



ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

Manufacturing And Strength test of E-glass Reinforced HDPE, And
Single Strap Joint For Exposed Auto Body

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By

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*Dedicated to my beloved family, for their immeasurable support,
encouragement and patience*

Abstract

Due to ever tougher environmental and passive safety regulations, lightweight materials are getting considerable attention to reduce vehicle weight, fuel consumption, and improve the crashworthiness. Some of the existing promising light weight materials are Fibre-reinforced polymers (FRP) that are made of reinforcing fibers embedded in a polymer matrix. FRP are used extensively in automotive, aeronautic and naval engineering. FRP offers substantial improvements over metals not only for the specific stiffness and strength, but also for their resistance to corrosion, fatigue, and allowing part consolidation.

In this work, to understand critical problems related to the application of FRP in automotive body production, a recyclable E-glass thermoplastic composite material was developed. Besides, to address the critical joining problems in lightweight design, a parametric study of adhesive joints was carried out using developed composite substrate and frequently used metallic substrate and adhesive material by local automotive manufacturers.

Experimental results revealed that the E-glass thermoplastic composite consisted of high density polyethylene matrix. The composite material exhibited reasonably acceptable strength for automotive body applications. Parametric study of adhesive joint showed that strain distributions for the joint configurations are more sensitive to changes in adhesive thickness, overlap length, overlap width and surface finish. The results also showed that the lap shear strength of the joint primarily depends on the surface parameters of the substrate material rather than the material itself. These results can be used by engineers/designers to design lightweight automotive body and to predict the static strength of its adhesively bonded joint. These results can also contribute to the improvement of the locally built automobile body in reducing the weight.

Key words: reinforced, thermoplastic, E-glass, joint, adhesive, compatible

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Nomenclature

Δl : extension or the deformation (mm)

E: Young's Modulus (Gpa)

σ : stress (Mpa)

ϵ : Strain (mm/mm)

A: Cross sectional area (mm²)

ρ : Density (g/cc)

RP: Reinforced Plastic

URP: Unreinforced Plastic

F: force(N)

cc: Cubic Centimeter

g: Gram

m: Meter

N: Newton

F/M w %: Fiber weight fraction of the matrix in percentage

GFRHDPE: Glass fiber reinforced High Density Polyethylene

UTM: Computer Controlled Electro-hydraulic Servo Universal Testing Machine

W: Overlap width (mm)

L: Overlap length (mm)

AT: Adhesive thickness (mm)

WB: Water bath duration

T: Temperature

SF: Surface Finish

t_o : Substrate thickness (mm)

t_2 : Strap thickness (mm)

l_o : original length (mm)

l : final length (mm)

Acronyms

RHS: Rectangular hollow section

cc: Cubic Centimeter

RTM: Resin Transfer molding

FRP: Fiber Reinforced Plastic

AF: Adhesive failure

CF: Cohesive failure

TLCF: Thin-layer cohesive failure

FTF: Fiber-tear failure

LFTF: Light-fiber-tear failure

HSLA: High-strength low-alloy steel

CFRP: Carbon fiber reinforced plastics

GFRP: Glass fiber reinforced plastics

ASM: American Society of Testing and Material

ISO: International Organization for Standardization

FEPA: Federation of the European Producers of Abrasives

SFG HITEN: Super Fine Grained High performance –High Strength Steel sheet for exposed auto body panels

RR: Rockwell R

SD: Shore Durometer

ATR: Attenuated Total Reflectance

LDPE: Low Density Polyethylene

HDPE: High Density Polyethylene

PP: Polypropylene

PC: Polycarbonate

ABS: Acrylonitrile Butadiene Styrene

FEA: Finite Element Analysis

R&D: Research and Development

CHAPTER ONE

INTRODUCTION

1.1 Background

For over 20 years, steel bodies have used adhesive bonding to enhance stiffness, and thereby improve automotive road handling. Steel has been the historic choice for automotive material because of its inherent stiffness, strength and cost benefits. Its main disadvantage is a relatively high density (7550 to 8050 kg/m³) and because fuel economy requires lightweight structures, materials such as aluminum alloys (2700 kg/m³) and polymeric composites (1700 to 1900 kg/m³) are now being chosen for vehicle body construction [4].

However, to be competent enough, there are active researches in improving the property of both steel and aluminum. High-strength low-alloy steel (HSLA) is a type of alloy steel that provides better mechanical properties or greater resistance to corrosion than that of carbon steel, which is mostly used by automotive industry.

Sheets-cold-rolled steel sheets, eg. SFG HITEN, has also been chosen in automotive body contraction for its excellent stretch-formability and excellent deep draw ability. On the other hand, aluminum alloy, such as, Aw-6016, is one of well recognized lightweight materials with good strength for lightweight designs. This material challenges composite materials from being substituted, at some extents, in auto body work due its improved properties, minimum value of specific materials costs ,and minimum manufacturing cost.

Conversely, when the decision is made to assemble an automotive body, a principal requirement to be considered is how to accurately join the body's structures. As well know automotive body is constructed by joining numerous thin walled metallic panels, hence, the choice of joining technique (e.g. continuous welding, resistance spot-welds, rivets and nuts and bolts, etc.) and joint detailing could greatly influence local and global stiffness. But, the construction we perform is expected to improve the fuel efficiency through weight reduction. Light-weighting not only enhances fuel efficiency, but also lowers emissions and improves driving performance ^[1].

The need for body design optimization (requiring minimum weight) has therefore been driven by the Corporate Average Fuel Economy (CAFE) Regulations ^[2] of North America and by a proposed European Carbon Tax ^[3]. Traditionally, weight reduction in a vehicle's structure has been achieved by: having a reduction in material thickness, using lightweight materials, introducing innovative hybrid structures, or a combination of these. Another option that is attractive is to replace the traditional joining techniques (listed above) with continuous adhesive bonding; as bonded joints will either increase body stiffness or provide the same stiffness when utilizing thinner, lighter panels.

Despite the anisotropic and heterogeneity properties, composites currently represent 50 percent of the total vehicle by volume ^[23]. Carbon fiber reinforced plastics (CFRP) and glass fiber thermoplastic are of this category. These composites have been becoming active area of research and development in automotive industry for weight reduction in a vehicle's structure and for the ease of mold into complex shapes at relatively low cost. This gives designers the freedom to create any shape or configuration. Some of their benefits, they provide long-term resistance to severe chemical and temperature environments. Thus, it makes them the material of choice for outdoor exposure, chemical handling applications, and severe environment service. One reason the composites industry has been successful in some application areas is because of its the low relative investment in setting-up a composites manufacturing facility. This has resulted in many creative and innovative companies in the field. Composite products and structures have an exceedingly long life span. Coupled with low maintenance requirements, the longevity of composites is a benefit in critical applications.

Today, glass fiber thermoplastic compounding and molding is expanding beyond non-appearance structural automotive parts to exterior body panels. Because, they provide light weight vehicle structures with low cost as compared to steel, aluminum and CFRP. Thus, it is the focus of this research also [17, 30].

To accommodate and well integrate the existing and newly introduced composite materials in the vehicle structure, alternative joining techniques are mandatory. One of promising solutions in this regard is adhesive joint that allows to join similar and dissimilar materials. Generally, adhesive bonding is beneficiary over the others not only in joining dissimilar materials, but also

for even stress distribution, to fill large gaps, to seal, to bond, for ease of automation and for aesthetic acceptance. Some generic joint types with static strength and efficiency ranks from the highest to the lowest are as follows: scarf joint, step lap joint, double strap joint, single strap joint, and double lap joint and single lap joint.

Even though adhesively bonded lap joint has already been widely applied in structures, the strength prediction of the joint is still a challenge. The parameters which affect the failure load of the bonded joint are surface finish, contact geometry (overlap-length & width), adhesive thickness, unsupported length, environmental conditions, load types, stress concentration, adhesive filler and etc.

Altering these parameters of bonded joint will invariably alter the stress and strain distributions within the adhesive layer [5-10]. These differences have a profound effect on the stress concentrations and consequently the load-capacity of the joint. It is therefore important to appreciate the consequences of changing geometric and material parameters.

In this work, the continuous adhesive bonding/ joint was developed to bond mild steel and reinforced plastic, RP, where mild steel is selected for its availability and RP is the composite that is developed for weight optimization of the vehicle. The application of mild steel and RP were considered for different parts of vehicle structures: mild steel was used as structural frame whereas RP was used as side panel [17].

As the materials to be joined and application areas are changed the strength prediction of the joint is still in a question. Also, the applicability of the joint at automotive exterior body is limited due to the combination of aesthetical values, strength and rigidity they offer, and etc.

Taking in to account the material considerations and the above limitations, single strap joint was selected for this case study. Besides, to address the critical joining problems in lightweight design, a parametric study of adhesive joints was carried. Experimental test were also conducted to study the strength of RP composite and to determine the effects of the adhesive joint parameters. Furthermore, the material composition of the chose composite materials was investigated.

1.2 Motivation

The driving forces to do this study are:

- There is abundant thermoplastic materials (eg. HDPE products) that is cheap to recycle and reuse.
- Applications and demand of adhesive joining technique in automotive body structure is continuously increasing.
- Thermoplastic materials and adhesive joint allows to reduces weight, which in turn increase fuel efficiency
- Adhesive joint eliminates stress concentrations present at the sites of fasteners and welds
- Use of such kinds of materials reduces part count.
- The local car body work remains stick with conventional joining techniques, such as welding, irrespective of current developments in using adhesive bonding.

1.3 Objective of The Research

General objective:

The main objective of this research is:

- To manufacture light-weight composite for automotive body material
- To carry out the parametric study of adhesively bonded single strap joint of similar and dissimilar materials for vehicle application.

Specific objective:

The specific objective of this research is:

- To fabricate the recycled (unreinforced) thermoplastic sheet.
- To manufacture the thermoplastic composite (reinforced) sheet for automotive body application.
- To prepare test-specimens with the required dimensions.
- To prepare both the reinforced and unreinforced test specimens of different thickness by grinding.

- To conduct the tensile test of both the reinforced and unreinforced plastic for comparison purpose.
- Preparing surface of both the substrates (RP) and strap (mild steel) for the bonding.
- To fabricate adhesively bonded joints
- To conduct the shear test of the adhesively bonded joints to investigate the effect of surface finish, contact geometry (overlap-length & width), adhesive thickness, environmental conditions, and etc on the strength of the joint.

1.4 Problem Statement

The increasing demand for lightweight and durable automotive body, and the need to have automated assembly rate is driving force to find a solution. To meet the need, composite materials have been becoming one of active areas of R&D in automotive industry. Conversely, to accommodate the newly introduced polymeric materials in the existing metal-intensive vehicle structure, beyond the existing well optimized joining techniques, such as mechanical fasteners and spot welding, use of adhesive joints is becoming common.

For example, nowadays bus body construction in Ethiopia is done by welding mild steel sheet with RHS mild steel body frames. During this construction the welders use more filler to compensate for the thin steel sheet, adding extra weight. Then after, the welded part is grinded and polished to improve the surface finish. Instead of mild steel sheet, the weight can be minimized using light weight materials such as plastic and composites, particularly for side panels. Joining two different materials requires the use of continuous adhesive bonding over the traditional ones keeping the aesthetical values, strength, rigidity and etc.

Thus, this research is aimed to solve the problems related to the material and the effect variations of parameters of adhesively bonded joint which affect efficient joint design between lightweight materials for automotive body. By analyzing the strength behavior of the material and the joint, efficient joint with efficient material is made.

Corresponding results based on experimental set-up is used to reduce these gaps. The results can contribute to the improvement of the locally built automotive body in reducing the weight.

1.5 Scope of the Research

The scope of this work is assessing the strength of this composite and joint in terms of material compatibility, environmental conditioning and practicality of using the test method.

In bonding the substrates of concern, the research is limited to investigate the effect of:

- Adhesive thickness: 0.12 to 0.6 mm, for ease of fabrication;
- Surface finish as a function of sand grade: 40 to 120, that are available and mostly used;
- Overlap length: 7.5 to 12.5 mm, relating to allowable size;
- Overlap width: 15 to 25 mm, relating to allowable size;
- Moisture: 2 to 12 hours water bath, that are related to exposure to rain and
- Temperature: 25 to 45 °C, are almost working temperature ranges in Ethiopia;

1.6 Organization of the Research

This paper consists of five chapters. The first chapter deals with the introduction while the second chapter focuses on the review of past works related to the paper. Chapter three addresses the methods, materials and procedures used throughout the paper. On other hand, chapter four comes with the test results and discussion. While chapter five comes up with conclusion, recommendation and future work of the research. And, the rest portion list down the references used and the appendixes.

1.7 Limitation of the Research

Some of the limitations to this research are unavailability of up to date and efficient machines, as well as, materials related to the thesis within our country. The unavailability of the adhesives for such low surface energy plastics (HDPE), heat press for composite manufacturing and efficient Universal Testing machine that is equipped with bi-axial extensometer or axial and transverse extensometers capable of recording axial strain and transverse strain simultaneously are the major ones.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Over the years, vehicle body-work compromises the high percentage steel sheet to meet the basic requirement of strength and functionality. Currently, complex and efficient body of modern automotive emerges with the development of lightweight materials. Lightweight composite materials, such as glass-fiber reinforced polymers, have been used to replace traditional steel and aluminum components. This is because composites offer significant opportunities for enhancement of product performance in terms of strength, stiffness and energy absorption, combined with weight reduction and space saving. Besides, today, the adhesive joint design of vehicles body that ensures reliability and road worthiness is of great concern. So, as a result of advancements in the areas of material, production methods, construction techniques, computational & design tools, optimization technique, etc., further improvement on vehicle body and joining techniques is still an active topic of research.

