet. Therefore, as specified in the specification data sheet, for the purpose of this work equal proportion by weight (50% part A and 50% part B) are used and properly hand mixed for three minutes.

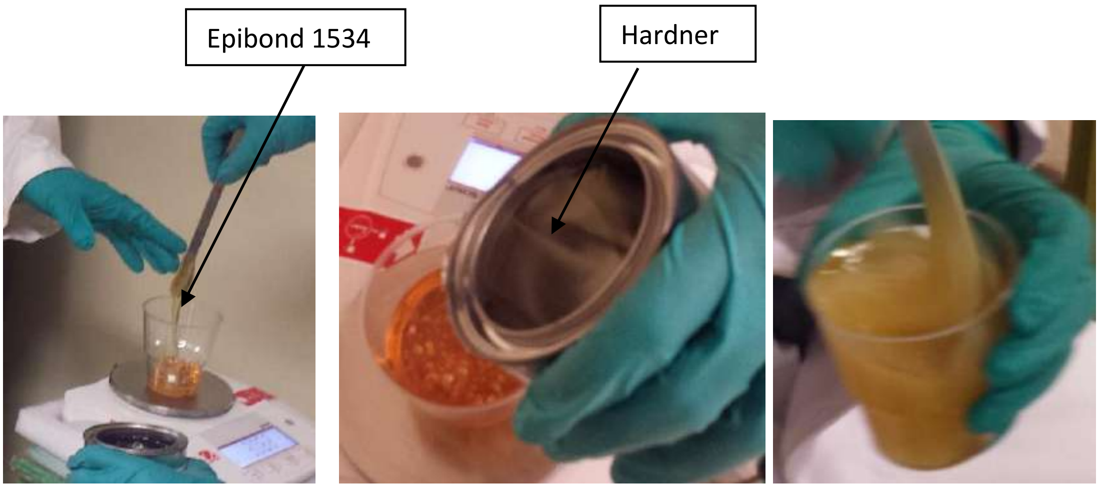


Figure: 3.4. Epoxy Resin and its hardener blending

Cure

- According to Epibond product data the curing cycle for class I epoxy is 250 ± 5F [121℃]. As to the manufacturer Aircraft structure repair manual, the recommended heat up rate from ambient to cure temperature is 3℃ per minute. HEATCONE COMPOSITE SYSTEMS has been used on this task to achieve proper curing cycle specified on the on manufacturer repair Manual.

Storage Life

- The storage life is determined from the date of receipt at the purchaser's facility and they should be kept stored below 40 F [4.5℃] upon received. Epoxy used for this work is confirmed that is has met specifications required by manufacturer like acceptable storage life and kept well below 40 F [4.5℃] before utilization.

Uncured/Cured Resin Properties

- The resin systems shall meet the applicable requirements in Table 3.2 and Table 3.3 when tested in accordance with the manufacturer (Boeing) specification.

Test	Test Temperature F(±5F) [℃]	Part A viscosity(Resin)	PartB viscosity(Hardener)
Viscosity ,cps	75F [24℃]	5000-7000cps	1300-2000
Density g/cc	75F [24℃]	1.22 ±0.05	0.98± 0.05
Gel time ,minutes	75F [24℃]	120min	
Part no.	75F [24℃]	Epibond 1534	
Manufacturer	-	Huntsman Advanced Material	Huntsman Advanced Material

Table3.2. Uncured resin Properties [30]

Test	Test Temperature F(±5F)	Strength (Mpa)	Resin Reinforcement
Tensile strength, ultimate, Mpa	75F [24℃]	40	Epibond 1534
Compressive, interlaminar shear strength	75F [24℃]	48.3	Epibond 1534

Table3.3. Cured resin Properties [30]

Resin Mixing Ratio

Wet layup resins come in two parts, which are mixed to the A stage by the user. Wet layup resins are used for repair, sealing, edge wrapping of square edged honeycomb panels, and secondary bonding. Wet layup resins used for repair are: BMS8-301, used for sealing purposes. This is not a structural resin system. Epibond 1534, used for wet layup repairs. Class I is a high temperature curing Class II is a low temperature curing system [3] thus high curing temperature (Class I) is selected for this work.

Epoxy resin, like all multi-part materials, must be thoroughly mixed. The resin was mixed slowly and fully for three minutes. If the resin is mixed too fast, air will be put into the mixture. The resin may not cure properly if the resin system is not mixed fully. For this work it has been used the resin mix ratios listed in the specification data sheet. These are the ratios referenced during a composite repair. Correct storage and handling of resins is done. Correct storage includes refrigeration, proper containers and keeping records of the material.
Mixing Ratio Resin (Part A) here after A and Hardener (Part B) here after B is given as below:

$$\text{A (Ratio)} = \frac{A}{A+B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

$$\text{B (Ratio)} = \frac{B}{A+B} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Mix Ratio	
Product	Parts by Weight
Epibond 1534 A Resin	50%
Epibond 1534 A Hardener	50%

Table3.4. resin mix ratio

E-glass Fabric/Epoxy Ratio

According to Epibond product data sheet the ratio given to E-glass/epoxy wet layup repairs is:(Total resin required) = (Dry E-glass fabric weight). For the fabrication of E-glass fiber with Epibond resin it is recommended to use both fabric and resin in equal amount. This will let the fabric to fully cover by the resin and avoid starvation which leads to weak tensile and compressive property. Therefore, according to the recommendation, equal ratio of fabric and resin have been used in this work. The ratio of the resin to the laminate can be determined through experience. It may be based on the volume ratio or weight ratio as indicated equation 3.5.

Mix Ratio	
Product	Parts by Weight
Total Resin Required	50%
Dry E-glass fabric weight	50%

Table3.5. Fabric to resin mix ratio

$$Fiber\ Weight\ Fraction = \frac{\text{Weight of fiber}}{\text{Total Weight}} \ldots\ldots\ldots 3.3$$

$$WF = \frac{\text{Wf}}{\text{Wf+Wmt}} \ldots\ldots\ldots 3.4$$

$$Matrix\ Weight\ \ Fraction = \frac{\text{Weight of Matrix}}{\text{Total Weight}} \ldots\ldots\ldots 3.5$$

$$WM = \frac{\text{Wm}}{\text{Wf+Wmt}} \ldots\ldots\ldots 3.6$$

$$\text{WF+ WM=1} \ldots\ldots\ldots 3.7$$

WF- Fibber Weight Fraction, WR- Matrix Weight Fraction,

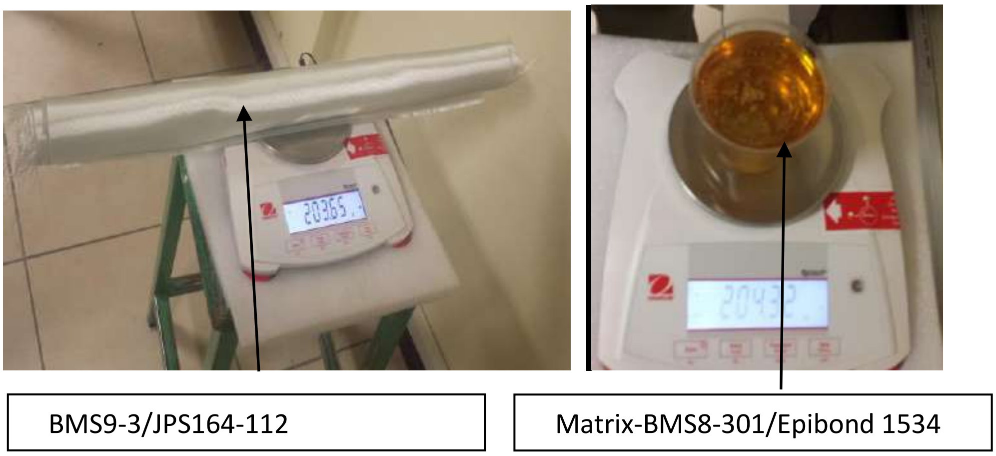


Figure 3.5: resin E-glass Fabric/Epoxy Ratio

3.2. Geometry and Dimensions

The specific dimensions off each specimen for each loading configuration are performed according to requirements on American Society of Testing & Materials (ASTM).

3.2.1. Tensile Specimen Geometry and dimensions

According to American Society for Testing & Materials (ASTM) test method D3039-00 [17] the constant rectangular cross section specimen was used. As it is shown in figure 3.6, 20 mm wide, 250 mm long and 2.5 mm thick by 150 mm gage length woven E-glass/ is prepared. Emery cloth is used as a fabrication per ASTM recommendation. All dimensions given in Fig.3.6 and 3.7 are in millimetres.

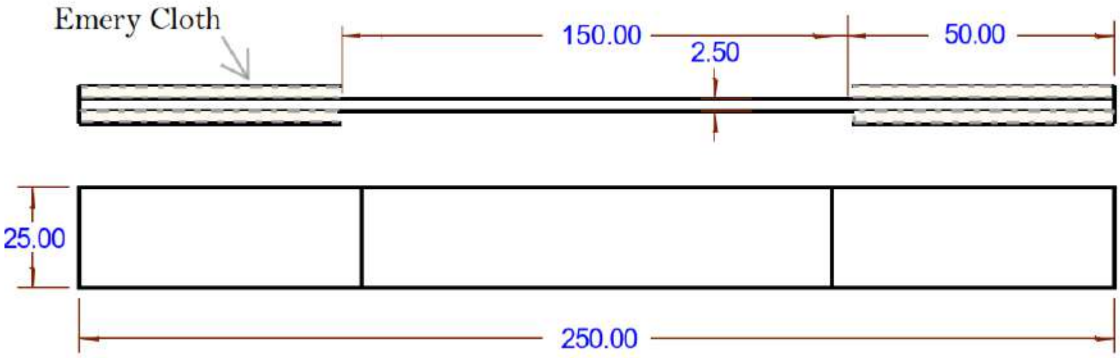


Figure 3.6: E-glass/Epoxy test specimen Heating Tensile Test Specimen

3.2.2. Compression Specimen Geometry and dimensions

The compressive test was conducted along the longitudinal direction of the fibres on universal testing machine according to ASTM standard [18].

As it is shown in figure 3.6, 25 mm wide, 150 mm long and 2.5 mm thick E-glass/ epoxy specimen was prepared. According to ASTM [18] tab length of 65mm is used with emery cloth.

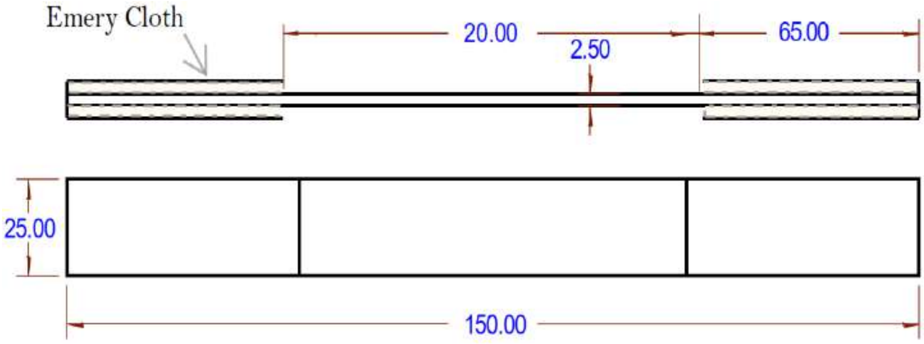


Figure 3.7: E-glass/Epoxy test specimen Heating Compression Test Specimen

3.3. Test sample fabrication process

3.3.1. Ply Stacking Sequence

The strength and stiffness of a composite build-up depends on the orientation sequence of the plies. The range of values is determined by the orientation of the plies to the applied load. Proper selection of ply orientation in advanced composite materials is necessary to provide a structurally efficient design. The part might require 0° plies to react to axial loads, ±45° plies to react to shear loads, and 90° plies to react to side loads. Because the strength design requirements are a function of the applied load direction, ply orientation and ply sequence have to be correct.

During composite repair it is important to consider the stacking sequence of plies and to be aware of symmetry and balance of the stack to avoid a tendency to bend and reduce shear coupling. The repair process undertaken in this work has been presented in this topic.

As the thickness given on Table 3.1 above (0.381mm) and total thickness required is 2.5cm, 6.66 plies approximated to 7 plies are used.

The stacking sequence of laminate used in this paper with its respected angle is shown in figure 3.6. 0^0 and 90^0 plies

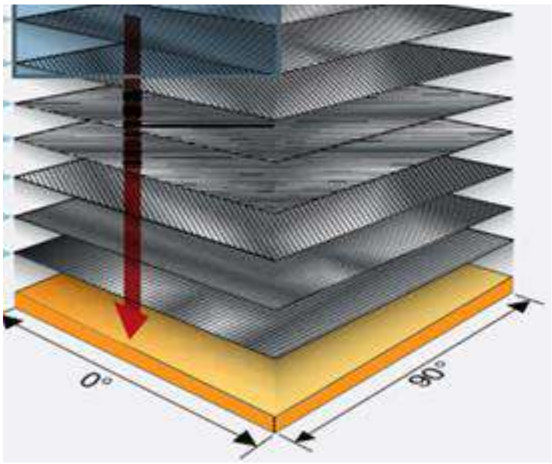
<table>
<tr><th>Ply No.</th><th>Orientation</th><td rowspan="8">
</td></tr>
<tr><td>1</td><td>0</td></tr>
<tr><td>2</td><td>90</td></tr>
<tr><td>3</td><td>0</td></tr>
<tr><td>4</td><td>90</td></tr>
<tr><td>5</td><td>0</td></tr>
<tr><td>6</td><td>90</td></tr>
<tr><td>7</td><td>0</td></tr>
</table>

Figure 3.8: Stacking sequences of laminated Composite structure [5]

3.3.2. Composite Manufacturing/repair technique

Here, Wet lay-up Vacuum assisted repair technique for E-glass/Epoxy composite samples is used in order to fabricate the samples. This method is recommended by the Aircraft manufacture and it is the only approved technique to perform repair on aircraft structures according to Boeing Aircraft structure manual.

Wet Lay-up Vacuum assisted technique (WLVAT)

This is basically an extension of the hand lay-up process where pressure is applied to the laminate once laid-up in order to improve its consolidation. This is achieved by sealing a plastic film over the hand laid-up laminate and on to the tool. The air under the bag is extracted by a vacuum pump and thus up to one atmosphere of pressure can be applied to the laminate to consolidate it.