A numerical and experimental investigations addressing the issues of non-linear stiffness characteristics of adhesively bonded joints to reduce the overall weight of vehicle, maintaining the integrity and performance, now exists. The optimization of the body work will be pursued by employing new materials that will be joined with continuous adhesive bonding.

2.2 Materials for Car Body Panels

Actual selection of a particular material for a specific application is primarily driven by the trade-off between the material's cost (purchase price and processing costs) and its performance attributes (such as strength and durability, surface finish properties, and flexibility.) How critical any one attribute is depends upon the desired performance objective. The interrelationships among objectives, such as fuel economy, recyclability, and economics, are sufficiently tight that

the materials engineer must always simultaneously balance different needs, and try to optimize decisions at the level of the entire system [25].

Materials for car body panels require certain specific characteristics to meet the industry's challenges. Quality characteristics under demand are improved formability for reduced rejection rate and better quality, higher yield stress (strength), toughness, fatigue strength, improved dent resistance as well as corrosion resistance in materials used for body panels for improved durability and reliability.

An intensive research and development are going on for alternate materials, manufacturing processes and stamping tools for sheet-metal components with the main objectives of cutting down the weight and unit cost of the vehicle. Simultaneously, the steel content of the car is falling with the use of aluminum composites, and plastic.

Composites have significant economic potential when considering emerging advances in the polymer composite body-in-white design against the mild-grade steel body currently on the road. With the significant implications of a polymer composite body for vehicle light-weighting and thereby improved fuel efficiency, these results come at a time when they are particularly applicable [24].

Some of the materials that are taken for comparative purpose are described as follows:-

High-strength low-alloy steel (HSLA): - is a type of alloy steel that provides better mechanical properties or greater resistance to corrosion than carbon steel. HSLA steels vary from other steels in that they are not made to meet a specific chemical composition but rather to specific mechanical properties. They are often used for automotive application than carbon steel since they are more resistant to rust and lighter with the same strength. Their yield strengths can be anywhere between 250–590 Mpa.

SFG HITEN: A fine-grained high-strength steel sheet strengthened by grain refinement, with high formability due to low yield strength, excellent stretch-formability and excellent deep draw ability. It is said to be suitable for exposed panel with severe forming such as side panel. Its yield strength is 235 Mpa [28].

Aw-6016: Al-Mg-Si alloy: - is used as a car body sheet due to its low weight and good strength. During paint baking of sheets, its strength increases due to precipitation of various phases containing Mg and Si. Storing Al-Mg-Si alloys at room temperature for extended period before ageing leads to lower peak hardness. Its yield strength is 50 Mpa [29].

Carbon fiber reinforced plastics (CFRP): - offer great potential for lightweight vehicle structures, especially in the field of outer body panels. Up to now the application of CFRP is limited to small series due to high costs and complex manufacturing. Hence new concepts for mass production are needed for material and manufacturing conformity of parts made of CFRP.

Glass fiber reinforced plastic:- Keeping only one variable constant (bending strength), it should be possible to reduce the weight of body components by 40 percent through the substitution of plastic for steel. For equal stiffness to steel automotive body of 0.9 mm, the glass fiber reinforced plastic of 2.55 mm can be used [16].

2.3 Common Adhesively Bonded Joint Types and Failure Modes

Adhesively bonded joints are usually designed with intent of carrying the load in shear than peel due to its strongest performance in shear. With good design the substrate may yield or fracture before the adhesive fails. Some generic joint types with static strength and efficiency ranks from the highest to the lowest are as follows: scarf joint, step lap joint, double strap joint, single strap joint, and double lap joint and single lap joint.

Finite element model with the fewest solid elements can predict the non-linear stiffness characteristics of adhesively bonded single lap-joints in vehicle bodies. To gain further understanding of the influence of the key parameters on joint stiffness, over a wider range of variables than could be practically achieved in the laboratory, the ANSYS finite element code can be used to simulate the highly non-linear (geometric and material) response of bonded joints. The three key parameters of adhered thickness, bond line (adhesive) thickness and overlap length are important to the non-linear stiffness of the joint. This finding was identified from the assessment of the laboratory test results. Moreover, the computational results showed that changes to the two key parameters of unsupported length and joint width have little effect on stiffness, and so they can be ignored in model development [6].

The parametric studies on the specimen geometry revealed that stress distributions are sensitive to changes in adhered material properties, adhered and adhesive thickness and the applied load. In general, stresses were reduced when changes to the joint resulted in smaller joint displacement or an increase in the ability of the adhesive layer to plastically deform [5].

Finite element analysis of adhesively bonded joints by developing a special 6 node iso-parametric element for adhesive layer was carried out. In this work, the adhesive layer is assumed to be relatively thin and behaves elastically as simple tension-compression spring connecting the substrates. The results of a metal-metal single lap joint are found to be in good agreement with the closed-form solutions of Goland and Reissner [7].

The global-local finite element approach eliminates the use of a fine mesh and provides a robust description of the stress field in the critical regions of the bonded lap joints. The influence of the adhesive overflow on the stress state is presented in terms of the strength of the singular stress field and the variation of the strain energy density at these junctions. The order of the singularity is not sufficient for predicting failure sites. Adhesive overflow has a significant impact on the stress reduction in single-lap joints and should be included in the stress analysis of single-lap joints. In conjunction with the strain energy density criterion and the concept of energy release rate, this capability may serve as a design tool to identify the effects of geometric and materials parameters on potential failure sites and failure loading [8].

Laser ablation pretreatment generates areas where the resin on the composite surface is selectively removed leaving behind exposed reinforcing fibers which the major load are bearing members of the composite. This type of pretreatment permits fibers to bridge and reinforce the interface between adhesive and adhered [10].

For the two joint configurations bonded with epoxy adhesives AV119 and XD4601, simple algebraic relationships can be used to estimate the effects of the geometric parameters on joint strength. The equations however are empirical, and therefore not related to any physical mechanism. The overall equations relating the main factors are only as good as the constitutive relationships incorporated. Any deficiencies in these relationships will result in poor correlation between predictive model and the measured data. In addition, the uncertainty can be expected to increase for specimen geometries outside the test matrix. They found that the key parameter for

the single-lap joint was bond length as to be expected. In contrast, adhered thickness had a moderate effect on joint strength and adhesive thickness tended to have a minimal effect on the joint strength. The strongest interaction by a considerable margin was the interaction between the bond thickness and bond length [9].

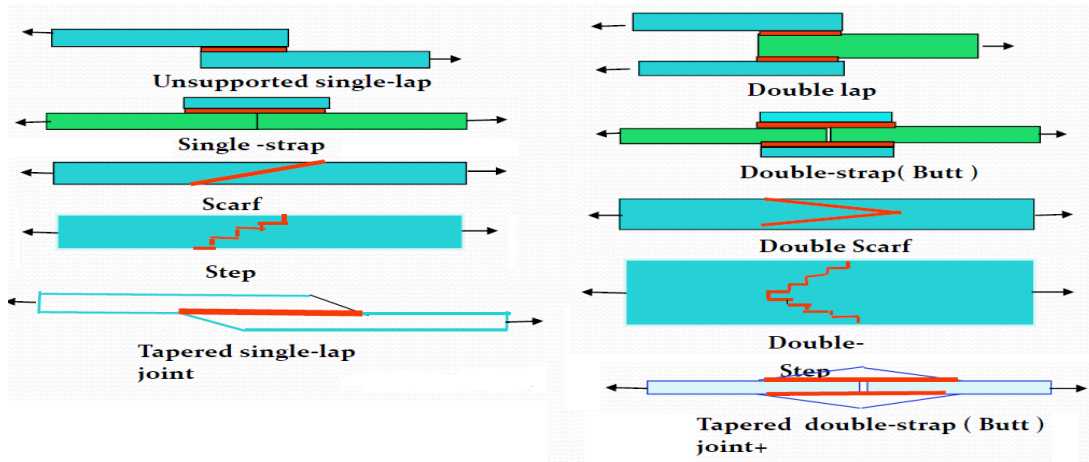


Fig.2.1 Common adhesively bonded joints

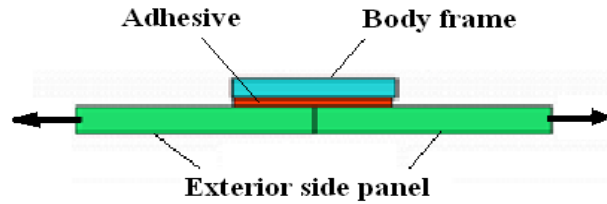


Fig. 2.2 Description of the adhesively bonded joint between the body frame and exterior side panel as single strap joint

For adhesively bonded joints, according to the ASTM standard D: 5573-99 ^[24], there are seven classes of failure modes in adhesive joints. Failure modes are as follows:

- Adhesive failure (AF) (sometimes referred to as interfacial failure): separation appears to be at the adhesive-substrate interface.
- Cohesive failure (CF): separation is within the adhesive.
- Thin-layer cohesive failure (TLCF) (sometimes referred to as inter-phase failure): failure similar to cohesive failure, except that the failure is very close to the adhesive- substrate

interface, characterized by a light dusting of adhesive on one substrate surface and a thick layer of adhesive left of the other.

- Fiber-tear failure (FTF): failure occurring exclusively within the fiber-reinforced plastic (FRP) matrix, characterized by the appearance of reinforcing fibers on both ruptured surfaces.
- Light-fiber-tear failure (LFTF): failure occurring within the FRP substrate, near the surface, characterized by a thin layer of the FRP resin matrix visible on the adhesive, with few or no glass fibers transferred from the substrate to the adhesive.
- Stock-break failure: this occurs when the separation is within the substrate but outside the bonded region.
- Mixed failure: a mixture of different classes.

A properly bonded joint with metal substrates usually fails by cohesive failure in the adhesive while the composite substrates usually fail by cohesive failure in the substrates due to its low transverse strength. But for this study, failure modes 4,5, 6 and 7 are not tolerated since one of the purpose of this research is limited to investigate the effect of the joint parameters on joint strength i.e. the composite substrates is assumed to have strong transverse strength to resist these failures.

2.4 Summary

Waste thermoplastic product, edible oil jerycans of HDPE category, was selected as matrix considering its local availability and performance (stiffness, corrosion resistant, elastic strength, light weight and etc). A composite, E-glass fiber reinforced recycled HDPE was developed and an experiment was conducted, considering the elastic strength of this composite, with the likelihood of the replacement of the automotive side panel with it.

And also, the shear strength of the adhesively bonded single strap joint between this composite and automotive body frame was investigated.

The effect of the adhesive thickness, surface finish, overlap length, overlap width, moisture and temperature on the shear strength of the this joint were considered. This work the substrate thickness was kept constant..

The influence of the adhesive overflow on the stress state is neglected even though it may have a significant impact on the stress reduction in single-lap joints due to difficulty of the actual measurements of the overflow dimensions.

Surface treatment prior to adhesive bonding was limited to sanding due to the availability and ease of the process [22].

The adhesive material chosen in this work was Araldite® Rapid: two component fast cure epoxy adhesive, that is available on the market and which in turn limits area of comparison of the results among different adhesive.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This work presents the development of reinforced thermoplastic automotive side panel and a parametric study of adhesive bonding in automotive body application. The material developed in this study was E-glass reinforced recycled HDPE. The adhesive used for this study was Araldite® Rapid: Two component fast cure epoxy adhesive.

Materials selection was made based on the availability of materials and design performance criteria.

Detail material discussion adopted procedures used for in this research are illustrated in the following sub-chapters.

3.2 Material

Over the last 60 years, thermoplastics have increasingly replaced traditional materials such as metals, wood and concrete in various industries, i.e. Automotive, Electrical & Electronic, Building, Appliances & Power tool, Industrial Engineering, Sports & Leisure. Their lightweight, attractive cost/performance ratio, easy colorability, function integration, resistance to corrosion, recoverability from parking lot dents, weight savings, efficient processing and chemical resistance make thermoplastics today's materials of choice, whatever we do – drive, work, cook, communicate, play or relax.

The economical development of emerging countries and the threat of climate change are behind a major drive towards more intensive use of thermoplastics around the world. The focus is not only on creating clean or recyclable materials but also on increasing part lifetime through higher mechanical performances, integrating end-of-life management and reducing number of parts thanks to modular assembly.

Thermoplastic composite materials have received widespread use in automotive world. Thermoplastic composite materials produce lightweight structures having relatively high strength characteristics. In addition, these types of materials have the characteristic of being reshaped: they can be repeatedly heated to the melting temperature of the material. In the automotive industry, the use of thermoplastic composite materials can produce significant weight savings and provide ease of replacement and repair.

Polypropylene (PP) is thermoplastic whose incorporation in to automotive body work takes highest percentage ^[16]. As seen from Table 3.1 and Table 3.2 below, the properties of High Density Polyethylene (HDPE) is very similar to that of PP, but not taken consideration in much of the previous works. Therefore, one of the thermoplastic products, HDPE edible oil jerycans, was selected as matrix in making reinforced body panel ^[17] due to its perfect flexibility, impact strength at low temperatures and handling, and weld ability properties in a wide temperature range as compared to other thermoplastic. It is also available at lower price.

Based on local availability, mild steel, E-Glass and Araldite Rapid Epoxy adhesive were selected as body frame, reinforcement and adhesive, respectively.

3.2.1 High Density Polyethylene (HDPE) as Matrix

FRP composites are composed of two materials or phases joined or connected to each other in such a way to give a combination of properties that cannot be attained otherwise. The properties of the individual components, the relative amount of phases, the orientation of various components, the degree of bonding between the phases, the size, shape and distribution of the discontinuous phase are very important in determining the properties of composite.

One of the phases of the composite is the matrix. There are several categories of plastic resins for the matrix available on the market, depending on the raw ingredients in their composition. They determine the physical properties of the end products. They are soft enough to allow tool shaping. If damaged, manufacturers can repair it by softening with certain solvents. In general, matrix is required to fulfill the following functions:

- To bind together the fibers and protect their surfaces from damage during handling, fabrication and during the service life of the composite;
- To disperse the fibers and separate them in order to avoid any catastrophic propagation of crack and subsequent failure of the composite;
- To transfer stresses to the fibers efficiently by adhesion and/or friction (when composite is under load);
- To be chemically compatible with fiber over a long period;
- To be thermally compatible with fibers.

There are two main types of resins:

Thermoplastic resins:- are those which soften, melt and flow upon heating, e.g., HDPE, PP, PC, and ABS. They are advantageous due to their unlimited shelf life, easy of handle (no tackiness), recyclability, post formability and higher fracture toughness than epoxy. But, the lower creep resistance than thermo sets and high viscosity $\sim 1,000,000$ cP are the main drawbacks. HDPE is the focus of this research.

Thermoset resins:- are liquid resins that get cured into cross linked network structure that will not melt upon reheating, e.g. Polyester, Epoxy, Vinyl ester, Urethane, Phenolics. They are advantageous due to their lower resin viscosity ($\sim 20 - 500$ cP), better fiber wet-out better creep resistance Polyester, excellent thermal stability after cure. But, brittle (low strain-at-break), limited storage life at room temperature, molding in the shape of a final part and non-recyclable via standard techniques are the main drawbacks. This type is not the focus of this research.

HDPE is a linear polymer, which is prepared from ethylene by a catalytic process. The absence of branching results in a more closely packed structure with a higher density and somewhat higher chemical resistance than LDPE. HDPE is also somewhat harder and more opaque and it can withstand rather higher temperatures (120° Celsius for short periods, 110° Celsius continuously).

HDPE, or type 2 plastics, make up the heavier containers that many of our everyday goods are stored in. A person can look at the bottom of a type 2 plastic and see the number 2 surrounded by a triangle of arrows and the abbreviation HDPE underneath it. This number and arrow show

that we can completely recycle it. The types of containers that are embossed with this code are milk containers, laundry detergent bottles, Tupper ware, bleach bottles, shampoo bottles, edible oil jerycans, motor oil bottles and etc.

The chemical composition of one of the HDPE products, edible oil jerycans that is the raw material to recycle for composite fabrication, is verified to be high density polyethylene using Spectroscopy Attenuated Total Reflectance (ATR) analysis with the instrument: Perkin Elmer Spectrum 100. 16 scans between 650-4000 cm^{-1} , see appendix-A.

Table 3.1 Comparison of HDPE with other competitive thermoplastic [32]

Property	HDPE	LDPE	PP
Flexural Modulus (Mpa)	1.3	0.3	1.5
Tensile strength (Mpa)	32	10	33
Specific density	0.96	0.92	0.905
Specific Modulus(Gpa)	1.35	0.33	1.66
Maximum continuous use temperature ($^{\circ}\text{C}$)	55	50	100
Surface hardness	SD68	SD48	RR90
Cost (£/tone)	660	730	660
Modulus per unit cost(Mpa/£)	1.97	0.41	2.27
Mold shrinkage (%)	3.0	3.0	1.9
Thermal expansion ($\times 10^{-5}$)	12	20	10
Notched Izod Impact strength (KJ/m) at 23 $^{\circ}\text{C}$	0.15	>1.5	0.07
RR=Rockwell R SD=Shore Durometer			

Table 3.2 Comparative ranking of HDPE with other competitive thermoplastic, where 0 represents unfavorable property and 9 represents favorable properties [32]

Property	PP homo-polymer	PP co-polymer	LDPE	HDPE
Bonding	5	5	5	5
Brittle Temperature	1	2	7	
Detergent Resistance	8	7	4	4
Dimensional stability	4	4	5	5
Flammability	1	1	1	1
Friction	5	5	1	6
Shrinkage	3	2	1	1
Surface Finish	8	8	7	8
Toughness at room temperature	4	6	9	6
weathering	3	3	2	3
Water absorption	9	8	9	9
Wear	5	5	4	5
extrusion	8	8	9	9
Injection molding	8	8	9	8
Machining	8	8	5	8
Vacuum forming	3	2	3	4

3.2.2 Reinforcement

Metal substitution has entered a new phase, further pushing the performance limits of thermoplastic materials. Thermoplastics that are reinforced with high-strength, high-modulus fibers provide dramatic increases in strength and stiffness, toughness, and dimensional stability. The performance gain of these composites usually more than compensates for their higher cost. Processing of composites usually involves the same methods used for unreinforced resins.

The desirable functional requirements of the fibers in a fiber-reinforced composite are the following:

- The fiber should have a high modulus of elasticity for an efficient utilization of reinforcement.
- The fiber should have a high ultimate strength.
- The variation of strength between individual fibers should be low.
- The fibers should be stable and retain their strength during handling and fabrication.
- The diameter and surface of the fiber should be uniform.

The following type of fiber used as reinforcement exists.

Glass Fibers: - is the most common fiber used in polymer matrix composites. A variety of different chemical compositions are commercially available. Common glass fibers are silica based (~50-60% SiO₂) and contain a host of other oxides of calcium, boron, sodium, aluminum, and iron. Among all the glass fibers used in composites, E-glass is the type most widely used. E-glass, which is essentially a borosilicate glass named for electrical applications, and S-glass (high strength), which is a magnesia/alumina/silica material with higher tensile strength than E-glass used for the same types of applications, but the E-glass is lower in cost and also it can be fabricated at lower temperatures.

Glass fibers used in reinforced compounds are high-strength, textile-type fibers, coated with a binder and coupling agent to improve compatibility with the resin and a lubricant to minimize abrasion between filaments. They can improve most mechanical properties of plastics: tensile strength, deflection temperature, flexural modulus, impact strength, tensile modulus, dimensional stability and fatigue endurance.

Carbon fibers: - added to thermoplastic resins provide the highest strength, modulus, and heat-deflection temperature, creep, and fatigue-endurance. These property improvements, coupled with greatly increased thermal conductivity and low friction coefficients, make carbon fibers ideal for wear and frictional applications where the higher cost can be tolerated. In applications where the abrasive nature of glass fibers wears the mating surface, the softer carbon fibers can be substituted to reduce the wear rate. Carbon fibers can also be used in conjunction with internal lubricants to further improve surface characteristics of most thermoplastic resin system.

Another useful property of carbon-fiber-reinforced thermoplastics is their low volume and surface resistivity's. Most resin systems reinforced with 15% or more carbon fibers can effectively dissipate static charge, which is a problem common to gears, slides, and bearings used in business-machine, textile, electrical, and conveying equipment.

Aramid fibers: - with greater specific strengths than steel or aluminum, should be an ideal reinforcement for thermoplastic resins. However, chopped aramid fibers do not adhere as well as the conventional glass or carbon-fiber reinforcements. Proprietary sizing systems aid in wetting

of the fiber, but extensive fiber damage results in properties for the composite that are less than spectacular.

On the plus side, aramid-fiber-reinforced composites have excellent wear and abrasion resistance, low coefficient of friction, and low thermal expansion. In addition, the mechanical properties of the composites are relatively uniform in all directions.

For this research purpose, E-Glass Woven Roving was selected since it can allow the through penetration of high viscous resins such as thermoplastic resin than others. That is why it is used in many hand lay-up and panel molding processes to produce FRPs. It is a high strength, coarsely woven fabric widely used in all phases of fiberglass molding. Higher physical properties are possible in laminates of this grade because of the reduced number of space in the fabric. It is compatible with many resin systems such as Polyester, vinyl ester, epoxy and phenol resins. And, it is high-performance reinforcement widely used in hand layup and robot processes for the production of boats, vessels, plane and automotive parts, furniture and sports facilities. The tensile and compressive strength of this fiber is 3445 Mpa and 1080 Mpa respectively. [29]

3.2.3 Automotive Frame

The frames used for automobiles have changed remarkably in terms of construction, weight and material used. Today, the conventional frames have been replaced by uni-body frames because they are shorter, sturdy, and have thinner wall thickness. In order to have improved mileage, automobile manufacturers are resorting to uni-body frames in which rocker panels, floor panels and other components are welded together in a single unit. The manufacturers are using passive safety design technology to develop frames of different sizes, variations, and compositions. The frame of an automobile is the necessary element in the designing of a car, as it is the supporting base which bears the loads laid by the terrain, engine, suspension system, tires, wheels, drive train, and steering system. It is the main backbone of the vehicle, which works just like the skeleton of bones inside the human body. A well-structured and properly built frame improves crash worthiness, passenger safety and weight efficiency.

Steel is the dominant automotive material, accounting for 55% the mass of an average 1997 family vehicle [15], because it's inexpensive per kg, strong and stiff, and relatively predictable

and manufacturable. But, steel is heavy, capital-intensive, and slow to tool-tooling for an all-new body and chassis.

The increased requirements on body strength and rigidity for safety and handling on one hand and the urge for weight reduction on the other have led to an increased use of high strength steel (HSS) in car bodies. Since 2001 best practice on steel car body design shows a reduction of 21% of body weight (source: world auto steel 2010). The use of HSS doubled since 2005 and is expected to triple in the period to 2020 as automakers strive hard to meet the future fuel economy legislation by 2016. Steel is not out. It is still very much alive as a cost effective material for car bodies. A further advantage of steel is that it takes a favorable position in well-to-wheel analysis. Compared to its alternatives steel takes little energy to produce and has good recycling capabilities.

Mild steel: DIN standard of St 37.2 is used to substitute automotive frame material in this experiment since it is available and used only as strap. It was cut in to strap with the dimensions of 25mmx25mmx1mm to represent RHS steel frame on the joint.

Table 3.3 Material property of RHS steel [21]

Material Property	Structural steel
Tensile yield strength	230 MPa
Compressive yield strength	230 MPa
Tensile ultimate strength	440 MPa
Density	7850 Kg/m ³
Young's modulus	200 GPa
Elongation	26%

Taking this steel as body frame and E-Glass Woven reinforced Recycled HDPE as body panel makes the joining techniques in question. Thus, to join effectively these two materials the third material called adhesive is required.

3.2.4 Adhesive

An adhesive is a material used for holding two surfaces together. Adhesives are scientifically and technologically diverse subjects encompassing the fields of polymeric materials, rheology, surface chemistry, engineering mechanics and process technology.

Adhesion on the other hand is a specific interfacial phenomenon pertaining to the degree to which the surfaces of two different materials are attracted to each other. The molecular basis of adhesion is rarely studied in practice; one resorts to secondary means of determining the forces of adhesion (contact angle, contact potential, adhesive joint strength). In particular, one must make a clear distinction between the forces of adhesion and adhesive joint strength. The latter is in the realm of engineering mechanics and is required for engineering design purposes, adhesive joint strength is therefore the most important engineering property of an adhesive material.

An adhesive must have to satisfy four main requirements:

- It must "wet" the surfaces - that is it must flow out over the surfaces that are being bonded, displacing all air and other contaminants that are present.
- It must adhere to the surfaces - That is after flowing over the whole surface area it must start to adhere and stay in position and become "tacky".
- It must develop strength - The material must now change its structure to become strong or non-tacky but still adherent.
- It must remain stable - The material must remain unaffected by age, environmental conditions and other factors as long as the bond is required.

Surface preparation before applying the adhesive is of prime importance. Not only this, the type of the substrates /surfaces to be joined also matters the strength of the joint. That is why; a useful way to classify adhesives is by the way they react chemically after they have been applied to the surfaces to be joined. There is a huge range of adhesives, and one appropriate for the materials being joined must be chosen.

Adhesives can be classified into three main types given below. There are of course several products that are combinations of these three types but essentially all adhesives can be grouped into these categories.

1. Chemical reactive types
2. Thermoplastic type
3. Evaporation or diffusion types

1. Chemical reactive types

Basically an adhesive of this type is supplied in a low molecular weight form and after application a polymerization reaction is allowed to take place. This polymerization can be achieved by:

Two component pack

Supply the produce as a two component pack, i.e. base plus hardener. Examples of this type are:

- Epoxy adhesives based on epichlorhydrin bisphenol. Cured with amines or polyamide.
- Phenolics adhesives i.e. a novalac type with hexamethylenetetramine.
- Unsaturated polyesters using an organic peroxide, i.e. M.E.K. peroxide and cobaltnaphthenate.
- Polysulfide with lead dioxide or an isocyanate.
- Polyurethanes with isocyanate.
- Silicone polymers utilising a metal salt of an organic acid, e.g. lead octoate.
- Reactive acrylics - rely on peroxides or amines.