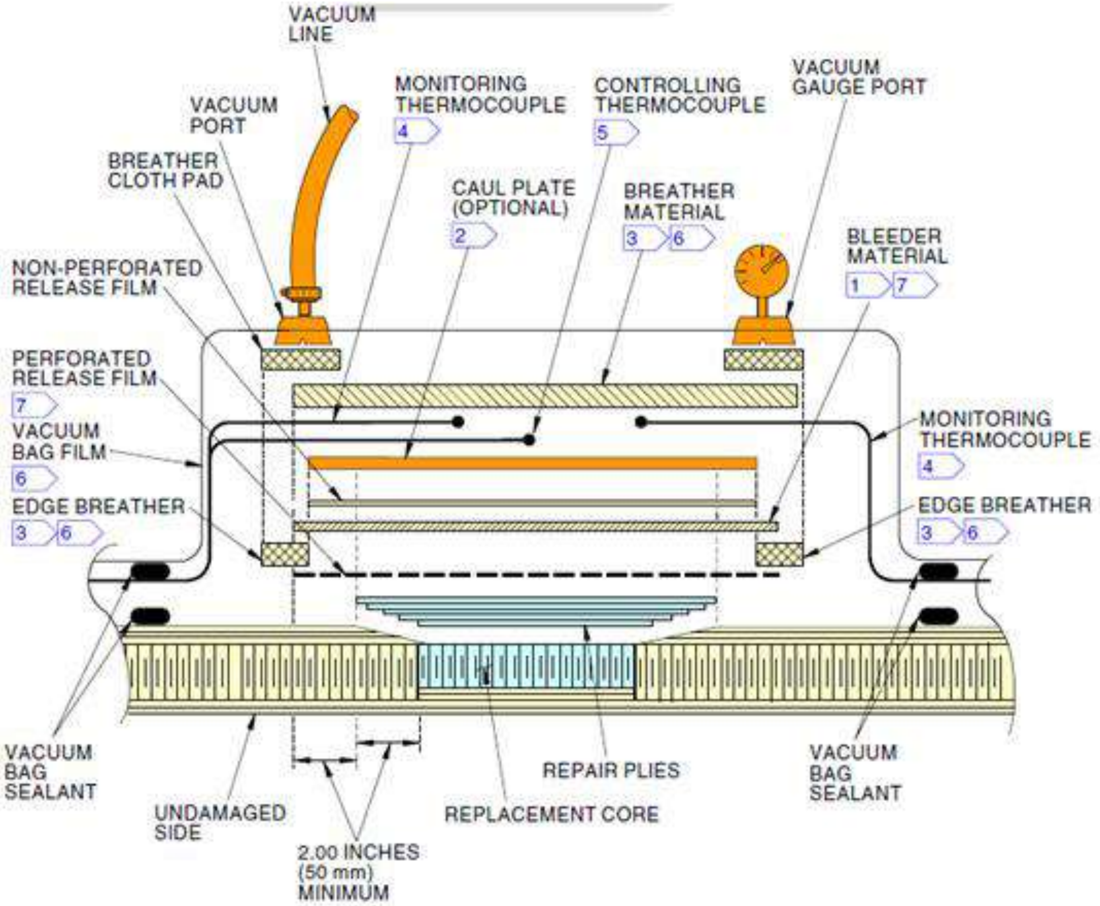


Figure 3.9: Wet layup Processing Technique [2]

Wet layup Processing Materials

Processing materials are the materials that we use when we make the repair. These materials do not become part of the repair. The following materials are common processing materials.

- Vacuum pump
- Weighing Scale
- Perforated parting film
- Bleeder material
- Solid parting film
- Caul plate
- Breather material
- Hot bonder
- Heater Blanket
- Vacuum bag material
- Vacuum bag sealing compound
- Marking pens and pencil

1. Vacuum pump

The pump used for this work is taken from Ethiopian Aviation Academy. The specifications and the photograph of the vacuum pump are illustrated below:

Specification:

Manufacturer Heat cone

Power: 220-240v/50Hz

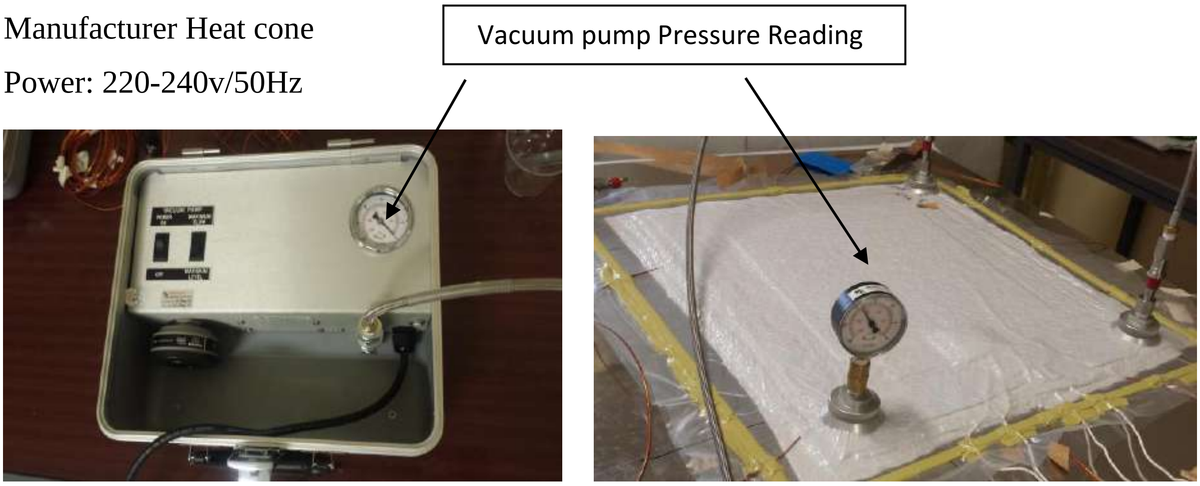


Figure 3.10: Wet layup Processing Materials

2. **Weighing Scale**

   The weighing scale used for this work is electrically operated brand new digital OHAUS product with a very high accuracy (10^3) and repeatability.

Figure 3.11: Fabric Measuring Scale

3. **Perforated Parting Film**

   Perforated parting film is used to allow air and volatiles out of the repair. It also prevents the bleeder ply from sticking to the repair. The bleeder ply gives an air path for the air and volatiles to escape from the repair.

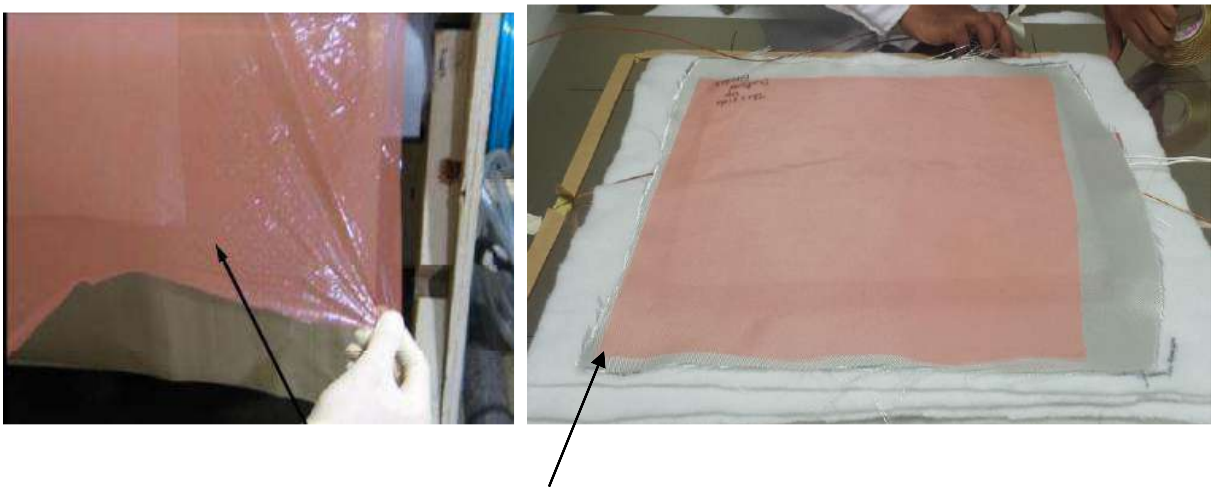


Figure 3.12: Perforated parts film

4. Bleeder material

Is a porous material that gives a continuous air path above and around a repair? Breather cloth consists of a woven fabric or non-woven mat. It is used in single or multiple layers that are placed inside the vacuum bag to provide a continuous vacuum path to remove the air initially inside the bag. Typical breather use for this study is shown in Figure 3.11 below.

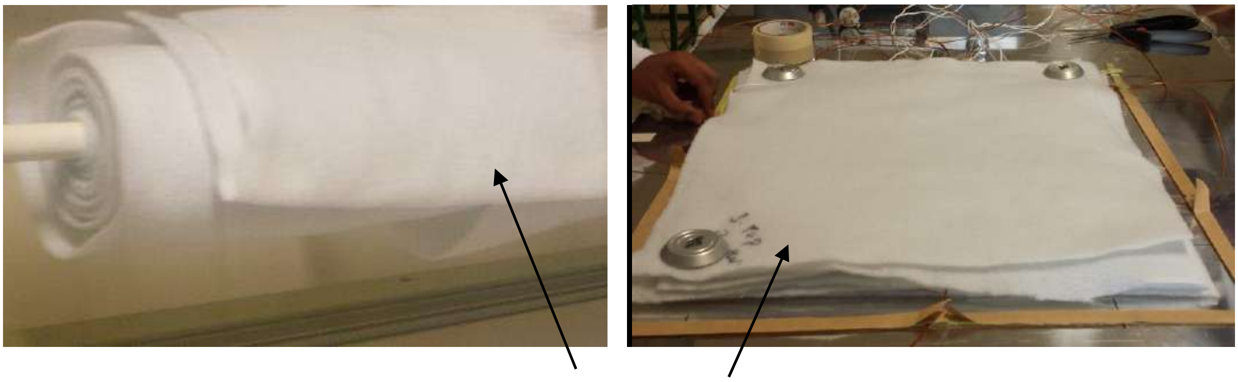


Figure 3.13: Bleeder material

5. Caul Plate

Is smooth metal or composite plate, which is virtually free from surface defects, used in close contact with the layup during the curing process to transmit even pressure and to provide a smooth surface on the finished part.

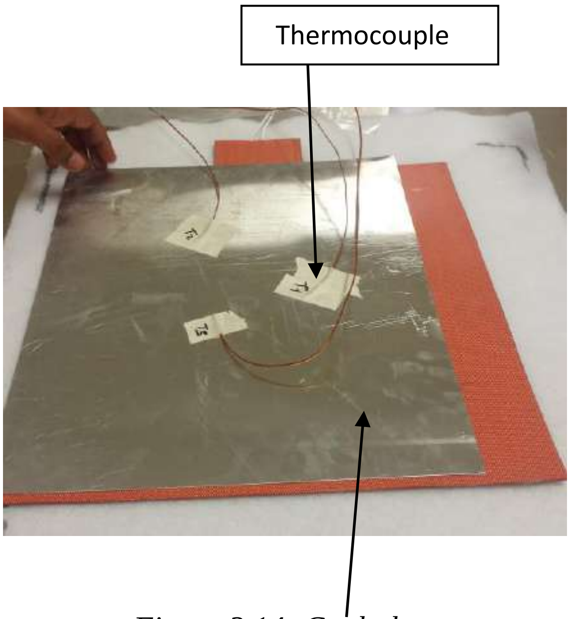


Figure 3.14: Caul plate

6. **Vacuum Bag Sealant Tape:**

A sealant used to seal off the edges of a vacuum bag used in the curing of resins.

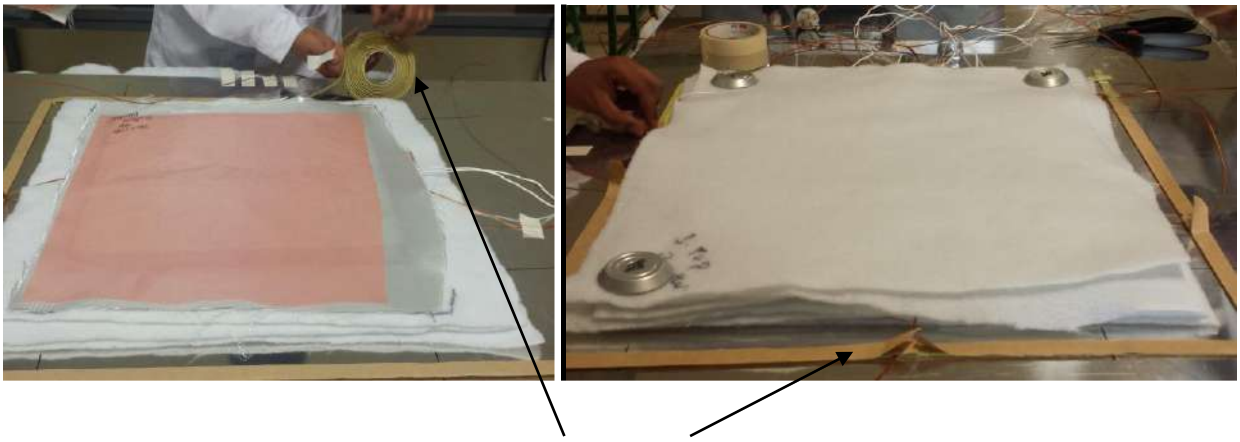


Figure 3.15: Vacuum bag sealant tape

7. **Vacuum Bag**

Is a film material that is used to cover and seal against the tool surface where a vacuum or pressure is applied? Bagging: Refers to the sealing of the repaired area using a plastic bagging film. Air can be evacuated from within the bag to create pressure upon the materials of the repair.

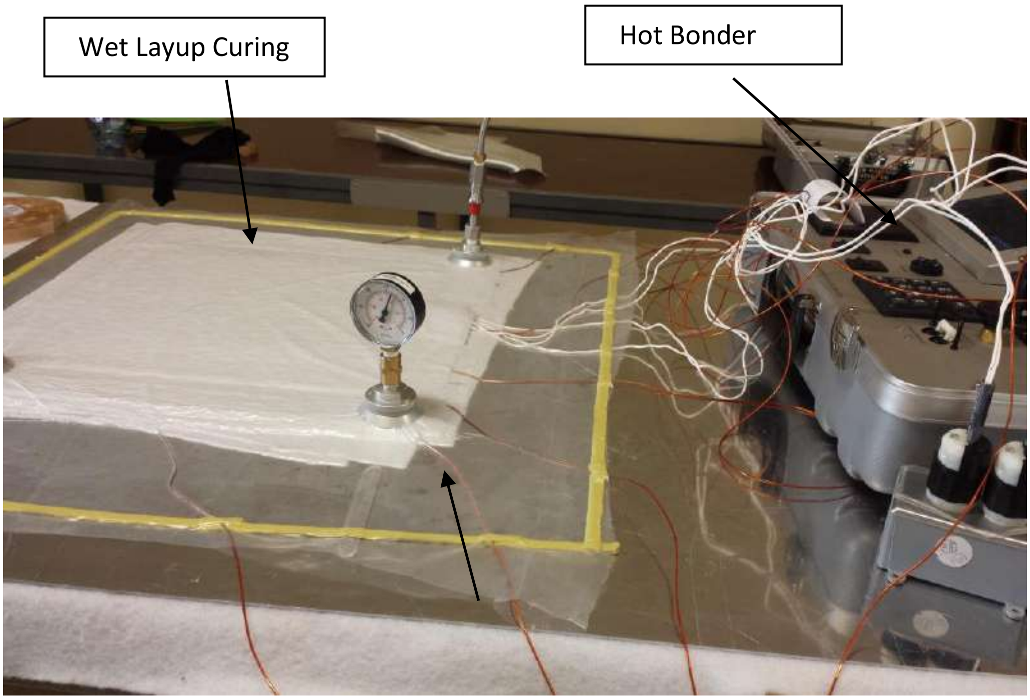


Figure 3.16: Vacuum bag

8. Vacuum Port Assembly

Is a fitting assembly that interfaces with a vacuum source and provides a means of evacuating air from a sealed vacuum bag.

Figure 3.17: Vacuum Port Assembly

9. Hot Bonder

The heat cone hot bonder used on this work is provided by Ethiopian airlines to monitor the curing cycle according to aircraft repair manual by heating and curing. The heat bonder has built in vacuum system to allow easier mobility without the need for alternative air source. It is also provided with dynamic alarm to monitor temperature exceedance and provision for data export which has helped a lot during this work for monitoring and record.

Figure 3.18: HCS9000B-EV Single Zone Hot Bonder

Specification:

Manufacturer Heat cone

Power: 220-240v/50Hz

9. Heater Blanket

The heater blankets used in this work are also obtained from Ethiopian airlines with standard heating value recommended by the manufacturer for composite repair.