Moisture

Polymerization can be achieved by relying on moisture either on the surface of the substrate or in the atmosphere to effect a cross-linking mechanism on some other "natural" component.

In this case the adhesive is supplied as a single component. Examples are:

- Polyurethane containing an isocyanate group.
- Cyanoacrylates. These are the instant bond adhesives.

- Silicones containing an acetyl group. These are the common R.T.V. silicones which with moisture releases acetic acid causing a cross-linking of the paste to an elastomer.
- Anaerobic which rely on absence of oxygen.

Heat

The final method of curing a chemical reactive type is by utilizing heat to polymerize the adhesive components. Examples are:

- Epoxies with the catalyst incorporated in the adhesive in a latent form, e.g. dicyandiamide which will require a temperature of 175°C to affect a cure.
- Phenolics of the resole type.
- Polyvinyl acetates which are based on polyvinyl alcohol reacted with an aldehyde.

The conversion is normally about 80% and on heating after application the cross linking is completed.

- Urethanes incorporating a blocked isocyanate. The free isocyanate groups are all reacted with a temporary blocking agent such as phenol which is stable up to 150°C.

The problems associated with the above three types of adhesives are:

- Two components types - difficult to ensure correct and adequate mixing of the two components (often by unskilled personnel or in adverse conditions).
- Moisture curing types - poor shelf life even when stored in sealed containers. Once container is opened the life will drop rapidly.
- Heat curing types - again poor shelf life plus the problem of heating the adhesive or adherend.

2. *Thermoplastic type*

Basically the adhesives in this class are thermoplastic in nature which means they are heated to a sufficient temperature where they will flow and wet the substrates and then set and develop the bulk strength on cooling. The ideal Hot Melt adhesive is a solid up to a temperature of 80°C (as a minimum) but will then melt sharply to give a low viscosity fluid that is easily applied and

capable of wetting the adherend followed by rapid setting upon cooling. They normally contain a base high molecular weight polymer together with tackifying resins and viscosity depressants.

Examples of polymers that are used as the base for Hot Melt adhesives are:

- Ethylene vinyl acetate - a polyethylene chain containing the highly polar acetate group.
- Ethylene-ethyl acrylate which has an ethyl acrylic grouping.
- Ionomers - derived from ethylene acrylic acid copolymers but including a metal cation or some of the pendant carboxyl groups. The metal cation is free to cross-link with the anionic side groups similar to a thermosetting resin but the reaction is thermally reversible.
- Phenoxies - similar chemical structure to epoxides.
- Polyamides of low to intermediate molecular weight based on the unsaturated dibasic acids of vegetable origin.
- Polyesters (saturated).
- Vinyl resins such as polyvinyl acetate, polyvinyl butyral and polyvinyl ethers used in various special areas.

3. Evaporation or diffusion types

In adhesives of this class the adhesive polymers is essentially in its final form however, wetting of the substrate is achieved by dissolving or dispersing the polymers in a suitable solvent.

Solvent Based Systems

- Rubber adhesives - usually based on an elastomer which is either natural or synthetic.

The synthetic rubbers that are used in adhesives are polychloroprene nitrile (a copolymer of butadiene and acrylonitrile) butyl (a copolymer of isobutylene and isoprene) and styrene butadiene rubber. Natural rubber is essential isoprene.

Normally resins, usually phenol-formaldehyde based, are incorporated.

- Phenolic or resorcinol formaldehyde resins dissolved in a solvent.
- Vinyl resins such as polyvinyl acetate, polyvinyl chloride, polyvinyl ether etc.
- Acrylic resins based on methyl methacrylate, ethyl acrylate, acrylic acid etc.

- Miscellaneous resins such as cellulose acetate and polyamides.

Water Based Systems

There are very few polymers of sufficient molecular weight to be attractive as adhesives that will dissolve in water. However, dispersions or emulsions are very important. Examples are:

- Rubber latices - again either natural or synthetic such as polychloroprene, nitrile or styrobutadiene rubber.
- Vinyl resins, where polyvinyl acetate emulsions are very widely used.
- Acrylic resins which offer some advantages over PVA types such as water and solvent resistance.

The problems associated with evaporation type adhesives are fairly straightforward.

- Elimination of the dispersing medium which could be toxic or inflammable or slow to leave the substrate.
- A large percentage of the adhesive is basically waste and non-recoverable.
- Possible damage to the substrate by the dispersing medium.

The disadvantages of Hot Melt adhesives are of course the heating associated with their application and possible thermal degradation if held at a high temperature for a long time and the thermoplastic nature of the polymer. Also the stress concentrations built up by the actual covering and shrinking process.

Based on availability high performance epoxy adhesive, Araldite® Rapid, Two component fast cure epoxy adhesive, was selected to join the substrates even though one of the substrate, HDPE, is low surface energy material that is difficult to bond easily. This adhesive is the chemical reactive types whose polymerization can be achieved by *two component pack*, i.e. base plus hardener. Its key properties are fast curing, general purpose, low shrinkage, bonds a wide variety of materials, and tough and resilient. Araldite® Rapid is a fast cure, multipurpose, two components, room temperature curing adhesive of high strength and toughness. It is suitable for bonding a wide variety of metals, ceramics, glass, rubbers, rigid plastics, and most other materials in common use. It is a versatile adhesive for the craftsman as well as most industrial

applications. Manufacturer, Huntsman Advanced Materials, instructions was used to bond the substrates effectively with the adhesive.

Table 3.4 Araldite® Rapid Two component fast cure epoxy adhesive product data [31]

Property	Araldite® Rapid Resin	Araldite® Rapid Hardener	Araldite® Rapid mixed with 1:1 Ratio
Color (visual)	opaque	pale yellow	pale yellow
Specific gravity	1.16-1.18	1.15-1.18	ca 1.18
Viscosity at 25°C (Pas)	30-75	20-40	typically 25-50
Pot Life (100 g at 25°C)	-	-	5 - 8 minutes

3.3 Methods and Procedures

The first part of this work deals with the manufacturing process both the reinforced and unreinforced plastic. While the second part of this work deals with the cutting of the manufactured test specimens in to the required dimensions, preparation of its surface for adhesive bonding and development of bond. The last part of this work, but not the least, deals with tensile and flexural tests of both the reinforced and unreinforced plastic, and the shear tests of the adhesively bonded joints.

Both the reinforced and unreinforced plastics were manufactured using injection molding. Then after, the test specimens were cut using band saw while the surface quality of each overlap will be obtained by sanding with sand paper of different grit diameters.

Then, the bond was developed using assembly tool in order to ensure the necessary repetition of the experiments and maintain the geometrical parameters invariable (overlap length and adhesive thickness).

In the stage of curing, it is very important to maintain the same environmental conditions (temperature and relative humidity). The room temperature and humidity in Laboratory of School of Mechanical and Industrial Engineering was used for the entire curing time (72 h). After the curing time, a dimensional verification was carried out with a digital gauge.

Lastly, tensile tests of both the reinforced and unreinforced plastic, and the shear tests of the adhesively bonded joints were performed using a Computer Controlled Electro-hydraulic Servo Universal Testing Machine (UTM): WAW-600; maximum capacity: 600kN and test speed: 0.01 to 500 mm/min.

3.3.1 GFRP Fabrication

The common manufacturing methods for FRP Composites are the following.

Hand Lay-up: - A manual fabrication process. It involves building up layers of chopped glass or woven glass mat impregnated with catalyzed resin around a suitable mold. The reinforcement is then rolled for better wet-out and removing trapped air. It is used for large diameter structure, custom shapes, like asymmetric shapes and bonding two or more modules

Compression Molding: - For thermo sets or thermoplastics. The process consisting of placing a charge in the mold, which is subsequently closed and held at a high pressure, and then heating the mold to initiate cure reaction.

Pultrusion Process: - A highly automated production process that continuously draws resin impregnated fiber reinforcements, at speeds ranging from 1 to 5 feet per minute, through a heated die which forms and cures to the desired cross-section with no part length limitation. It produces high strength structural shapes with high volume reinforcements at moderate tooling and capital equipment cost.

Resin Transfer molding: - is a low pressure, "closed mold" process. This means that RTM parts are made by injecting liquid resin and catalyst into a closed mold cavity containing dry fiber reinforcements. Some of the benefits of this type of fiberglass manufacturing include: fast cycle times, parts that can be produced to very close tolerances, parts that are smooth on both sides, and production rate capacity up to 10,000+ parts per year. Glass fiber reinforced plastic is a great solution for applications where metal is currently used.

Filament Winding: - A process where continuous fiber filaments called roving, are saturated with catalyzed resin and helically wound around a mandrel. The fibers are fed through a device which moves up and down the length of rotating mandrel.

Injection molding: - is a manufacturing process for producing parts by injecting material into a mold. Injection molding can be performed with a host of materials, including metals, glasses, elastomers, confections, and most commonly thermoplastic and thermosetting polymers. Material for the part is fed into a heated barrel, mixed, and forced into a mold cavity where it cools and hardens to the configuration of the cavity. After a product is designed, usually by an industrial designer or an engineer, molds are made by a mold maker (or toolmaker) from metal, usually either steel or aluminum, and precision-machined to form the features of the desired part. Injection molding is widely used for manufacturing a variety of parts, from the smallest components to entire body panels of cars.

Specifically, the manufacturing process followed in this study is categorized to injection molding. Because, the test specimen material was manufactured by sandwiching a layer of woven E-glass fiber between two sheets of pre-weighted HDPE. Then, the sandwich is melted down and is forced into a mold cavity where it cools and hardens to the configuration of the cavity. Here the sandwich is limited to one fiber layer and two matrix layers due to the difficulty of attaining specific melting temperature of the sandwich volume using the furnace at hand. Even, for the manufactured sandwich a trial and error was used to obtain the correct through-melting temperature (240- 450 °C) of the sandwich volume, as opposed to the 130 °C melting temperature of the HDPE. And thus, since only one fiber to matrix ratio is manufactured, the fiber weight fraction of the matrix was varied by surface grinding of the manufactured sandwich.

The following things are used in the manufacturing process:

- HDPE plastic sheet (from high density polyethylene jerycans used for cooking oil storage)
- Woven E-glass fibers sheet
- Aluminum foil
- Weight for press
- Water, kerosene and soap for washing
- Metal mold (420mmx155mmx100mm)
- Induction Furnace (A-A-U-T -08-1989 ,capable of 25-900 c°)

As it can be seen from fig.3.1 below, the procedures followed are as follows:

1. HDPE plastic sheet of on average 2 mm thickness was cut into 155mmx415mm for composite fabrication from the jerycans sides. Hand saw was used to cut though the jerycans, however the cap and threaded opening are thicker and stronger. These parts were discarded.
2. Plastic sheet was washed with hot water and kerosene to remove oil residue. The jerycans label was removed and dried.
3. Woven E-glass fibers of 0.5 mm thickness was cut into 155mmx415mm.
4. Sandwich layers of fibers between sheets of pre- weighted HDPE were made.
5. The sandwich was covered by aluminum foil to prevent the plastic from both sticking to the mold and oxidizing in the presence of air.
6. Covered sandwich was placed in between two steel molds and placed in the induction furnace, where it was heated from 240°C to 450°C by increasing the temperature every 4 min by 14°C to completely melt the polymer. (The temperature ranges are used for this furnace only).
7. The soften sandwich was taken out of the furnace, and immediately forced/pressed into a mold cavity with 42 Kg for 15 min within the mold.
8. The composite material was removed from the press and
9. The composite material was removed from the foil.

The above procedure is repeated to manufacture the recycled plastic sheet except the fiber is not inserted in to the sandwich.

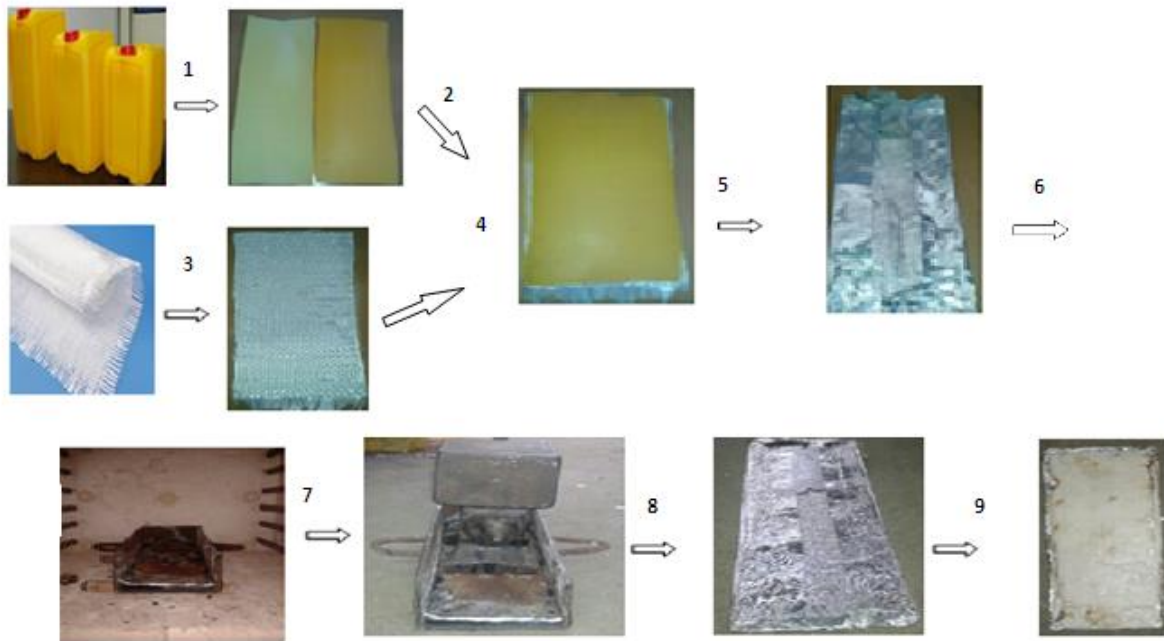


Fig. 3.1 The illustration of the manufacturing procedures of the test specimen material.