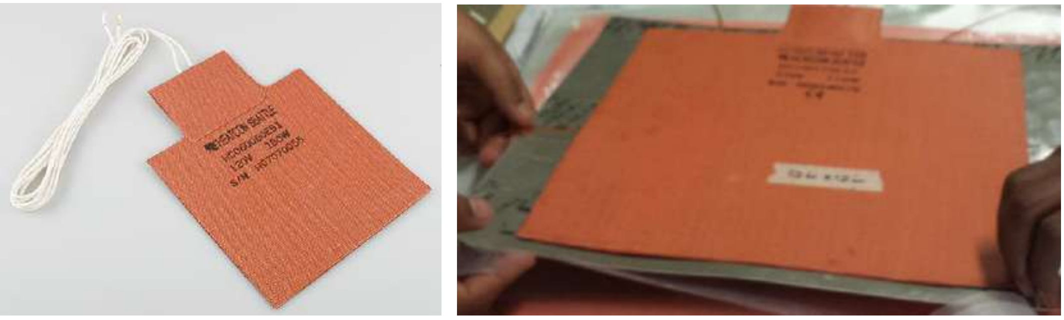


Figure 3.19: Heater Blanket

Specification:

Manufacturer Heat cone

Power: 220-240v/50Hz

3.3.3. Test Specimens Fabrication Process

Lay out

Referring to dimensions given ASTM, a proper layout on the Glass fiber has been has put with a standard layout pen. Following the proper mixing, epoxy has been poured slowly and adequately to be applied on the glass fiber. Equal distribution and adequate application of resin to avoid localizes starvation has been fully validated using standard spatula (P.A-1) 3M. Once the mixing is done as to the standard small air pockets entrapped inside the Vacuum bag were allowed to escape by piercing the fabricated specimen with a small needle.

Figure 3.20: E-glass/Epoxy test specimen Layout

Properly mixed E glass/Epoxy finally cut in to the standard size and kept for controlled curing process using heat bonder.

Figure 3.21: E-glass/Epoxy test specimen sizing

Bagging

Referring to wet layup procedure plies to meet the thickness provided bn ASTM are interlaced properly at 0-90 warp direction. To undergo wet layup fabrication equipment like breather ply, breathing ply, perforated parts film and coul plate are used.

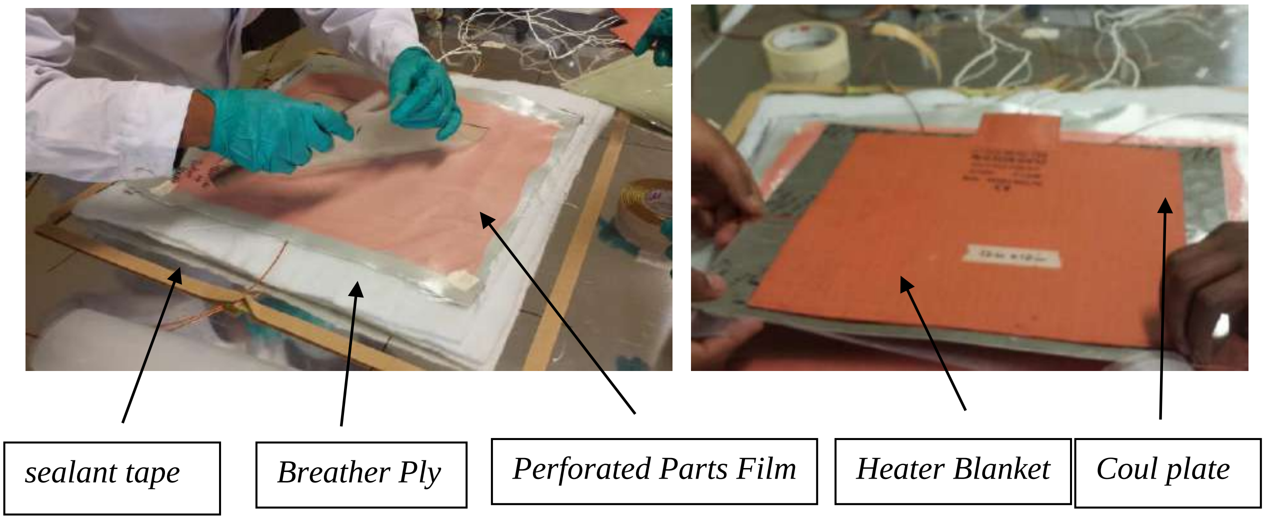


Figure 3.22: E-glass/Epoxy test specimen bagging

Curing Cycle

The fabricated specimens called in this work are wet layup E-glass/Epoxy composites. For size and limits of such fabrication see applicable procedure in chapter three. The specimen fabrication in this subject is performed at temperature 250°F, of which the cure may be accelerated by the application of heat as specified. To obtain maximum properties, it is recommended by consumable product data. The curing cycle used to cure Epibond 1534 test specimen is explained in the below graph.

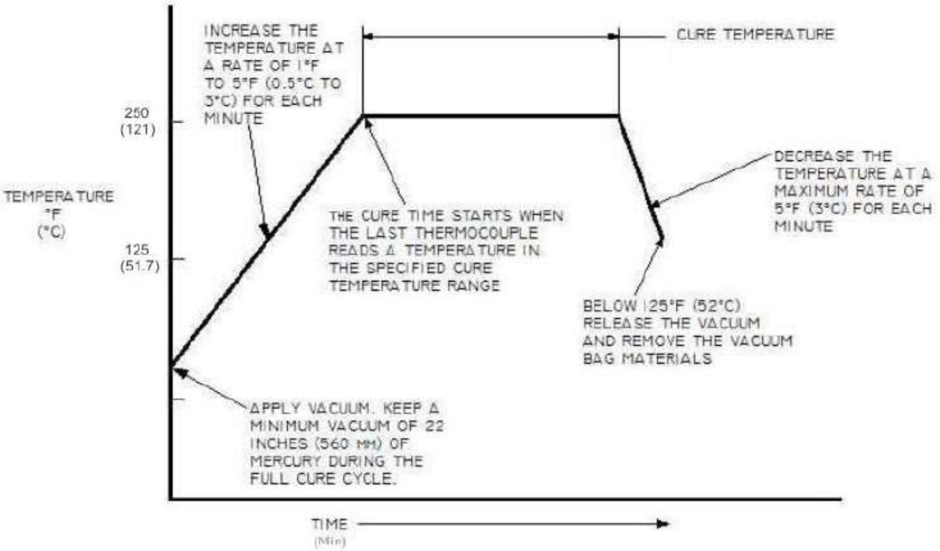


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Figure 3.23: Cure Cycle for Epibond 1534, Class I

To monitor the temperature, three thermocouples were placed above the heater blanket and below the coul plate. This thermocouple gives advanced warning if the heater blanket gets too hot and is connected to the temperature-controlled device.

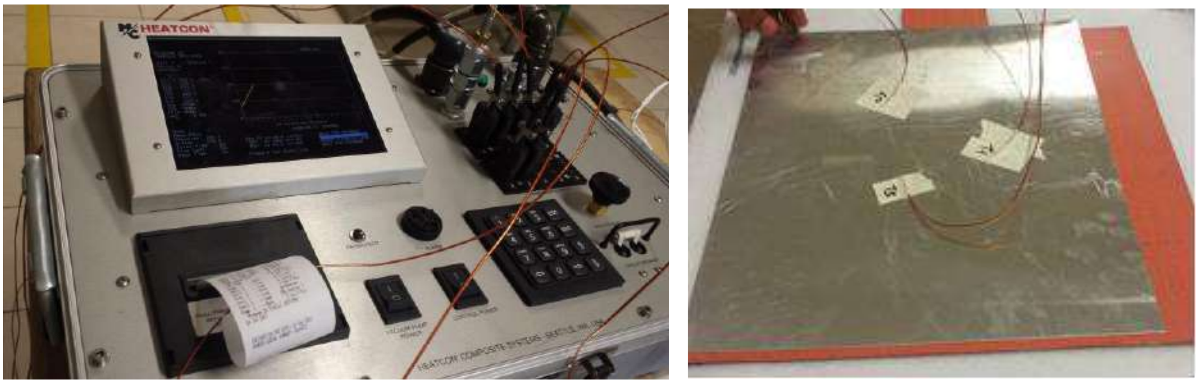


Figure 3.24: E-glass/Epoxy test specimen heating

Curing Vacuum Pressure

The role of pressure on the curing extent and its effect on a composite repair are tested in order to evaluate the property of E-glass/Epoxy composite. Such studies may also be used to provide insight into the maintenance procedure followed in these days on aircraft structure. On this specific work, three sets of specimen were prepared each at different vacuum pressure.

The researcher has intended to prepare three sets at 13 inches of mercury, 16 inches of mercury and 19 inches of Hg. Accordingly, the fabricated specimens are tested for compression and tensile properties with the intent of investigating the mechanical characteristics.

Figure 3.25: Application vacuum to E-glass/Epoxy

The vacuum pressure applied to fabricated test samples is achieved by allowing controlled leakage. By The vacuum pressure made the vacuum bag conform to the shape of the part. The final curing product is depicted below.

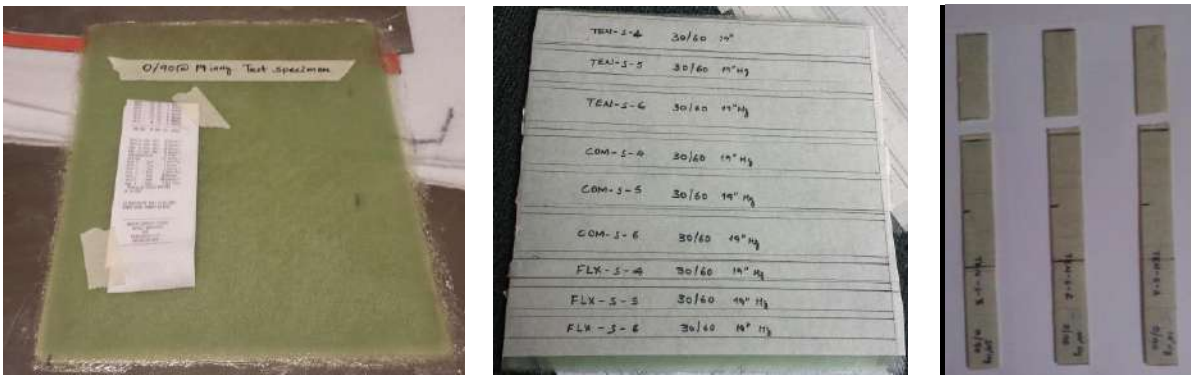


Figure 3.26: Fabricated test samples

3.4. Test Methods

The tensile test was performed on flat specimen. Tensile test of composite sample is carried out in accordance with ASTM D 3039/D 3039M – 00 test standard at Laboratory of Ethiopian Conformity Assessment Enterprises. In tensile test, a uniaxial load was applied through both the end.

The Compressive test was performed on flat specimen on the same test machine as tensile test. The difference is that, the standard used for compressive test is ASTM 3410M and the machine is set to move in opposite direction to test compression. The machines use to shape and test the specimen are described below.

1. **Band Saw**

Band Saw is used for cutting of specimens after fabrication process in to the required dimension. The machine has a cutting speed of 500-1000m/min, with blade length 2560mm and maximum work piece height of 230mm which is shown in figure 3.28.

Figure 3.27: Band Saw

2. Universal Testing Machine

Mechanical testing of tensile and compressive of E-glass/Epoxy composites are tested using Computer Controlled Electro-Hydraulic Servo Universal Testing Machine. Three specimens were fabricated for each configuration in order to portray repeatability of the test results. The Compression test was conducted at Defense Engineering College and the Tensile test was done at Ethiopian Conformity Assessment Enterprises test Lab with a universal test machine.

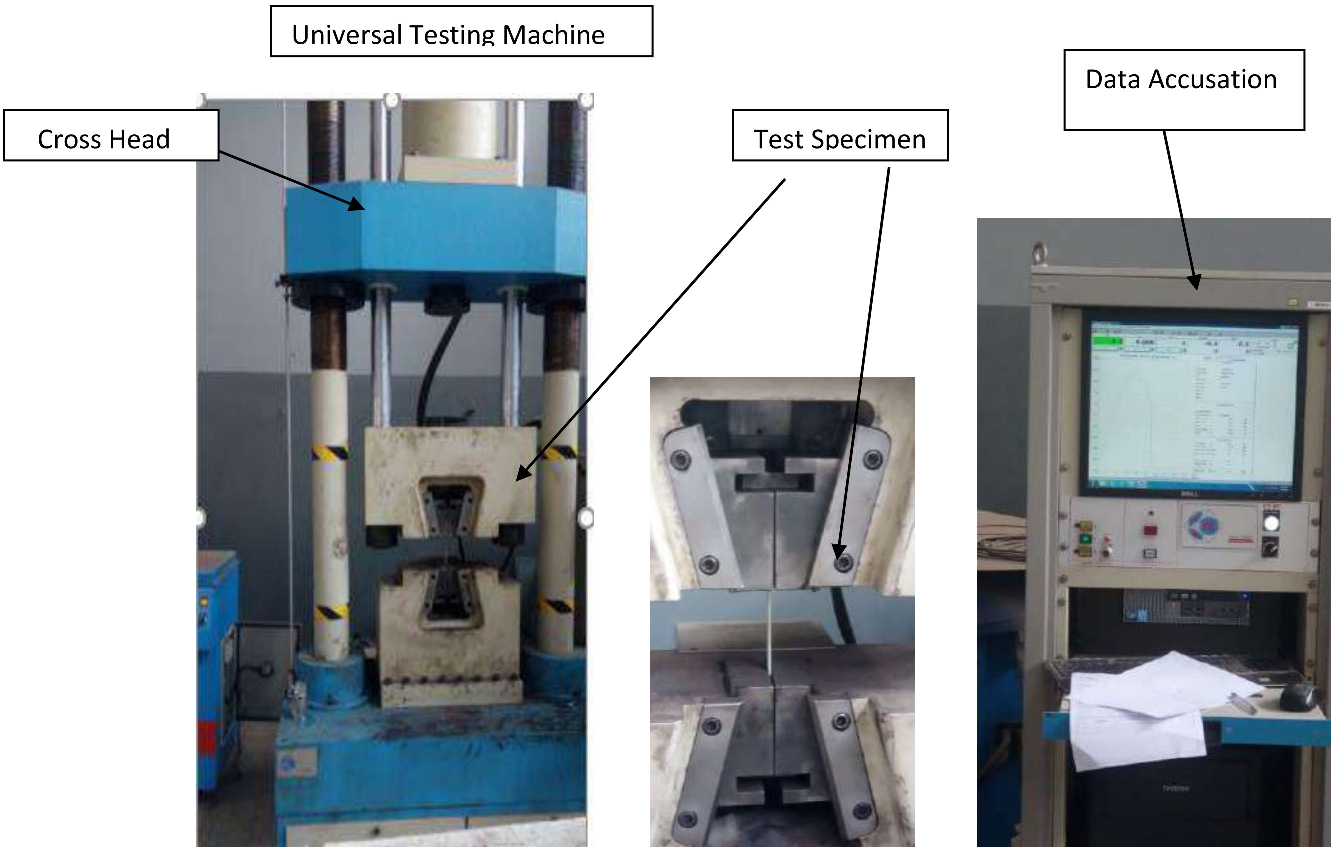


Figure 3.28: Computer-Electrohydraulic Universal Testing Machine

3.5. Testing conditions

The test is performed to make sure repairs performed at high altitude are provided with supplemental repair procedure recommendations by the manufacturer. Three test configurations are considered in this work. The first configuration was intended to test quality against tensile and compression parameters for a specimen fabricated at 13 inches of Hg. Similarly, the remaining two configurations consider testing of a specimen prepared at 16 and 19 inches of Hg. The objective of the test is to identify failure characteristics of each specimen and come up with recommendations on the test result.