3.3.2 Preparation of the Test Specimen Surface

Whenever structural components are to be produced using adhesive bonding, the condition of the substrate surfaces must be considered. They are likely to be contaminated with materials which could affect adversely the performance of the resultant joint. Surface pretreatment will, therefore, normally be necessary if optimum performance is to be achieved. It will be vital if good environmental or thermal durability is required.

Dependent on the substrate, surfaces are prepared by one of the following pretreatment procedures (for many substrates, this list is in increasing order of effectiveness):

- Degrease only.
- Degrease, abrade and remove loose particles.
- Degrease and chemically pretreated.

Care must be taken to avoid contaminating the surfaces during or after pretreatment.

Whatever the pretreatment procedure used, it is good practice to bond the substrates as soon as possible after completion, i.e. when the surfaces are most 'active' (surface properties are at their best).

Degreasing Methods: - For nearly all bonding applications, the removal of all traces of oil and grease from the substrate is essential.

Remove all traces of oil and grease as follows:

Suspend the part in the vapor of a suitable alkaline degreasing agent in a vapor degreasing unit.

Immerse successively in two tanks each containing the same solvent. The first tank acts as a wash, the second as a rinse.

If safety considerations permit, brush or wipe the substrate surfaces with a clean brush or cloth soaked in clean acetone. For fine work, washing down with solvent applied by aerosol spray may be a more suitable alternative; this technique also ensures that the solvent used is clean.

Scrub the substrate in a solution of liquid detergent.

Abrading Methods: -Light abrasion of the surfaces to be bonded can allow the adhesive to key better than when a highly polished substrate is used. Highly active surfaces, such as those produced immediately following abrasion, tend to have a better affinity for the adhesive.

The choice of grit type will be dependent on the substrate to be abraded. Selection of grit size will also depend on several factors: again, the metal to be pretreated, the type of equipment being used, the pressure and angle of blast impact and the blasting time.

In general, for soft materials the optimum grit size will be towards the finer (i.e. 125 μm) end of the range.

Chemical Pretreatments: -The surface pretreatments described above, i.e. degreasing alone or degreasing followed by abrasion and removal of the loose particles is sufficient to ensure, for several substrate types, that good, strong bonds will be formed with the adhesive being used. However, for many substrates, to obtain maximum strength, reproducibility and long-term

durability, a chemical pretreatment will be required to modify the surface, or surface chemistry, in such a way as to make it suitable for structural adhesive bonding.

Focusing to thermoplastic plastics substrates, thermoplastic polymeric substrates vary in the ease with which they can be bonded. Significant factors are the type and grade of polymer, the compounding ingredients and the molding conditions. Tests may be needed to determine bond strength under a given set of conditions.

In this study, in order to obtain the different degrees of surface roughness in the thermoplastic plastics substrates, surface pretreatment was made by light abrasion of the surfaces with different grades of sand paper. For each samples, to obtain five different surface finishes, five sand paper grades from the fine to the coarse ones were used. [22] The description, sand grit designation and average particle diameter of the sand paper used was depicted in table 3.5

Description	ISO/FEPA Grit designation	Average grit diameter (μm)
Coarse (Rapid removal)	P40	425
	P50	336
Medium (gentle removal)	P60	269
	P80	201
Fine (slow removal)	P120	125

3.3.3 Manufacture of the Single Strap Joints

Simple assembly too is prepared to direct the manufacturing of the joint, in order to ensure the necessary repetition of the experiments and maintain the geometrical parameters invariable (overlap length and adhesive thickness).

In assembling process, aluminum foil was used to create different adhesive thicknesses while the masking tape was used to shield the surface areas of contact of the adhesive which in turn creates different overlap widths and lengths.

After mixing the resin and the hardener in ratio of 1:1, the mixture is carefully placed on the strap at bottom followed by placing the two substrates at the top. Once assembled, the excess

adhesive was removed (to avoid possible origins of fractures) and a 1.78 kg weight was placed on the joint for 15 min.

In the stage of curing, it is very important to maintain the same environmental conditions (temperature and relative humidity). But here, the room temperature and humidity in Laboratory of School of Mechanical and Industrial Engineering was used for the entire curing time (72 h). After the curing time, a dimensional verification was carried out with a digital gauge.

The following things are used in the manufacturing process:

- 51ml hardner and resin
- Aluminum foil and masking tape
- Weight for press
- Flat table
- Simple assembly tool

Generally, to manufacture of the Single Strap Joints the following instructions are followed:

- Treat and flatten the surfaces that will be bonded together. Scrape away any bumps or protrusions. Wipe the area clean. For the adhesive to be effective, the two surfaces must be completely level and clean.
- Prepare assembly guide to direct the manufacturing of the joint
- Mix both the hardener and the resin with correct ratio as provided by the manufacturer.
- Apply a layer of the mixed adhesive to each surface. Immediately press the three surfaces together and hold them tightly for at least 15 min. If necessary, use clamps or vices to hold the pieces tightly together.
- Scrape away excess adhesive that seeps out of the seam between the two surfaces. If it is still wet, wipe it away with a rag or towel; if it dries quickly, scrape it away with a utility knife or scraper.
- Allow the adhesive to dry overnight before putting any pressure on the joint or expecting the bond to hold effectively.



Fig. 3.2 The adhesively bonded single strap joint

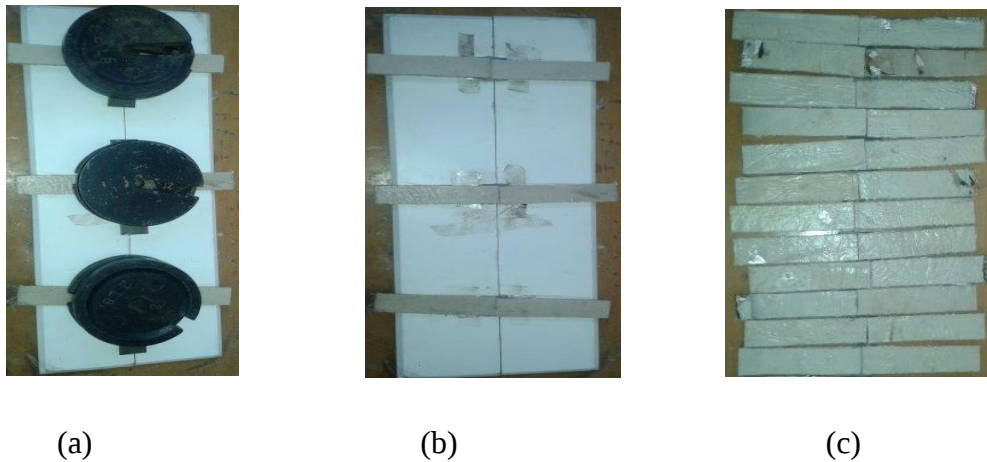


Fig. 3.3 Simple Assembly tool (a), the bonded joint (b) and the appearance of external surface of this bonded joint (c)

3.3.4 Physical properties of the reinforced (RP) and unreinforced plastic (URP)

The density of the manufactured composite and the fiber weight fraction of the matrix were given great concern here. Because the target is developing competent light weight material i.e. of low density and optimum strength. The typical density of HDPE and Woven E-glass fiber is known to be 0.96 g/cc and 2.5 g/cc respectively. Thus, the density of the manufactured composite is the function of these densities. They are given as follows:

$$\text{Density of the composite } (\rho) = \frac{\text{Total mass of the composite}}{\text{Total volume of the composite}}$$

$$\text{Fiber weight fraction of the matrix (F/M w \%)} = 100 * \frac{\text{Total Fiber weight}}{\text{Total matrix weight}}$$

After weight measurements and volume calculations, the properties illustrate in table 3.6 below are derived.

Table 3.6 Physical Properties of RP and URP

Reinforced plastic (RP)				Unreinforced plastic (URP)		
Samples designations	Thickness (mm)	ρ (g/cc)	F/M w (%)	Samples designations	Thickness (mm)	ρ (g/cc)
RT1	2.2	1.19	79.6	URT1	2.4	0.96
RT2	3.2	1.118	48.7	URT2	3	0.96
RT3	3.6	1.1	42.4	URT3	3.6	0.96
RT4	4.3	1.07	34.6	URT4	3.8	0.96
RT5	5	1.06	29.2	URT5	4.2	0.96

3.3.5 Mechanical Tests

3.3.5

The experimental study consisted of a test of 5 samples representative of each of the parameters considered following standard ISO 2602^[11]. To provide reliability, three repetitions were performed. Tests will be conducted using a Computer Controlled Electro-hydraulic Servo Universal Testing Machine (UTM): WAW-600; maximum capacity: 600kN and test speed: 0.01 to 500 mm/min. The specimens are mounted on the UTM machine and dimension of the specimens are entered into the software. There were performed two types of tests: tensile and shear tests.

The tensile test of both the reinforced and unreinforced plastic is done assuming that it the backbone to describe the performance of the materials as automotive side body panel, to be shure of the manufacturing process used, to compare the reinforced with the unreinforced ones and to be sure of the strength of the reinforced plastic is greater than the strength of its single strap joint with St 37.2.

And the shear strength test was conducted for the adhesively bonded single strap joint to investigate effect of the parameters stated in section 1.5. Because, for normal working conditions, the side panel is adhesively bonded along the lateral surface of the body frame which is assumed to be rigid enough along the axis normal to it.

The data obtained from tensile test measurements are nominal (or engineering) values. Measurements of the following data are required, where stresses and strains have been calculated using the initial specimen dimensions.

- Stress (MPa)
- Strain
- Tensile Strength (MPa)
- Yield stress (MPa)
- Young's Modulus (GPa)

Stress: is a measure of the internal force an object is experiencing per unit cross sectional area. Hence, the formula for calculating stress is the same as the formula for calculating pressure:

$$\sigma = \frac{F}{A}$$

Where σ is stress (in Newtons per square meter or, equivalently, Pascals). F is force (in Newtons, commonly abbreviated N) and A is the cross sectional area of the sample.

Tensile strength: is the level of stress at which a material will fail. Tensile strength is also known as fracture/ultimate stress. If a material fractures by 'crack propagation' (i.e., it shatters), the material is brittle.

Yield stress: is the level of stress at which a material will deform permanently. This is also known as yield strength.

Strain: is the geometrical measure of deformation representing the relative displacement between particles in the material body.

$$\epsilon = \frac{l_o - l}{l} = \frac{\Delta l}{l}$$

Where l_o is the original length of a test specimen being stretched, and l is its length after it has been stretched. Δl is the extension of the test specimen, the difference between these two lengths.

Young's Modulus: is a measure of the stiffness of a material. It states how much a material will stretch (i.e., how much strain it will undergo) as a result of a given amount of stress. For the linear regions of stress-strain graph, the formula for calculating it is:

$$E = \frac{\sigma}{\epsilon}$$

The values for stress and strain must be taken at as low a stress level as possible, provided a difference in the length of the sample can be measured. Strain is unit-less so that Young's Modulus has the same units as stress, i.e. N/m² or Pa.

3.3.6 Dimensioning of the Tensile and Shear Test specimens

A. Dimensioning of the test specimens for tensile test

For tensile tests of both reinforced and unreinforced plastic, using ASTM Standards: D 638 – 03, Standard Test Method for Tensile Properties of Plastics dimensions of the tensile test specimens are depicted below. The thickness, t , of the test specimen was varied to investigate the effect of fiber to matrix ratio by weight on tensile strength for the case of reinforced plastic. And also, t was varied to get the tensile strength of the recycled plastic for the case of unreinforced plastic.