For the aim of enlightening repeatability and minimalizing experimental errors that could occur during manufacturing or testing, three specimens for each configuration were tested. The tests have been conducted with standard and computer aided electro-hydraulic universal testing machine. The test results were retrieved through USB key from the on-board data acquisition access.

During the test each specimen was clamped by means of hydraulically operated grips and the testing machine was provided with standard load cell. The experiment was conducted with constant strain rate 2mm/min at around room temperature.

3.6. Experimental Setup

The specimens were prepared as a single unit and needed to be properly cut to its size in accordance to dimensions given by ASTM. To provide the required size a standard band saw was used. To avoid errors a great care was taken during cutting the test specimens to their required size.

For the experimental investigation of mechanical property of E-glass/Epoxy composite a universal testing machine with the following description is used (model: WAW-600) with a capacity of 500 kN, precision grade is 0.5 with 0.01 - 500 mm /min test speed and manufactured in Shanghai Hualong Testing Instruments Co.LTD.

Chapter -4
Result and Discussion

4.1. Experimental Results

4.1.1. Tensile Test

Tensile tests have been conducted on fabricated specimens and the result is summarized and presented below.

Hereunder, test results have been discussed for three sets of test specimen fabricated at different altitude/pressure resembling location of repair stations at different altitudes from sea level. Engineering stress against engineering strain have been plotted refereeing to the conducted test. The mechanical property of E-glass/Epoxy characterized to display the effect of strength for a repairs fabricated at different bagging.

The below tables indicates stress stain diagram for E-Glass/Epoxy composite fabricated at 13inch of Hg ,16 inch of Hg and 19 inch of Hg.

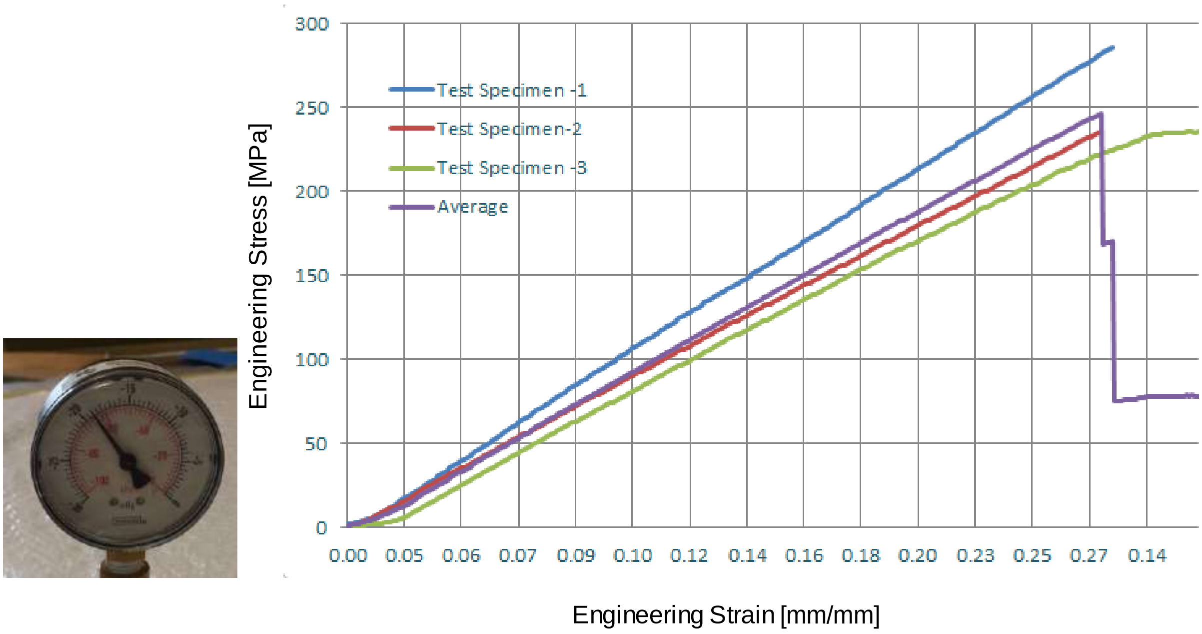


Figure 4.1 E-Glass/Epoxy composite fabricated at 19 “Hg.

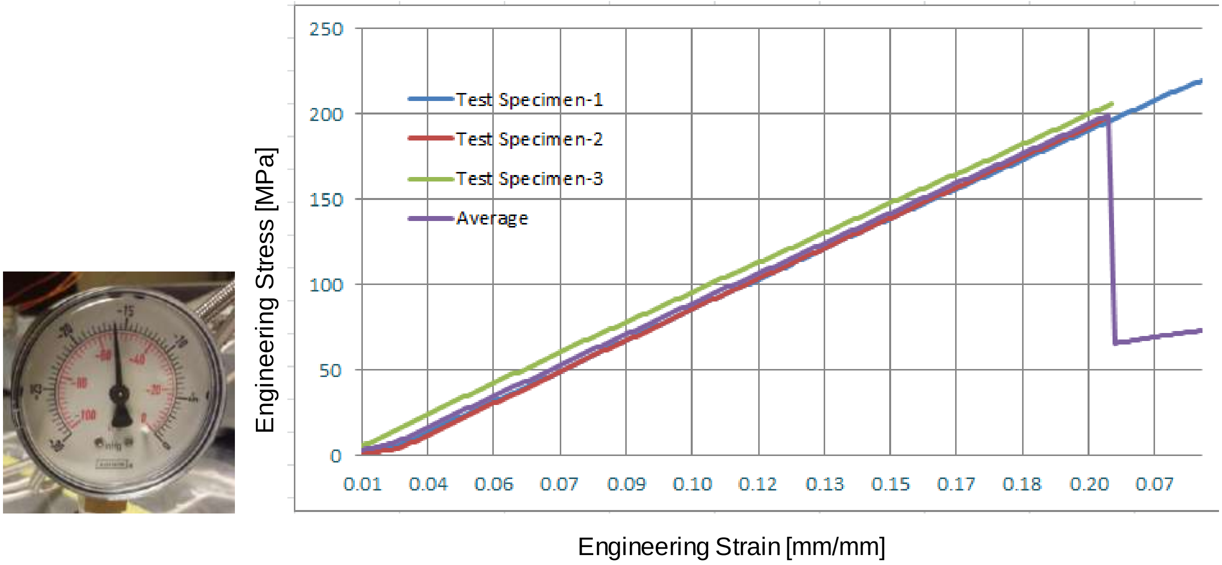


Figure 4.2 E-Glass/Epoxy composite fabricated at 16 "Hg.

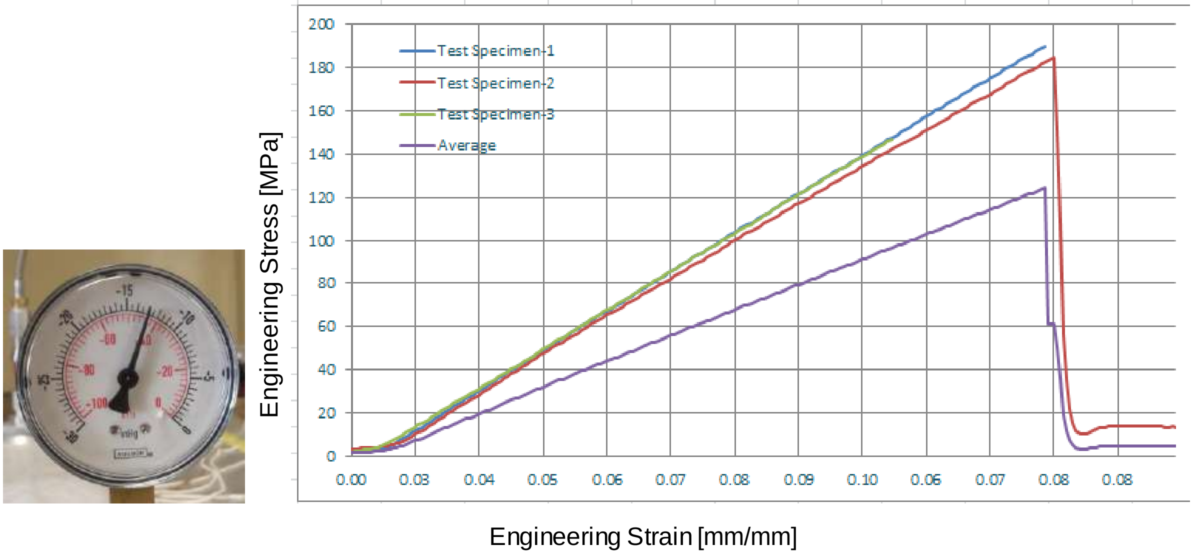


Figure 4.3 E-Glass/Epoxy composite fabricated at 13 "Hg.

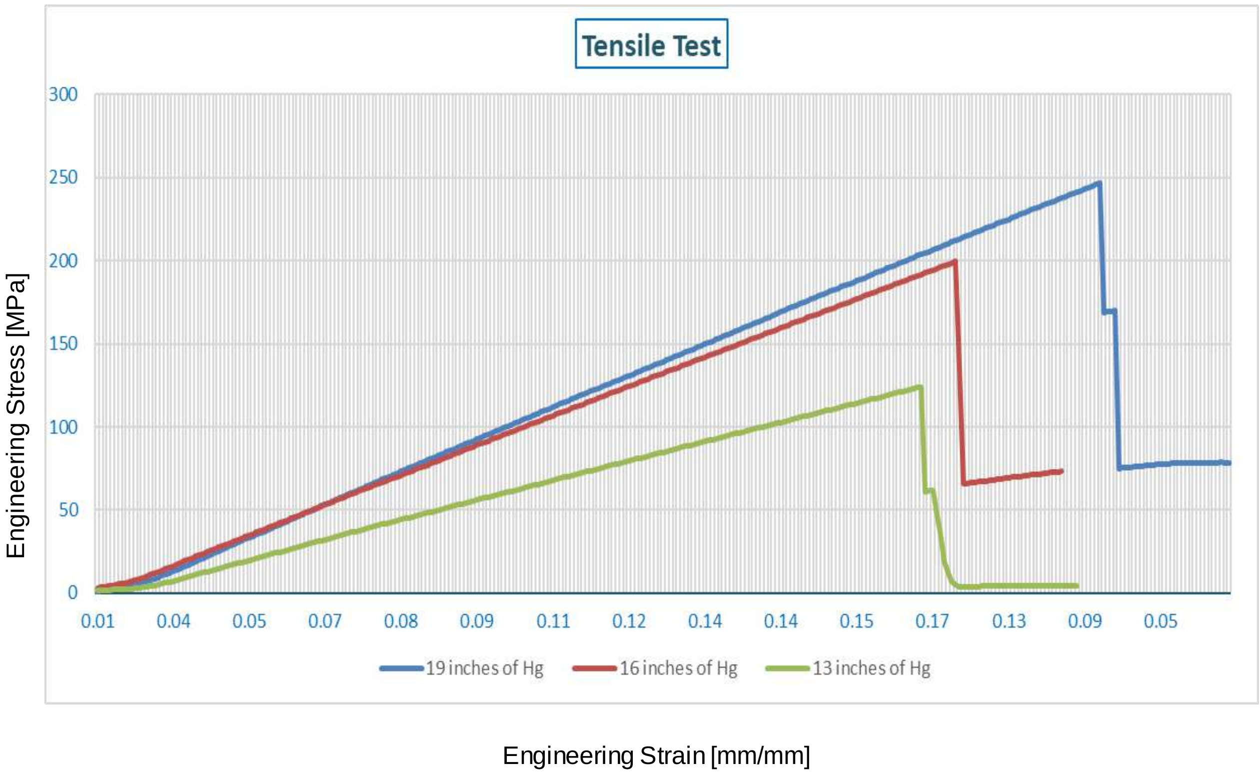


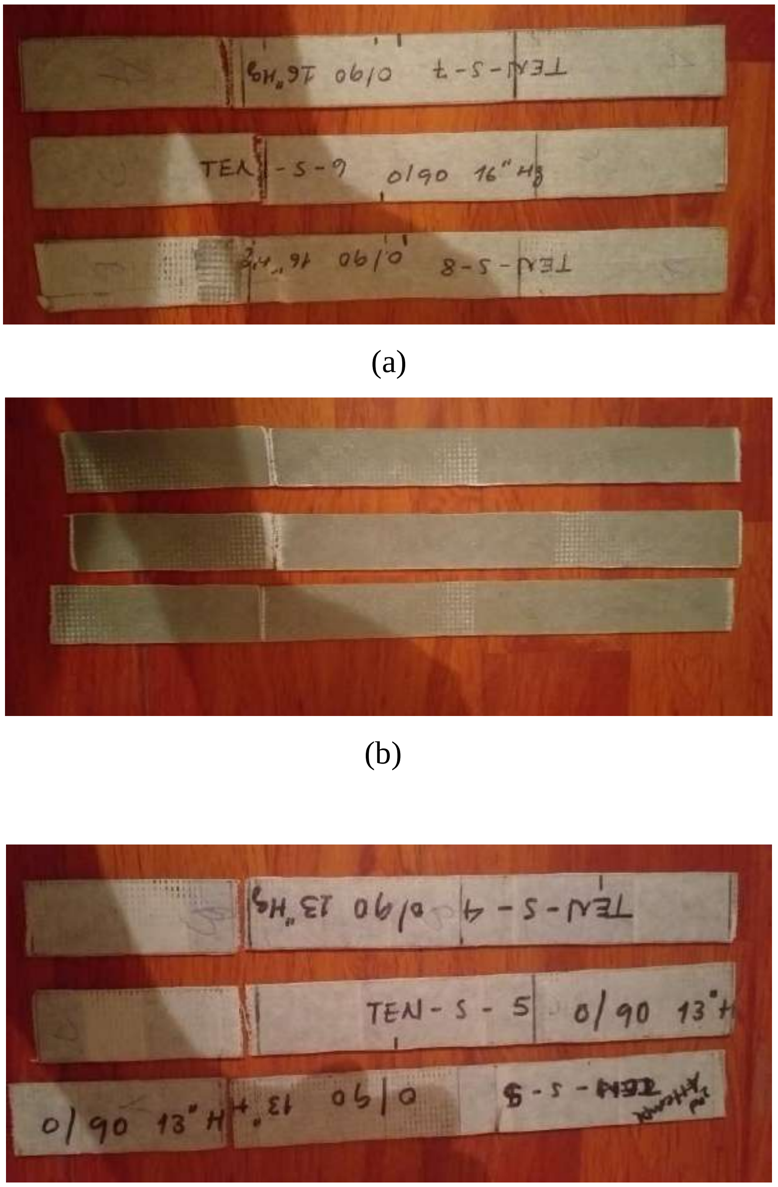
Figure 4.4 E-Glass/Epoxy Tensile Test

Understanding the behavior E-glass/Epoxy composite fabricated under various discrete curing pressures from the graph plotted above, it has been indicated that there is a rapid increase in engineering stress when the engineering strain is increased up to the maximum or ultimate tensile stress is obtained and the there is a rapid drop from ultimate value to the minimum. At the final point the graph drops suddenly as the sample reached to the point where it can no more resist the load.

Further to the general indication on Figure 4.4, the upper depicted figures Fig. 4.1, 4.2 and 4.3 indicate tensile strength of E-glass/Epoxy composite as a function of strain. The overall test result shown in figure 4.4. is based on the average value of three sets of specimens for each configuration fabricated at different vacuum pressure. The result has clearly indicated that, the tensile strength of the material decreased as the curing pressure is reduced or indirectly the more the altitude increases the more the tensile strength reduces.

Regarding tensile failure mode, E-glass/Epoxy composite has showed similar failure modes in all test specimen fabricated for 19,16 and 16 inches of Hg with varying vacuum pressure.