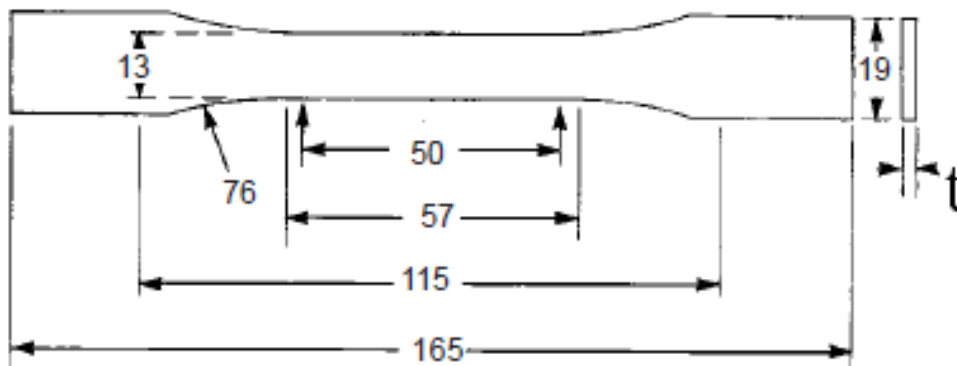


Fig.3.4 Tensile test specimen dimensions (mm) for both the unreinforced and reinforced plastic [19]

B. Dimensioning of the test specimens for shear test of adhesively bonded joint

Using ASTM D 5868-01, 2008, Standard practice for lap shear adhesion for Fiber Reinforced Plastic (FRP) bonding, in addition to those depicted on the fig. 3.5, the shear test specimen dimensions used were:

- Overlap width: $15 \leq W \leq 25 \text{ mm}$;
 - Overlap length: $15 \leq 2L \leq 25 \text{ mm}$;
 - Adhesive thickness: $0.12 \leq t1 \leq 0.6 \text{ mm}$;
 - Substrate thickness: $t_o = 5 \text{ mm}$ and
 - Strap thickness: $t2 = 1 \text{ mm}$
- } varied to consider the geometric effect

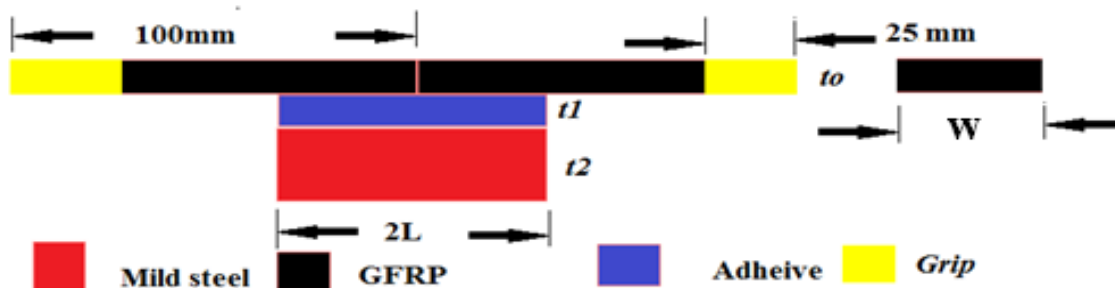


Fig.3.5 Shear test specimen dimensions of adhesively bonded joint [13]

CHAPTER FOUR

RESULT AND DISCUSION

4.1 Results

4.1.1 Tensile Test Results

Following ASTM Standards: D 638 – 03 test conditions, the specimens are subjected to uni-axial load until they failed in Universal Testing Machine. The crosshead speed was maintained at a rate of 5mm/min. The test was conducted at room temperature and humidity in Material testing lab of School of Mechanical and Industrial Engineering, AAiT, Addis Ababa, Ethiopia

Both the reinforced (RP) and unreinforced (URP) were subjected to uni-axial load to compare their strength. After the tensile test is conducted, the Stress Vs Strain Curve plot is obtained experimentally by taking load & displacement of each test specimen under uni-axial loading and calculating the corresponding stress and strain values. To provide reliability of the test data, three repetitions were used. The following stress-strain graphs are plotted for tensile test specimens.

A. Stress Vs Strain Curve plot of URP against RP

Under the same manufacturing conditions, the URP and RP of the same geometries,URT3 and RT3, (see table 3.6) were exposed to uni-axial loading. RP that was designated with RT3 was manufactured with 42.4% fiber to matrix weight fraction and URP that was designated with URT3 was manufactured with the same thickness as RT3. As shown on fig.4.1 below, the manufacturing process used and the selection of the compatible reinforcement is good enough since the ultimate tensile stress of unreinforced HDPE is improved from 14.92 to 28.01 Mpa as it is reinforced with the woven E-glass fiber.

B. Comparison of the effect of Fiber to matrix weight ratio on strength of RP under Uni-axial loading.

By varying the Fiber to matrix weight ratio from 29.2 % to 79.6 %, the RP were exposed to uni-axial loading, (see table 4.2). As shown by fig.4.2, RP of fiber to matrix ratio of 48.7% has highest ultimate tensile stress of 32.5 Mpa with smallest deformations before failure. This figure is small as compare to that of other alternatives seen in section 2.2, but close to that of AW-6016. So, can be used for exposed auto body work along with some improvements stated for future work.

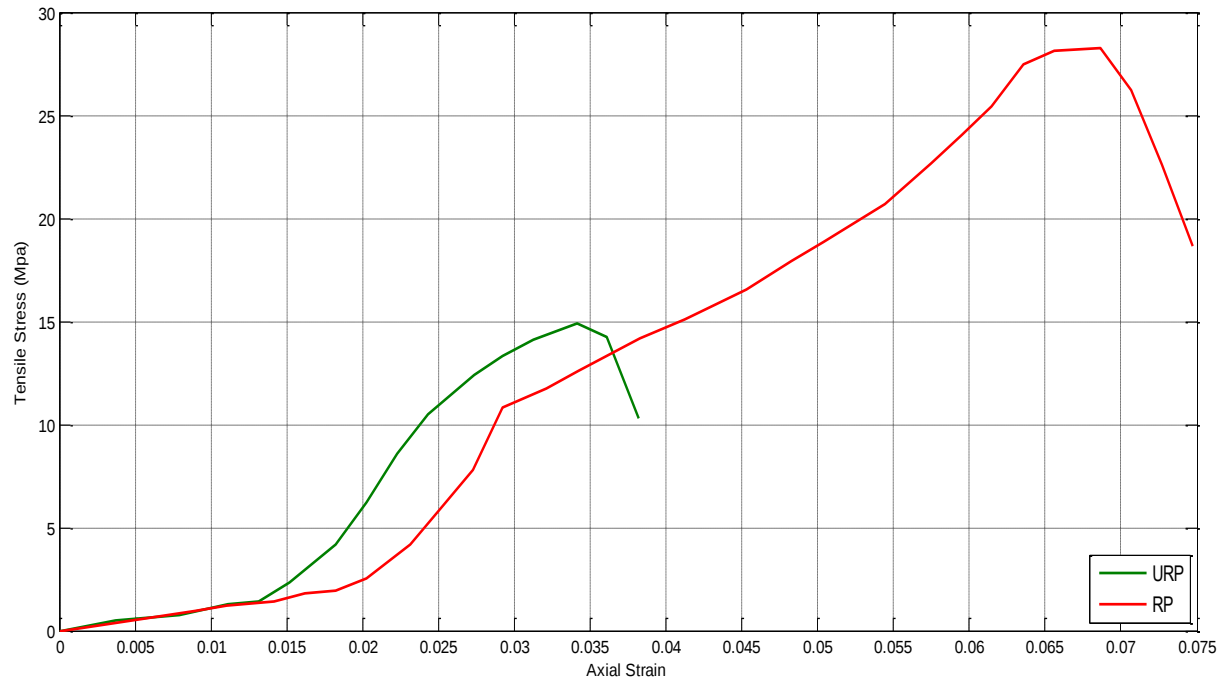


Fig.4.1 Stress Vs Strain Curve plot of URP against RP

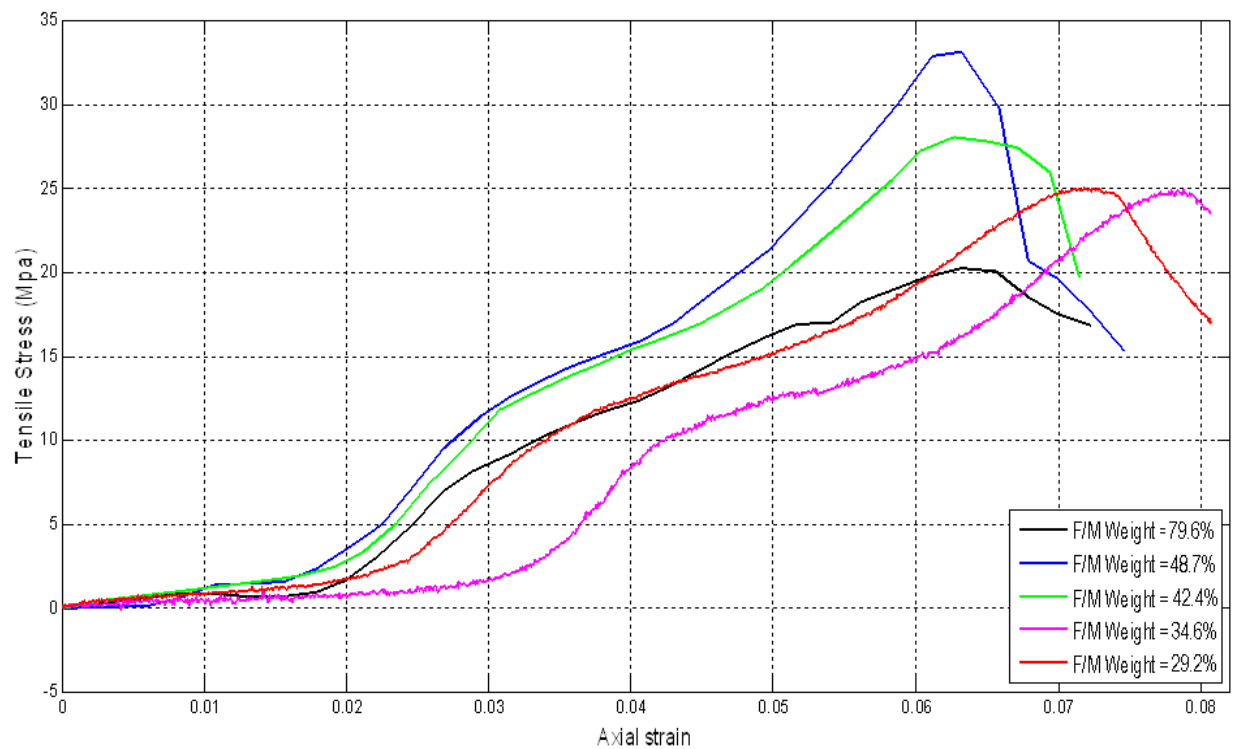


Fig.4.2 Stress Vs Strain Curve plot for fiber to matrix ratio by weight (%) as parameter

4.1.2 Shear Test Results

Following ASTM D 5868-01, 2008, Standard practice for lap shear adhesion for Fiber Reinforced Plastic (FRP) bonding, the adhesively bonded single strap joint is subjected to shear load until they failed in Universal Testing Machine. The crosshead speed was maintained at a rate of 0.15mm/min. The test was conducted at room temperature and humidity in Material testing lab of School of Mechanical and Industrial Engineering, AAiT, Addis Ababa, Ethiopia

Adhesively bonded single strap joint that was manufactured using RP as substrate, mild steel as strap and Araldite ® Rapid: Two components fast curing adhesive is exposed to shear load. The shear test is conducted for different parameters to investigate its effect variation on the shear strength of this joint. And, the Stress Vs Strain Curve plot is obtained experimentally by taking load & displacement of each test specimen under shear loading and calculating the corresponding stress and strain values. Again, to provide reliability of the test data, three repetitions were used. The following stress-strain graphs are plotted for shear test specimens.

A. Comparison of the effect of water bath duration (moisture) on shear strength adhesively bonded single strap joint.

Five adhesively bonded single strap joint samples each with three repetitions was placed dip in to the same cold water for varied duration, then after they were exposed to shear loading. Fig.4.3 depicts the Stress Vs Strain Curve plot.

B. Comparison of the effect of heat/temperature on shear strength adhesively bonded single strap joint.

Five adhesively bonded single strap joint samples each with three repetitions was exposed to the varied temperature for same duration, then after they were exposed to shear loading. Fig.4.4 depicts the Stress Vs Strain Curve plot.