As shown in Fig. 4.5 (a),(b)and (c) limited damage within the center gage length and less fiber pullout is indicated while the damage is extended to gage length near grip area.



(a)

(b)

(c)

Figure 4.5 Tensile Failure modes (a) E-glass/Epoxy composite at 0/90 (b) E-glass/Epoxy composite at 45/45

4.1.2. Compression Test

Compressive tests have been conducted on the fabricated tensile test specimens and the result is summarized and presented below.

Hereunder, test results have been discussed for three sets of test specimen fabricated at various vacuum pressure resembling repair stations located at different atmospheric altitude. Engineering stress against engineering strain have been plotted refereeing to the conducted test and analyzed to show the effect of repair quality conducted at various repair stations located at different altitude.

The below tables indicates stress stain diagram for E-Glass/Epoxy composite fabricated at 13inch of Hg ,16 inch of Hg and 19 inch of Hg.

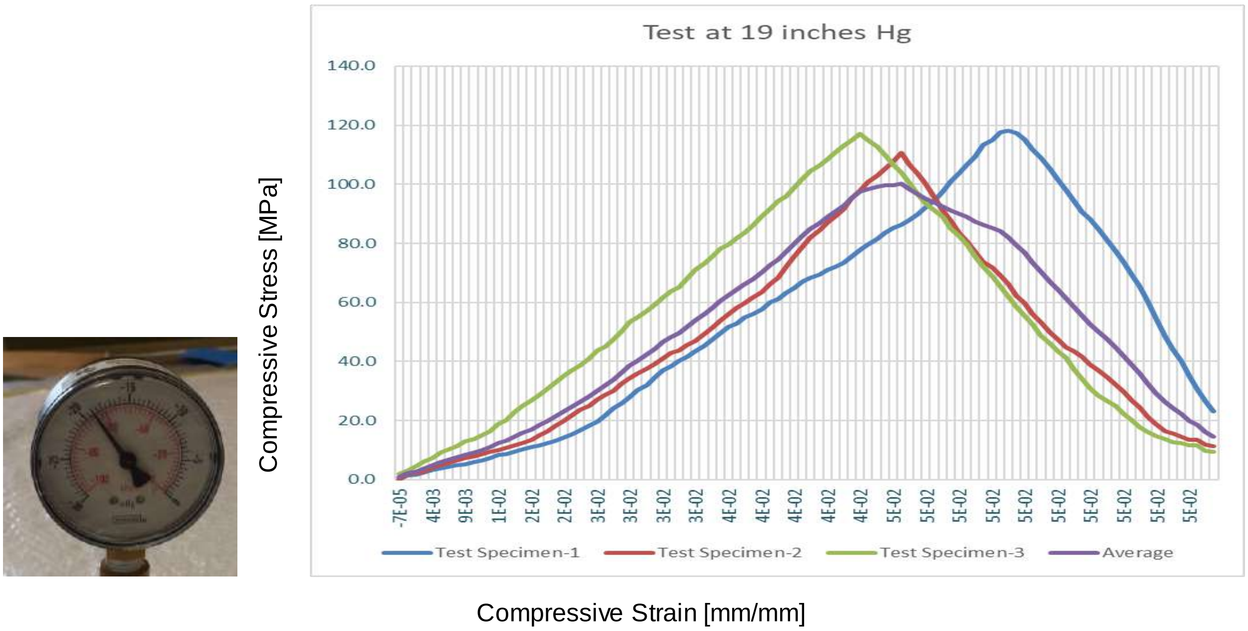


Figure 4.6 E-Glass/Epoxy composite fabricated at 19 “Hg.

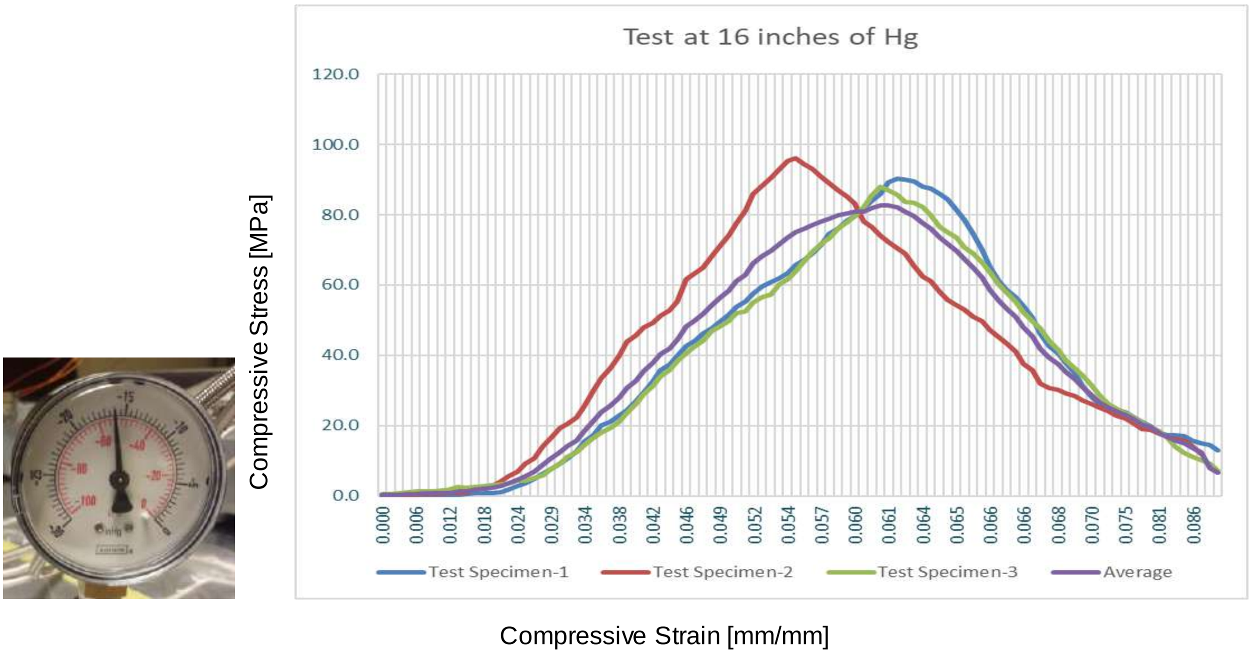


Figure 4.7 E-Glass/Epoxy composite fabricated at 16 "Hg.

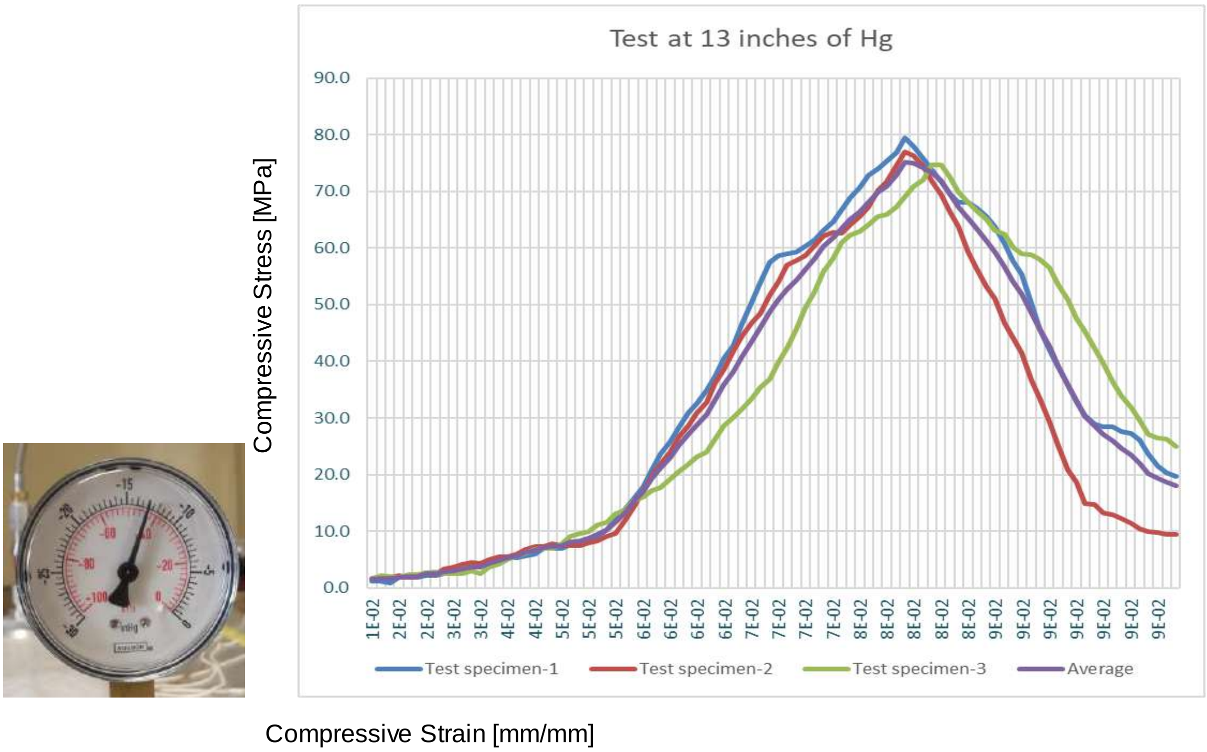


Figure 4.8 E-Glass/Epoxy composite fabricated at 13 "Hg.

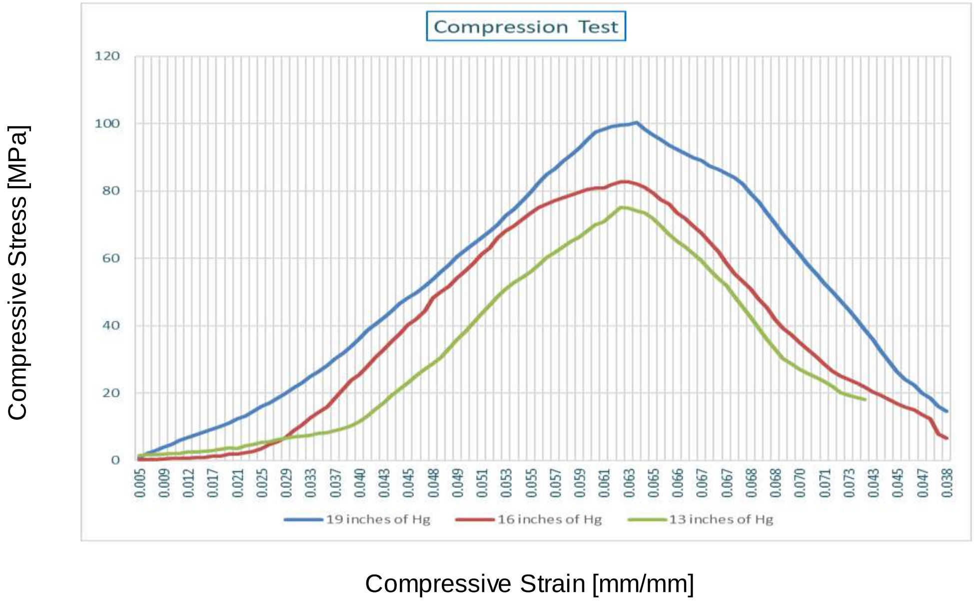


Figure 4.9 E-Glass/Epoxy Compression Test

The effect of altitude/pressure on compressive strength of E-glass/Epoxy composite is clearly identified in the above plotted graphs. The compression test also indicated that there is a rapid increase in engineering stress when the engineering strain has increased up to the maximum or ultimate tensile stress is obtained and there is a rapid drop from ultimate value to a value around 30Mpa.The graphs also has indicated that declining from 30Mpa, engineering stress slowly reduced with an increase in engineering strain.

Additionally, on this work it has been identified that, the maximum compressive strength recorded has a direct relation to the amount of vacuum pressure applied during curing process. The more the pressure applied during curing the more the strength of the material. This also highlighted that, repairs being performed on repair stations located at higher altitude are highly influenced with this matter as it is difficult to get good working pressure to avoid presence of air pockets leading to weak mechanical strength.

Regarding Compressive failure mode, E-glass/Epoxy composite has showed similar failure modes with varying vacuum pressure. As shown in Fig. 4.6 the micro-buckling of fibers along the shear plane due to global shearing of laminate.

4.2. Discussion

4.2.1. Tensile Test

Figure 4.10 presents the effect of altitude on ultimate tensile stress. From the graph it can be understood that, the tensile stress of E-glass/Epoxy composite significantly decreases as the altitude increases (Vacuum Bagging pressure decrease). As the applied curing pressure slowly decreased due to increasing altitude, air pockets inside the E-glass/Epoxy matrix fail to be sacked and discharged by the vacuum pump. This therefore, has a tendency to create inter-ply volatilities in to the structure leading to less adhesion between fabric and resin. Porosity is the result of trapped volatiles or air bubbles during wet layup process and significantly compromised the strength of fiber reinforced composites as it is depicted in the figure below.

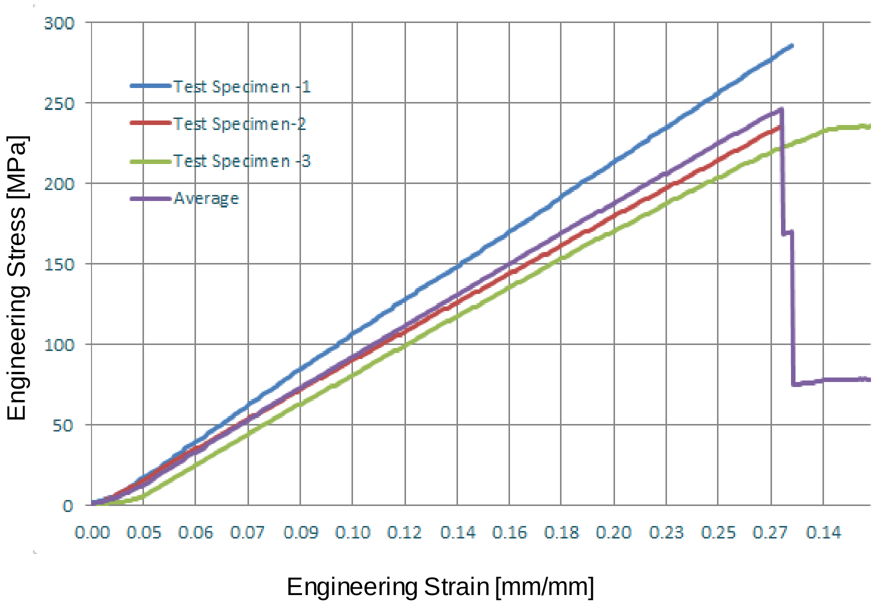


Figure: 4.10 Effect of altitude on tensile strength of E-glass Epoxy Composite

The effect of altitude on E-glass/Epoxy composite repairs are compared with an experimental result for a similar material fabricated by Esmael [2] at Debrezeit. Debrezeit is located at a much lower altitude of 6300ft [1920m] in comparison to Addis Ababa that is located at 7600ft [2317m]. Esmael tested E-glass/Epoxy composite specimen to investigate the effect of strain rate on tensile property. The procedures followed to fabricate the test specimens in both papers is similar apart to the highly refined wet layup composite fabrication technique deployed specifically on this work.

.

On the below graph, it is implicated that, the tensile stress of E-glass/Epoxy composite has significantly decreased as the altitude increases (Vacuum Bagging pressure decrease). The tensile composite test conducted at Debrezeit by Esmael indicated an ultimate engineering stress of 327Mp.Conversely, test specimen conducted in Addis Ababa around bole international airport has experienced un ultimate strength 284Mpa prior to failure which is comparatively low. This indicates that even though, procedures to fabricate the test specimens are to the highest manufacturing standard with state of the art facility, the specimen fabricated at lower altitude (Debrezeit) experienced good tensile property.