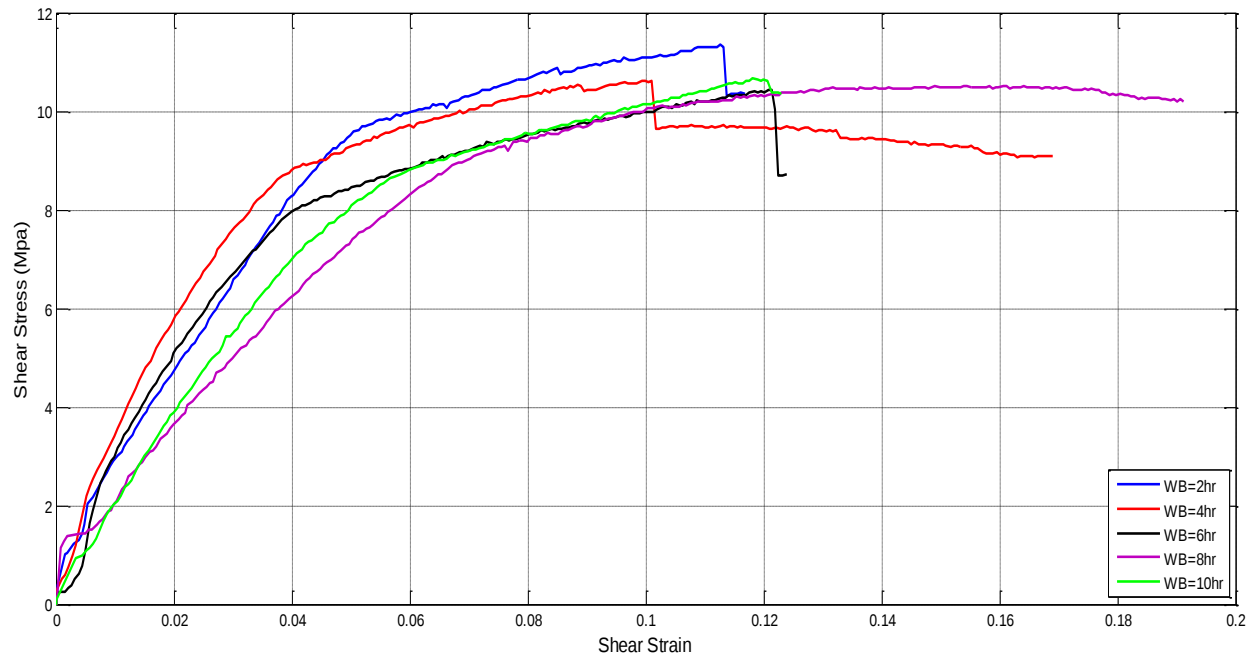


Fig.4.3 Stress Vs Strain Curve plot for water bath duration (hr) as parameter

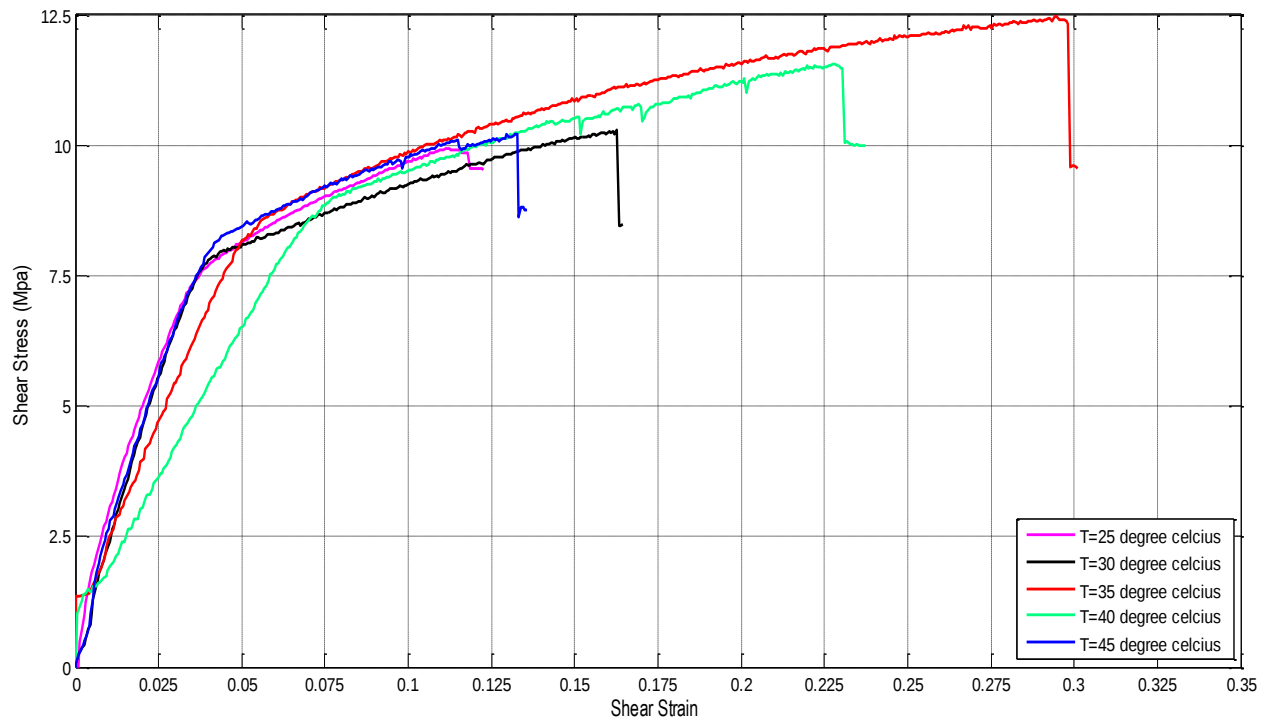


Fig.4.4 Stress Vs Strain Curve plot for temperature (°C) as parameter

C. Comparison of the effect of adhesive thickness on shear strength adhesively bonded single strap joint.

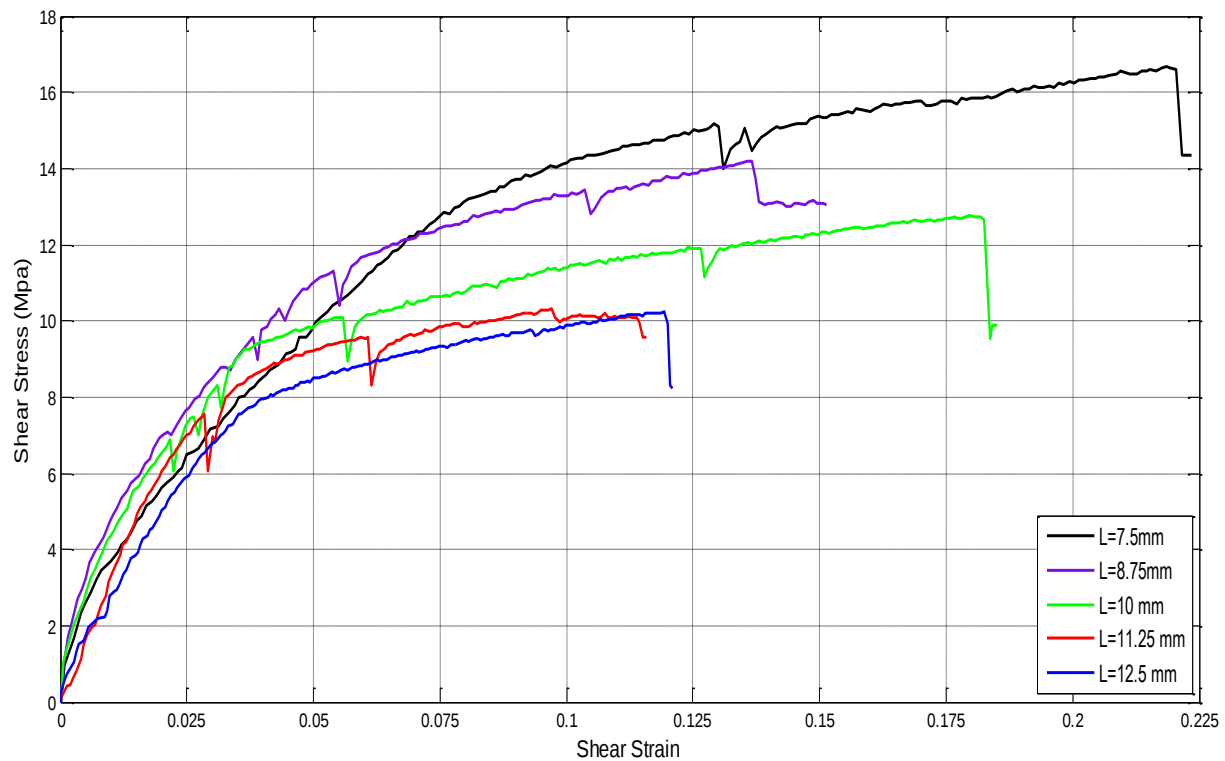
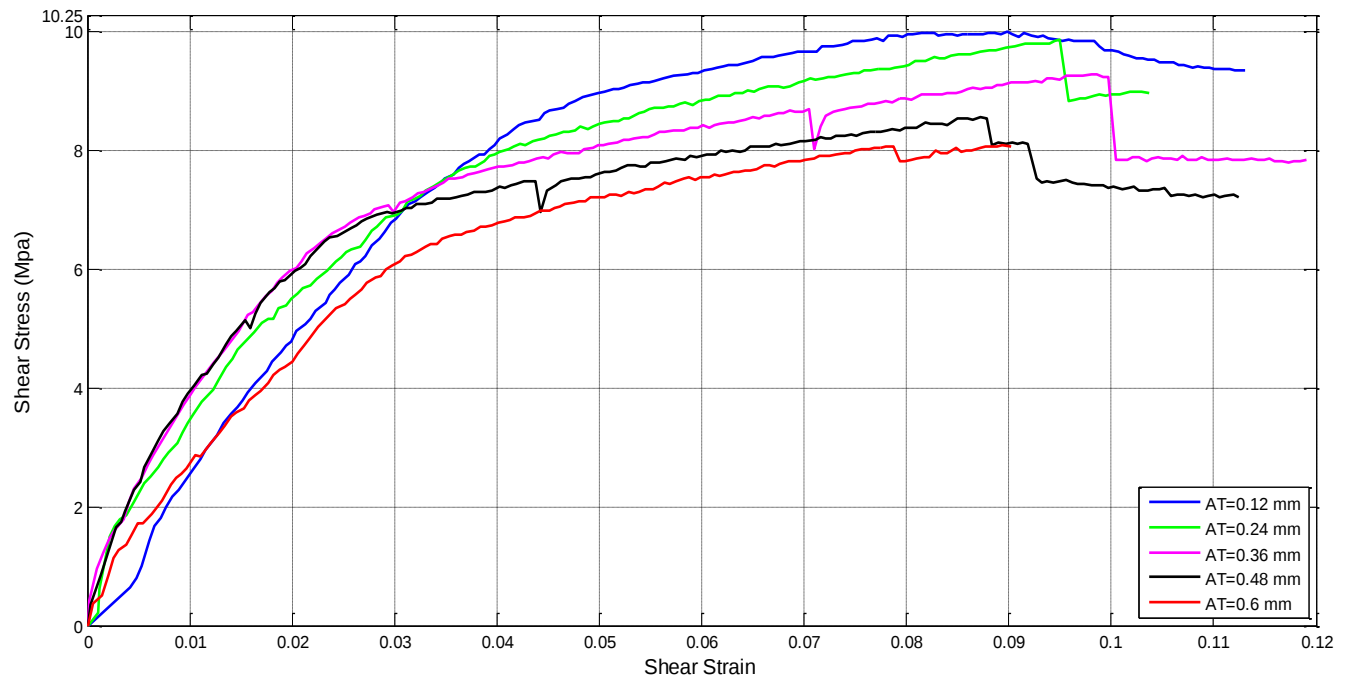
Keeping other geometric parameters constant and varying the adhesive thickness, the adhesively bonded single strap joint were exposed to shear loading. Fig.4.5 depicts the Stress Vs Strain Curve plot.

D. Comparison of the effect of overlap length on shear strength adhesively bonded single strap joint.

Keeping other geometric parameters constant and increasing the overlap length or the shear area along the shear load axis, the adhesively bonded single strap joint were exposed to shear loading. Fig.4.6 depicts the Stress Vs Strain Curve plot of the joint of different overlap length (mm) or corresponding shear area (not shown here. See appendix B, table B.3).

E. Comparison of the effect of overlap width on shear strength adhesively bonded single strap joint.

Keeping other geometric parameters constant and increasing the overlap width or the shear area orthogonal to the shear load axis, the adhesively bonded single strap joint were exposed to shear loading. Fig.4.7 depicts the Stress Vs Strain Curve plot of the joint of different overlap width (mm) and corresponding shear area (not shown here. See appendix B, table B.3).



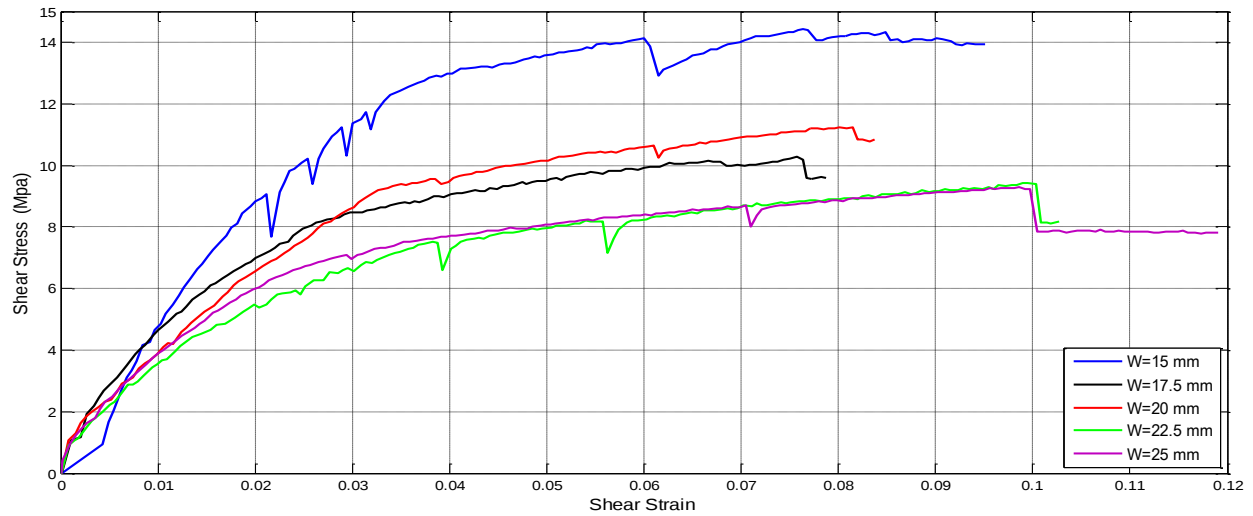


Fig.4.7 Stress Vs Strain Curve plot for overlap width (mm) as parameter

F. Comparison of the effect of surface finish on shear strength adhesively bonded single strap joint.

Keeping other geometric parameters constant and varying the surface finish, the adhesively bonded single strap joint were exposed to shear loading. Fig.4.8 depicts the Stress Vs Strain Curve plot of the joint of different surface finish as a function of sand grade.