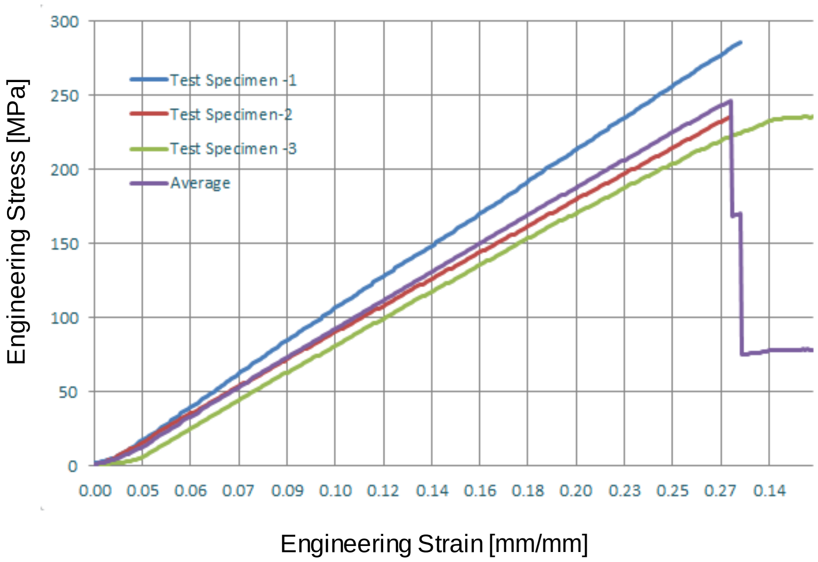


Figure: 4.11 E-glass Epoxy Composite Tensile Test at 7600ft

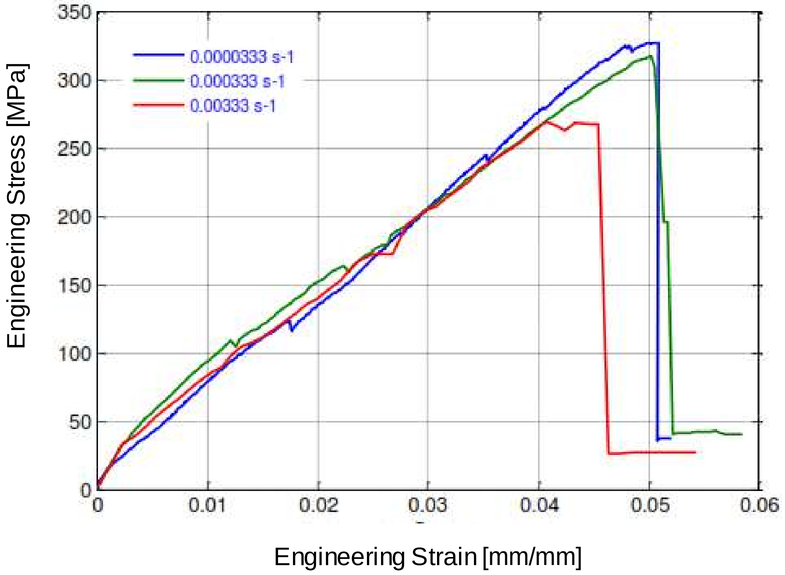


Figure: 4.12 E-glass Epoxy Composite Tensile Test at 6300ft [2]

Conferring to ASTM standard [21], the ultimate tensile stress, tensile strain and modulus of elasticity can be obtain using the following formula:

$$F^{ut} = P^{ut}/A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4.1)$$

$$\varepsilon = \delta/L$$

$$E^{chord} = \Delta\zeta/\Delta\varepsilon$$

Where:

F^{ut}= Ultimate Tensile Strength, MPa

P^{ut}= Maximum load before failure, N

A= Average Cross-sectional Area, mm^2

ε= tensile strain

L= gage length

δ= displacement

E^{chord}= tensile chord modulus of elasticity, MPa

$\Delta\zeta$ = change in stress between two strain points

$\Delta\varepsilon$ = change in strain between two points

According to the graph indicated below, it can be taken that the tensile stress of E-glass/Epoxy composite decreases as the altitude increases. The percentage of decrement on tensile is 19.13% and 37.8% for the first and the second curing altitude.

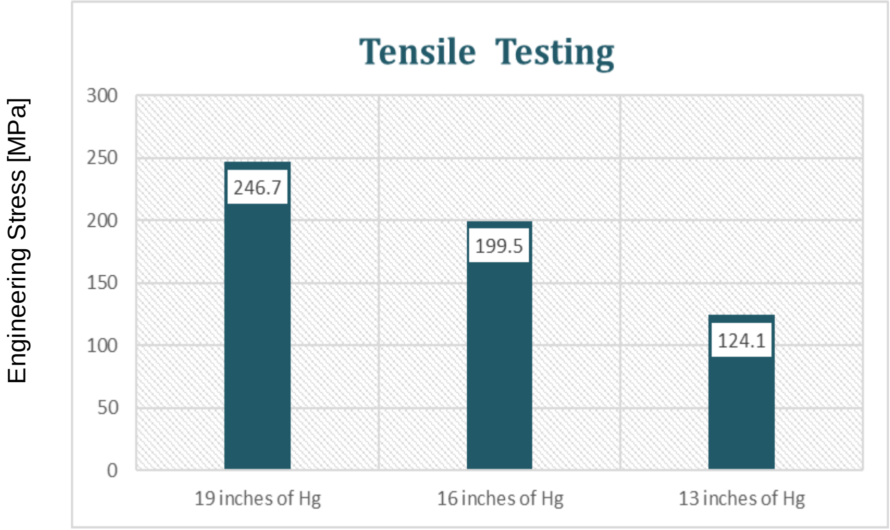


Figure 4.13 Altitude Effect on Tensile Stress E- glass/Epoxy Composite

4.2.1. Compression Test

The effect of altitude on compressive strength of E-glass/Polyester composite is shown in figure 4.14. From the graph it can be understood that, the compressive stress of E-glass/Epoxy composite has also shown a significant decrease as the altitude increases (pressure decrease). The test results presented are based on average values of three specimens for each simulated altitude. It can be clearly seen that the compressive strength follows an increasing trend with the increase of pressure. This test also indicates that E-glass/Epoxy composites are comparatively feeble to withstand compressive stress.

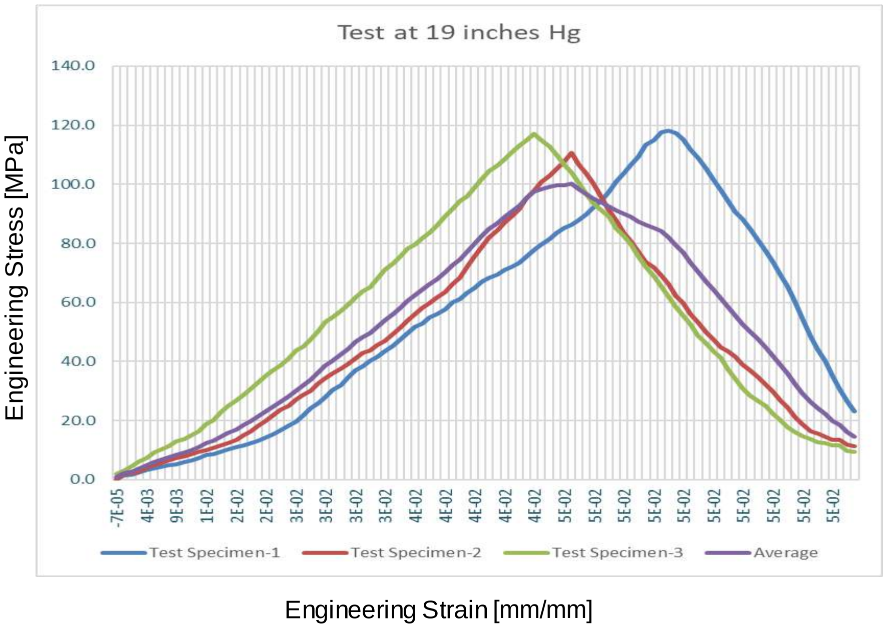


Figure: 4.14 Effect of altitude on tensile strength of E-glass Epoxy Composite

Likewise, the effect of altitude on E-glass/Epoxy composite repair has been compared to similarly fabricated composite test specimen tested by Esmael [2] at similar strain rate. Esmals' [2] has plotted engineering stress against engineering strain graph under varying strain rate. However, his work with strain rate 0.000166 (blue color) was referred to compare with this work considering similarity in applied strain rate. The result indicates that, the fabrication process implemented on this work has vital contribution towards appreciable compressive property of E-glass Epoxy composite. The ultimate compressive stress obtained by Esmael [2] using hand layup technique and cured at free air environment is 65Mpa.However, the ultimate compressive strength obtained on this work using highly refined and vacuum assisted wet layup technique is 118 Mpa.

Therefore, this tells that, altitude has its own contribution to significantly affect compressive property of E-glass Epoxy composite since, increasing strain rate to 0.0016 by Esmaele [2] has achieved as equal ultimate engineering stress to that of this work. This indicates that, even though a highly refined wet layup specimen preparation technique and controlled curing temperature is employed to this work, the final ultimate strength is almost equal to Esmael's [2] work. Excluding all other environmental properties as the specimen preparation in this work has been performed inside controlled room, this can be considered is as a result of less curing pressure introduced to this work due to comparatively high altitude repair/working station.

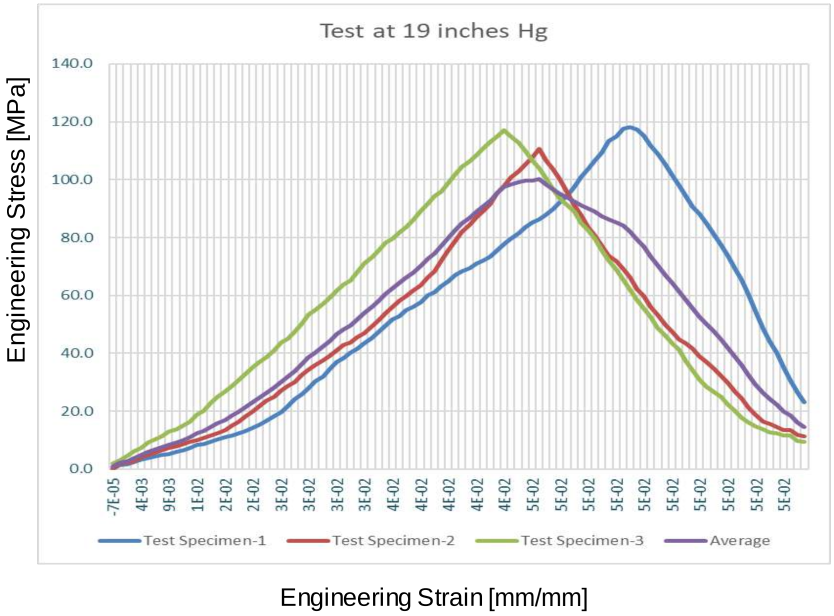


Figure: 4.15 E-glass Epoxy Composite Compressive Test at 7600ft

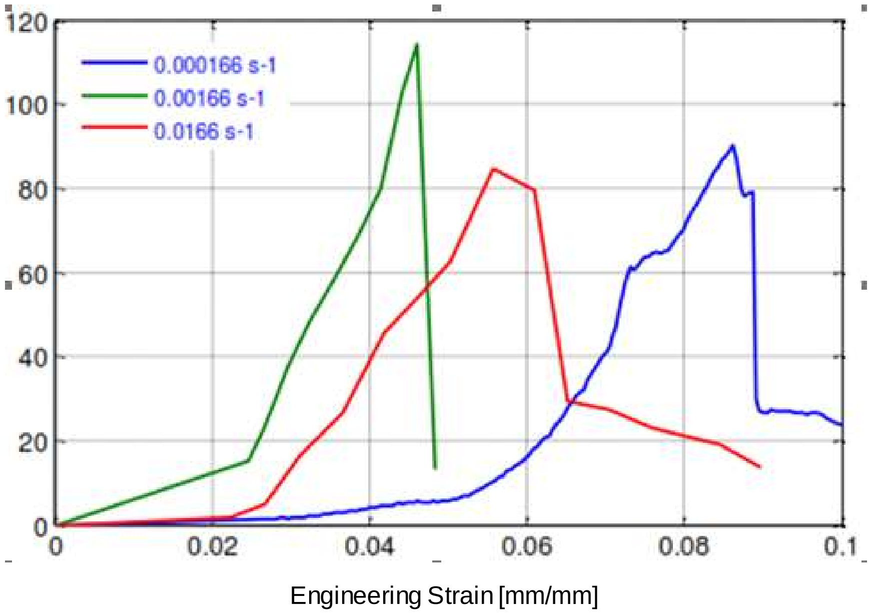


Figure: 4.16 E-glass Epoxy Composite Compressive Test at 6300ft [2]

According to ASTM standard [22], the maximum compressive stress can be calculated using the following formula:

$F^{ut} = P^{ut}/A$………………………………………………….. (4.2)

Where: F^{ut}= Ultimate/Maximum Compressive Strength, MPa

P^{ut}= Maximum load before failure, N

A= Average Cross-sectional Area, mm2

Figure 4.17 presents the effect of altitude on ultimate compressive stress. As of the graph indicated below it can be considered that the tensile stress of E-glass/Epoxy composite decreases as the pressure increases. The percentage of decrements on modulus is 17.5% and 10.5% for the first and the second simulated curing altitude.

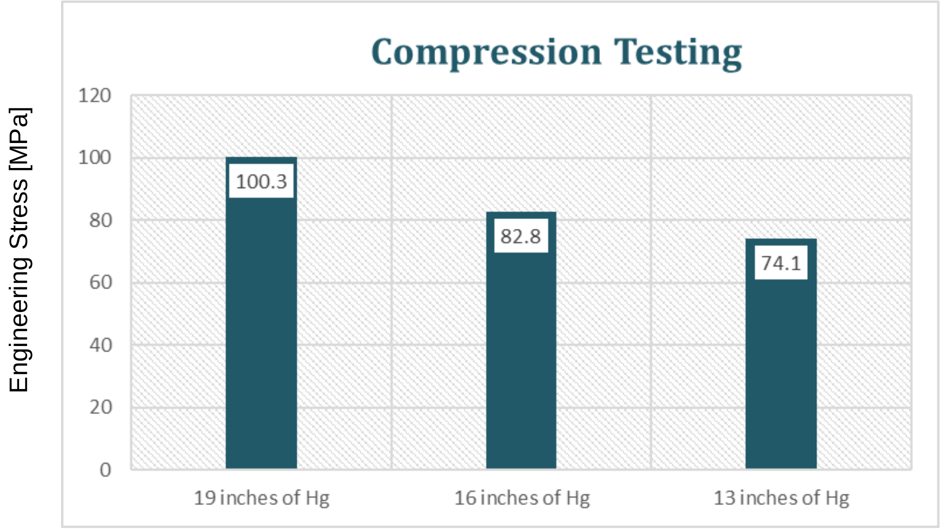


Figure 4.17 Altitude Effect on Compressive Stress E- glass/Epoxy Composite

Chapter -5

Conclusion, Recommendation and Future works

5.1. Conclusion

The purpose of this paper is to experimentally investigate the effects of altitude/vacuum bagging pressure on the mechanical property of E-glass /Epoxy. Hence, 0/90 orientation E-glass/Epoxy composite specimens for tensile and compressive test are prepared in accordance with ASTM [18] and the subsequent conclusions are prevailed.

- The tensile and compressive properties of E-glass/Epoxy composite experiences an increasing trend when the applied bagging vacuum pressure increased during fabrication process.
- The test results revealed that E-glass/Epoxy repairs performed relatively at a lower altitude shows good mechanical property (tensile and Compression) than those fabricated at high altitude.
- The tensile test result revealed that, failure occurred abruptly without yielding while compressive test results showed significant yielding after reaching ultimate strength.
- Properties obtained from the test result showed that, further to this work plain shear, flexural and fractural analysis need to be conducted since, effects of altitude or curing pressure on tensile and compressive properties of e-glass/epoxy composite is significant.

5.2. Recommendation

Composite Manufacturing or repairs performed at a relatively high altitude should be done with controlled environment to minimize the effect of altitude. If a composite is to be manufactured/repaired at Manufacturing/repair stations located at high altitude like Ethiopian Airlines, additional vacuum pressure is required to meet manufacturer requirement. Unless additional vacuum pressure is used, air pockets inside the E-glass/Epoxy matrix fail to be discharged by the vacuum pump. Therefore, inter-ply volatilities are created in to the structure leading to less adhesion between fabric and resin. Less adhesion due to porosity in the matrix reduce the composite property and leads to unpredicted failure. As a result, unless other means of compliances are recommended, final product of composite products fabricated at high altitude are liable to effect of porosity. To increase compaction and reduce voids that lead to porosity during fabrication and increase strength, the researcher recommends to use Double-bagging technique apart its complexity and capital investment.

Double bagging technique prevents atmospheric pressure from being applied to the laminate and pinching the edges off, which allows the inner vacuum to remove more volatiles in a shorter time. Then, at a specified point, the vacuum in the rigid enclosure was vented to allow the flexible bag to collapse onto the laminate and apply consolidation pressure.

5.3. Future Works

Areas for further study or advance requirement relentless to this paper are highlighted below. The subsequent suggestions are listed as a future work for further study:

1. Effect of Altitude on E-glass/Epoxy Composite repair for flexural and in plane shear.
2. Effect of Altitude on fracture properties of E-glass/Epoxy Composite
3. Modelling Effect of altitude on E-glass/epoxy Effect using Finite Element Software’s
4. Effect of fiber orientation on the mechanical properties of E-glass/Epoxy or E-glass/Polyester composite fabricated at high altitude
5. Effect of Altitude on E-glass/Epoxy Composite repair fabricated Double bagging technique

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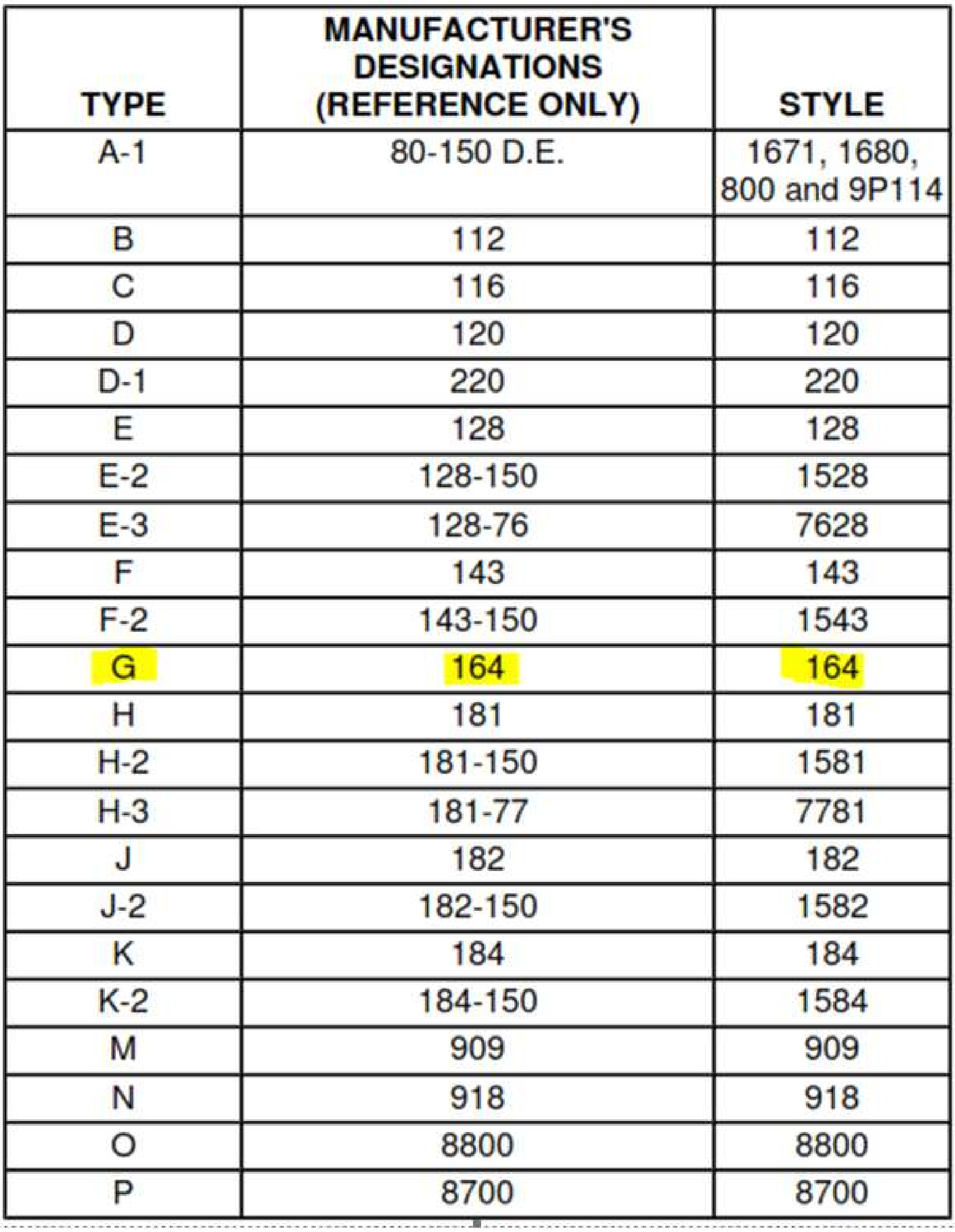
Appendix

A. Mechanical Properties of materials

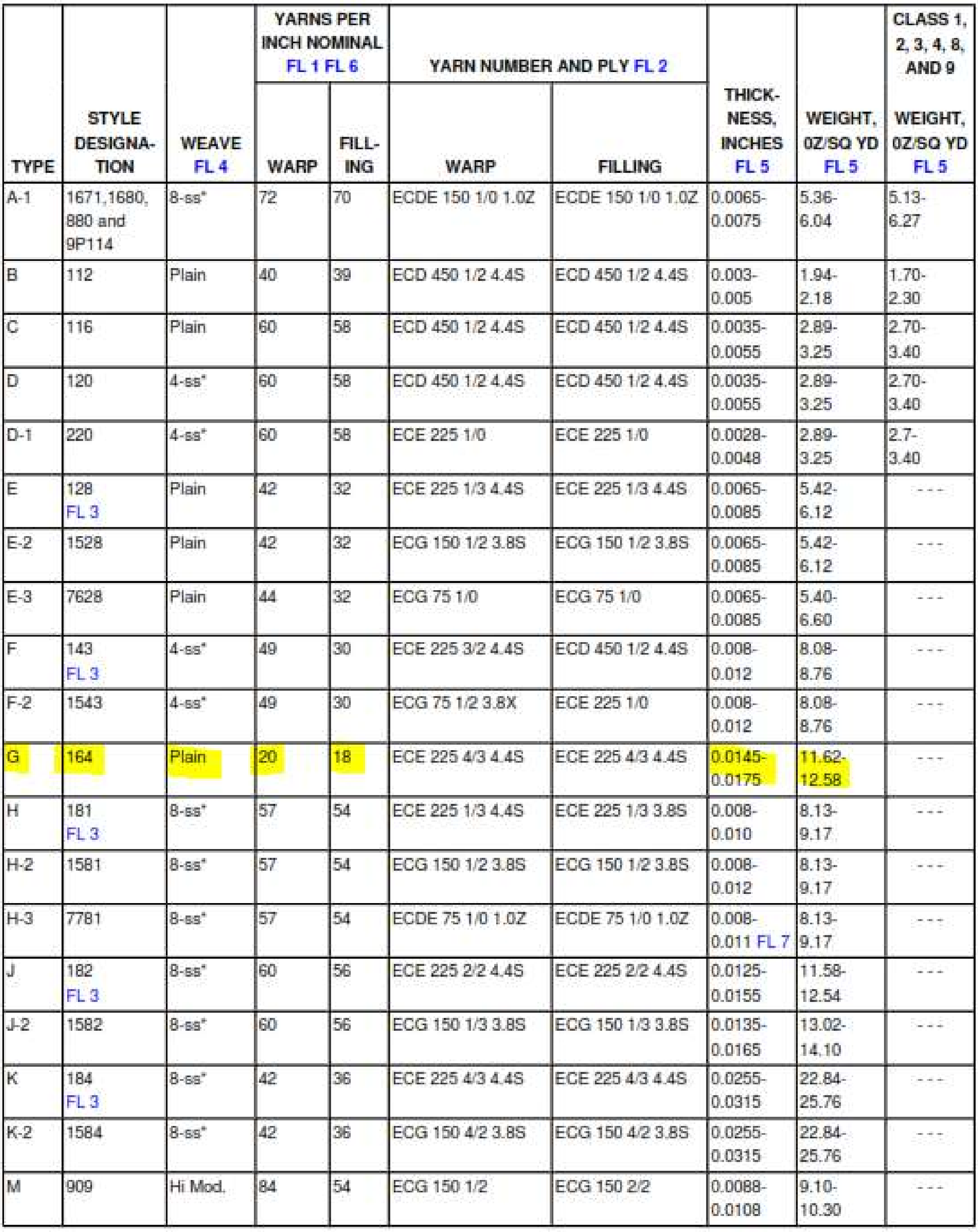
Mechanical properties of plain woven fabric E-glass fiber, epoxy and hardener

- Woven Fabric E-Glass fiber BMS9-3



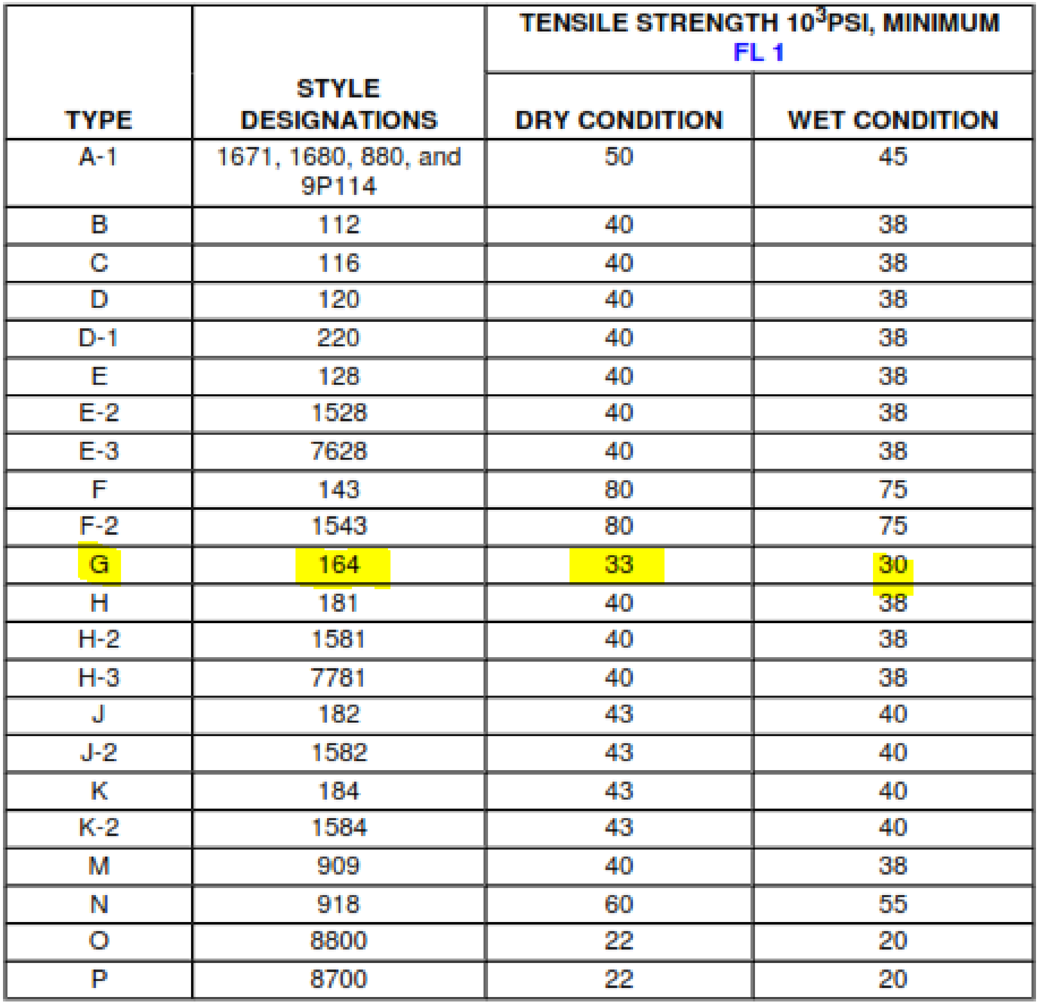
TYPE	MANUFACTURER'S DESIGNATIONS (REFERENCE ONLY)	STYLE
A-1	80-150 D.E.	1671, 1680, 800 and 9P114
B	112	112
C	116	116
D	120	120
D-1	220	220
E	128	128
E-2	128-150	1528
E-3	128-76	7628
F	143	143
F-2	143-150	1543
G	164	164
H	181	181
H-2	181-150	1581
H-3	181-77	7781
J	182	182
J-2	182-150	1582
K	184	184
K-2	184-150	1584
M	909	909
N	918	918
O	8800	8800
P	8700	8700

Table I. Glass Fabric Type
[Source: Boeing Material Specifications standard: BMS9-3 Rev: (U) 12-Nov-2019]



TYPE	STYLE DESIGNATION	WEAVE FL 4	YARNS PER INCH NOMINAL FL 1 FL 6		YARN NUMBER AND PLY FL 2		THICKNESS, INCHES FL 5	WEIGHT, 0Z/SQ YD FL 5	CLASS 1, 2, 3, 4, 8, AND 9
			WARP	FILLING	WARP	FILLING			WEIGHT, 0Z/SQ YD FL 5
A-1	1671,1680, 880 and 9P114	8-ss*	72	70	ECDE 150 1/0 1.0Z	ECDE 150 1/0 1.0Z	0.0065-0.0075	5.36-6.04	5.13-6.27
B	112	Plain	40	39	ECD 450 1/2 4.4S	ECD 450 1/2 4.4S	0.003-0.005	1.94-2.18	1.70-2.30
C	116	Plain	60	58	ECD 450 1/2 4.4S	ECD 450 1/2 4.4S	0.0035-0.0055	2.89-3.25	2.70-3.40
D	120	4-ss*	60	58	ECD 450 1/2 4.4S	ECD 450 1/2 4.4S	0.0035-0.0055	2.89-3.25	2.70-3.40
D-1	220	4-ss*	60	58	ECE 225 1/0	ECE 225 1/0	0.0028-0.0048	2.89-3.25	2.7-3.40
E	128 FL 3	Plain	42	32	ECE 225 1/3 4.4S	ECE 225 1/3 4.4S	0.0065-0.0085	5.42-6.12	- - -
E-2	1528	Plain	42	32	ECG 150 1/2 3.8S	ECG 150 1/2 3.8S	0.0065-0.0085	5.42-6.12	- - -
E-3	7628	Plain	44	32	ECG 75 1/0	ECG 75 1/0	0.0065-0.0085	5.40-6.60	- - -
F	143 FL 3	4-ss*	49	30	ECE 225 3/2 4.4S	ECD 450 1/2 4.4S	0.008-0.012	8.08-8.76	- - -
F-2	1543	4-ss*	49	30	ECG 75 1/2 3.8X	ECE 225 1/0	0.008-0.012	8.08-8.76	- - -
G	164	Plain	20	18	ECE 225 4/3 4.4S	ECE 225 4/3 4.4S	0.0145-0.0175	11.62-12.58	- - -
H	181 FL 3	8-ss*	57	54	ECE 225 1/3 4.4S	ECE 225 1/3 3.8S	0.008-0.010	8.13-9.17	- - -
H-2	1581	8-ss*	57	54	ECG 150 1/2 3.8S	ECG 150 1/2 3.8S	0.008-0.012	8.13-9.17	- - -
H-3	7781	8-ss*	57	54	ECDE 75 1/0 1.0Z	ECDE 75 1/0 1.0Z	0.008-0.011 FL 7	8.13-9.17	- - -
J	182 FL 3	8-ss*	60	56	ECE 225 2/2 4.4S	ECE 225 2/2 4.4S	0.0125-0.0155	11.58-12.54	- - -
J-2	1582	8-ss*	60	56	ECG 150 1/3 3.8S	ECG 150 1/3 3.8S	0.0135-0.0165	13.02-14.10	- - -
K	184 FL 3	8-ss*	42	36	ECE 225 4/3 4.4S	ECE 225 4/3 4.4S	0.0255-0.0315	22.84-25.76	- - -
K-2	1584	8-ss*	42	36	ECG 150 4/2 3.8S	ECG 150 4/2 3.8S	0.0255-0.0315	22.84-25.76	- - -
M	909	Hi Mod.	84	54	ECG 150 1/2	ECG 150 2/2	0.0088-0.0108	9.10-10.30	- - -

Table II. Glass fibre Construction properties
[Source: Boeing Material Specifications standard: BMS9-3 Rev: (U) 12-Nov-2019]

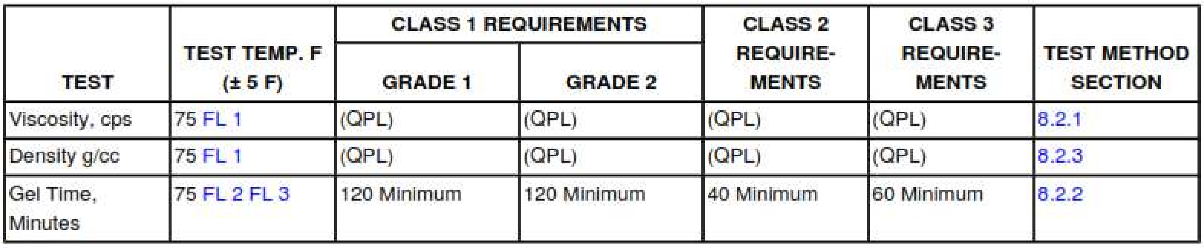


TYPE	STYLE DESIGNATIONS	TENSILE STRENGTH 10^3PSI, MINIMUM FL 1	
		DRY CONDITION	WET CONDITION
A-1	1671, 1680, 880, and 9P114	50	45
B	112	40	38
C	116	40	38
D	120	40	38
D-1	220	40	38
E	128	40	38
E-2	1528	40	38
E-3	7628	40	38
F	143	80	75
F-2	1543	80	75
G	164	33	30
H	181	40	38
H-2	1581	40	38
H-3	7781	40	38
J	182	43	40
J-2	1582	43	40
K	184	43	40
K-2	1584	43	40
M	909	40	38
N	918	60	55
O	8800	22	20
P	8700	22	20

Table III. Laminate mechanical properties

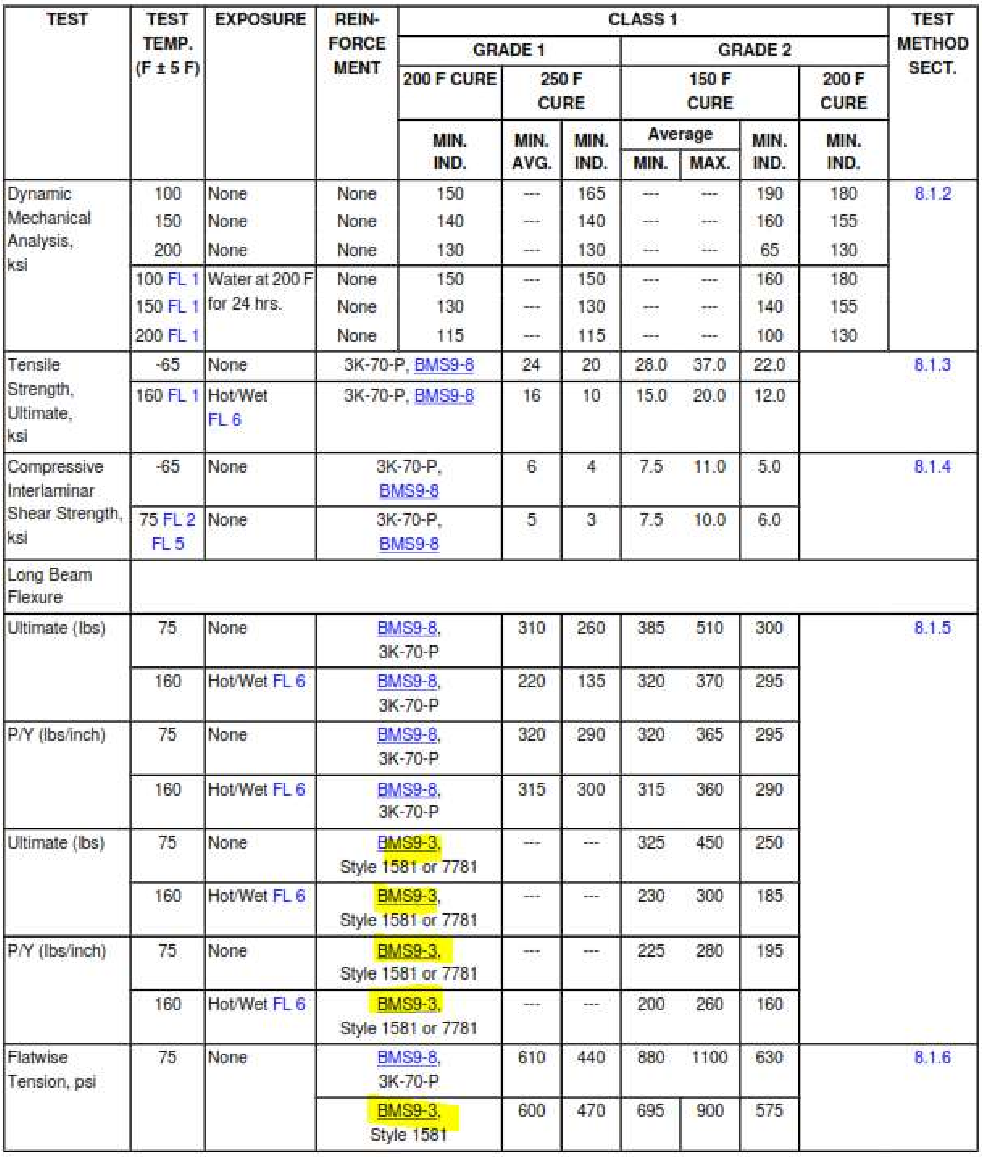
[Source: Boeing Material Specifications standard: BMS9-3 Rev: (U) 12-Nov-2019]

- Woven Fabric E-Glass fiber BMS8-301



TEST	TEST TEMP. F (± 5 F)	CLASS 1 REQUIREMENTS		CLASS 2 REQUIRE-MENTS	CLASS 3 REQUIRE-MENTS	TEST METHOD SECTION
		GRADE 1	GRADE 2			
Viscosity, cps	75 FL 1	(QPL)	(QPL)	(QPL)	(QPL)	8.2.1
Density g/cc	75 FL 1	(QPL)	(QPL)	(QPL)	(QPL)	8.2.3
Gel Time, Minutes	75 FL 2 FL 3	120 Minimum	120 Minimum	40 Minimum	60 Minimum	8.2.2

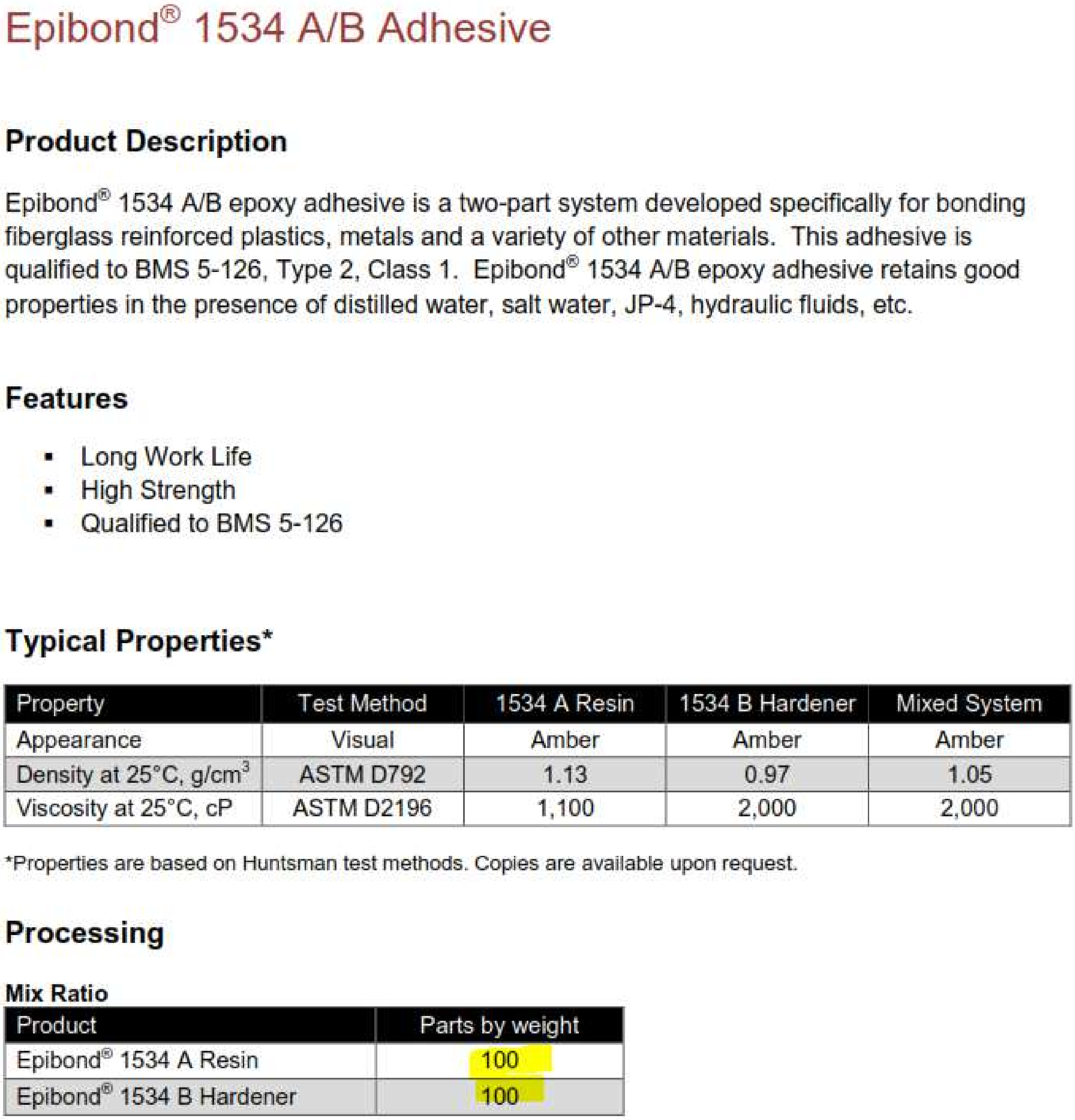
Table IV. Uncured Resin Properties



TEST	TEST TEMP. (F ± 5 F)	EXPOSURE	REIN-FORCE MENT	CLASS 1							TEST METHOD SECT.
				GRADE 1			GRADE 2				
				200 F CURE	250 F CURE		150 F CURE			200 F CURE	
				MIN. IND.	MIN. AVG.	MIN. IND.	Average		MIN. IND.	MIN. IND.	
							MIN.	MAX.			
Dynamic Mechanical Analysis, ksi	100	None	None	150	---	165	---	---	190	180	8.1.2
	150	None	None	140	---	140	---	---	160	155	
	200	None	None	130	---	130	---	---	65	130	
	100 FL 1	Water at 200 F for 24 hrs.	None	150	---	150	---	---	160	180	
	150 FL 1		None	130	---	130	---	---	140	155	
	200 FL 1		None	115	---	115	---	---	100	130	
Tensile Strength, Ultimate, ksi	-65	None	3K-70-P, BMS9-8		24	20	28.0	37.0	22.0		8.1.3
	160 FL 1	Hot/Wet FL 6	3K-70-P, BMS9-8		16	10	15.0	20.0	12.0		
Compressive Interlaminar Shear Strength, ksi	-65	None	3K-70-P, BMS9-8		6	4	7.5	11.0	5.0		8.1.4
	75 FL 2 FL 5	None	3K-70-P, BMS9-8		5	3	7.5	10.0	6.0		
Long Beam Flexure											
Ultimate (lbs)	75	None	BMS9-8, 3K-70-P		310	260	385	510	300		8.1.5
	160	Hot/Wet FL 6	BMS9-8, 3K-70-P		220	135	320	370	295		
P/Y (lbs/inch)	75	None	BMS9-8, 3K-70-P		320	290	320	365	295		
	160	Hot/Wet FL 6	BMS9-8, 3K-70-P		315	300	315	360	290		
Ultimate (lbs)	75	None	BMS9-3, Style 1581 or 7781		---	---	325	450	250		
	160	Hot/Wet FL 6	BMS9-3, Style 1581 or 7781		---	---	230	300	185		
P/Y (lbs/inch)	75	None	BMS9-3, Style 1581 or 7781		---	---	225	280	195		
	160	Hot/Wet FL 6	BMS9-3, Style 1581 or 7781		---	---	200	260	160		
Flatwise Tension, psi	75	None	BMS9-8, 3K-70-P		610	440	880	1100	630		8.1.6
			BMS9-3, Style 1581		600	470	695	900	575		

Table V. Cured Resin Properties

[Source: Boeing Material Specifications standard: BMS9-3 Rev: (U) 12-Nov-2019]



Epibond® 1534 A/B Adhesive

Product Description

Epibond® 1534 A/B epoxy adhesive is a two-part system developed specifically for bonding fiberglass reinforced plastics, metals and a variety of other materials. This adhesive is qualified to BMS 5-126, Type 2, Class 1. Epibond® 1534 A/B epoxy adhesive retains good properties in the presence of distilled water, salt water, JP-4, hydraulic fluids, etc.

Features

- Long Work Life
- High Strength
- Qualified to BMS 5-126

Typical Properties*

Property	Test Method	1534 A Resin	1534 B Hardener	Mixed System
Appearance	Visual	Amber	Amber	Amber
Density at 25°C, g/cm^3	ASTM D792	1.13	0.97	1.05
Viscosity at 25°C, cP	ASTM D2196	1,100	2,000	2,000

*Properties are based on Huntsman test methods. Copies are available upon request.

Processing

Mix Ratio

Product	Parts by weight
Epibond® 1534 A Resin	100
Epibond® 1534 B Hardener	100

Table V. Mixing Ratio
[Source: Epibond 1534 A/B Adhesive product data sheet]