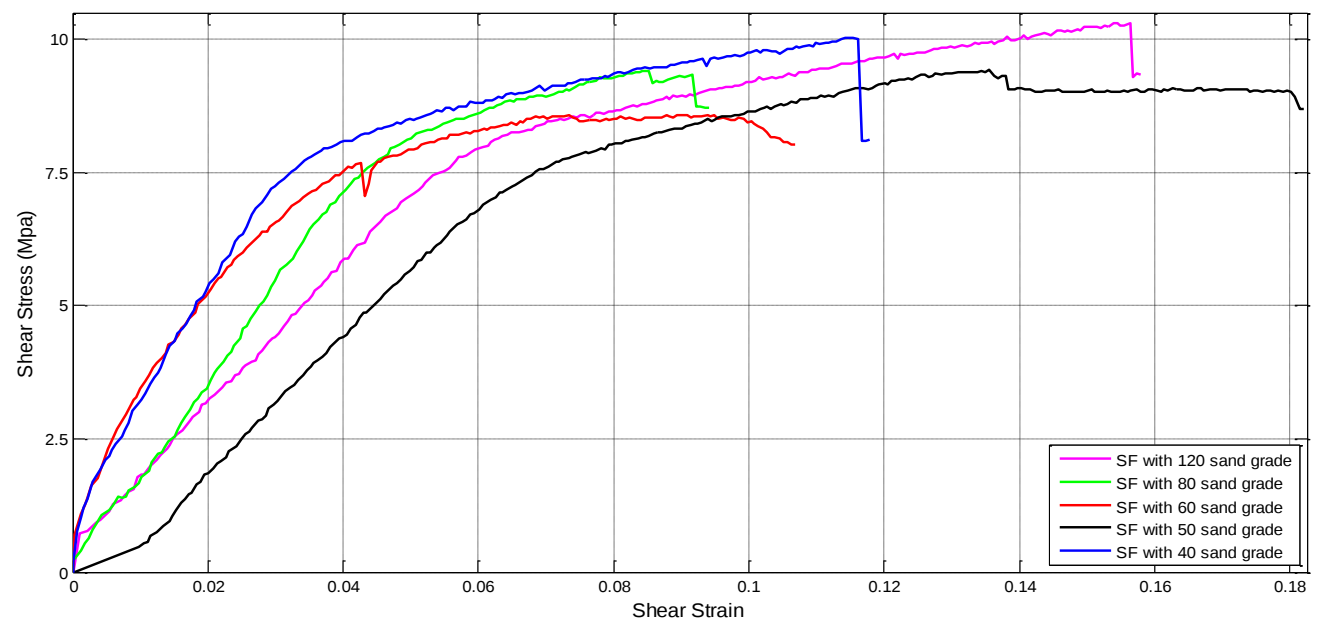


Fig.4.8 Stress Vs Strain Curve plot for surface finish as a sand grade as parameter

4.2 Discussion

4.2.1 Chemical Composition of The Matrix

Thanks to those manufacturers who stamp Standard Class and Recycleability Symbol on plastic products, We can differentiate varieties of plastics products around Us. However, knowing the detail chemical compositions, some added chemicals (additives) that are incorporated to modify or add certain specific properties of plastic products, is given consideration. Because, the matrix chemical compositions is used as guide in selecting the type of the reinforcement. That is why the study of the detail chemical compositions of the matrix is done to select the chemically and thermally compatible fiber over a long period. According to the test result, the chemical composition of matrix is verified to be high density polyethylene using Spectroscopy Attenuated Total Reflectance (ATR) analysis, that agrees with the Standard Class, HDPE, and Recyclability symbol, 2. So, there is no manifestation of chemicals (additives) that are incorporated. (See appendix A)

4.2.2 Density of the URP and RP

For the same manufacturing conditions and thickness, when the recycled HDPE product, edible oil jerycans, is reinforced the density is increased from 0.96 g/cc to 1.1 g/cc, i.e. by 12.73 %, due to the high density of the fiber. (See table 3.6) This increase seems divert from the development of the light weight material. But not, it is still lighter than steel (7.55 to 8.05 g/cc), aluminum (2.7 g/cc) and other polymeric composites (1.7 to 1.9 g/cc). [4]

4.2.3 Strength of URP and RP under Uni-axial loading

Improved strength, fatigue resistance, Young`s modulus, and strength to weight ratio are provided in most fiber reinforced composites by incorporating strong, stiff, but brittle fibers into a softer, more ductile matrix. The matrix material transmits the force to the fibers, which carry most of the applied force. The matrix also provides protection for the fiber surface and minimizes diffusion of species such as oxygen or moisture that can degrade the mechanical properties of fibers. The strength of the composite may be high at both room temperature and elevated temperatures.

Seemingly, for the same manufacturing conditions and thickness, when the recycled HDPE product, edible oil jerycans, is reinforced there are improvements in the following properties as depicted by fig.4.9

- Maximum yield shear strain increased by 20.94%.
- Maximum failures shear strain increased by 45.57%.
- Yield stress is increased by 11.28 %.
- Ultimate stress is increased by 46.75 % and
- Elastic Modulus is increased by 41.54 % all due to the corresponding high value of the fiber.

But, as compared to the properties of typical reinforced HDPE given in table 4.1 below, again there is a need to improve the tensile property of this composite.

Also, as shown on fig. 4.1, for the axial strain in between 0.0125 and 0.035 the URP can support higher load than the Rp under the same elongation. But, almost above 0.035 strain the URP can not withstand any load while the RP can withstand the load under which URP fails and greater.

Table 4.1 The property of typical glass fiber filled/reinforced HDPE [33]

Physical Properties	Average values
Density (g/cc)	1.16
Filler content (%)	25.7
Water absorption (%)	0.0786
Linear mold shrinkage (cm/cm)	0.00618
Linear mold shrinkage, Transverse (cm/cm)	0.00833
Melt flow (g/10min)	3.74
Mechanical properties	-
Hardness, Rockwell R	74.3
Tensile strength, Ultimate (Mpa)	46.2
Tensile strength, Yield (Mpa)	45.3
Elongation at break (%)	9.13
Elongation at Yield (%)	2.75
Modulus of Elasticity (Gpa)	4.58
Flexural yield strength (Mpa)	66.0
Flexural Modulus (Gpa)	3.77
Compressive Yield (Mpa)	32.2
Izod Impact Notched (J/cm)	1.08

4.2.4 Failure Modes of the tensile test specimens

4.2.4

The following respective failure modes have appeared after the tensile tests for both RP and URP were conducted.

The fig.4.10 shows the pictures of URP (a) and RP (b) that have failed under uni-axial loading. Here some encircled black to show the delamination of the composite, green to show accepted failure regions and red to show unaccepted failure regions by ASTM standard. As shown here, most of the tensile test specimens have failed at accepted failure regions and some are failed at unaccepted failure regions. As seen visually, those failed at unaccepted failure regions are due to created stress concentrations of indentation of band saw machine blade in to the specimens body. And, the case of delamination also appeared due to uneven pressure distribution during manufacturing of the composite.

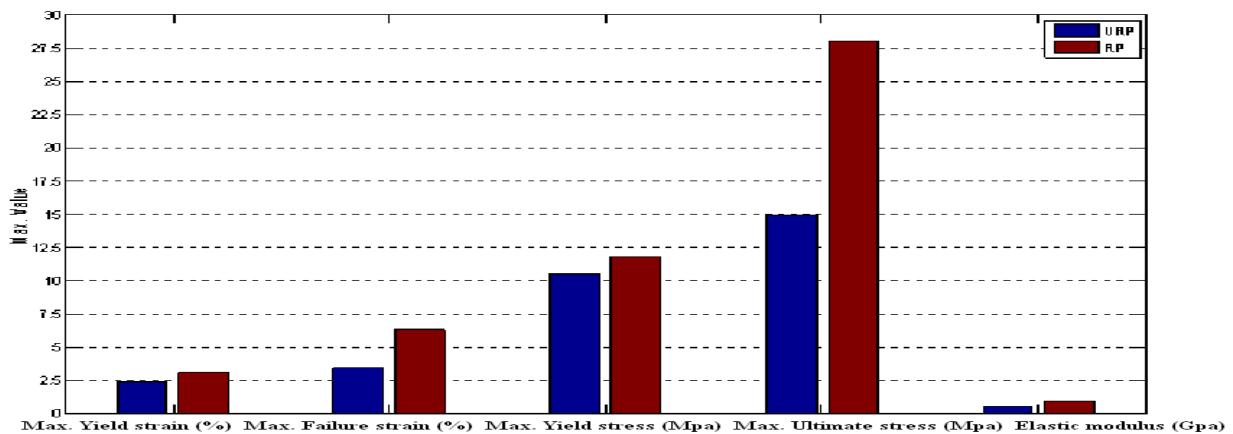


Fig. 4.9 Comparison of the strength of URP and RP under Uni-axial loading



Fig.4.10 The failure modes of URP (a) and RP (b) under uni-axial loading

4.2.5 Fiber to matrix weight ratio of RHDPE (RP)

Also, as shown on fig. 4.11 below, RP of fiber to matrix weight ratio of 48.7 % can support highest load both at the yield and failure for the same elongation. While, RP of fiber to matrix weight ratio of 42.4% follows it. As noticed again, the RP of fiber to matrix weight ratio of 34.6% support higher load than that of 29.2% allowing larger elongation. And as fiber to matrix weight ratio increases from 29.2% to 34.6% both the maximum yield shear strain and the maximum failure shear strain increases while the maximum yield shear stress and maximum ultimate shear stress remains somewhat constant. But from 42.4% to 79.25 both the maximum yield shear strain and the maximum failure shear strain while the maximum yield shear stress and maximum ultimate shear stress shows decreasing trend.

4.2.6 Effect of Water bath duration (Moisture) on shear strength of the joint

By varying the water bath duration, the adhesively bonded single strap joint were exposed to shear loading. Fig.4.12 shows that the joint can support maximum and minimum shear load after 2 hours and 8hours water bath duration respectively. As the joint exposure to moisture increases from 2-8 hours, the yield shear strain, yield shear stress and ultimate shear stress decreases. And after 9 hours they show gradual increase. But, further increase beyond 9 hours decreases both the yield and failure shear strain while the yield and ultimate shear stress remains fairly constant. The maximum failure shear strain is obtained at 9 hours while the minimum is at 6hours. As compare to room moisture (see fig.4.13 below at 25 °C), the exposure to more moisture increases both the yield and ultimate shear stress, and the yield and failure shear strain.

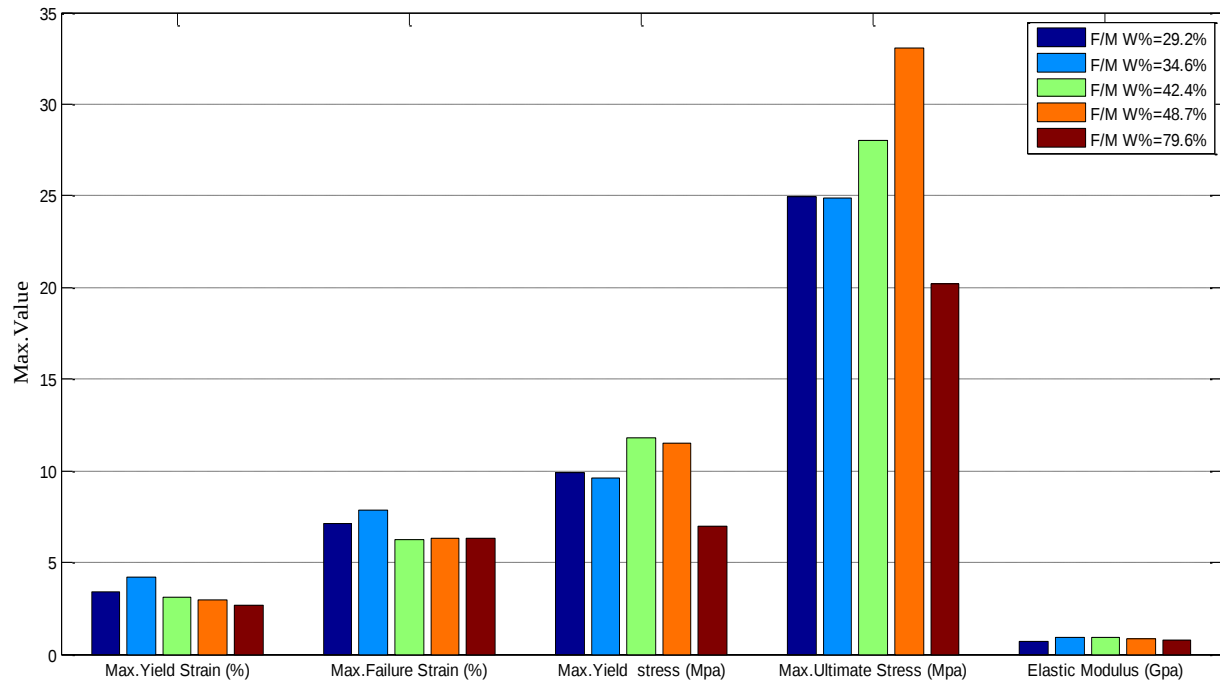


Fig.4.11 Comparison of the effect of fiber to matrix weight ratio on strength of RP under Uni-axial loading

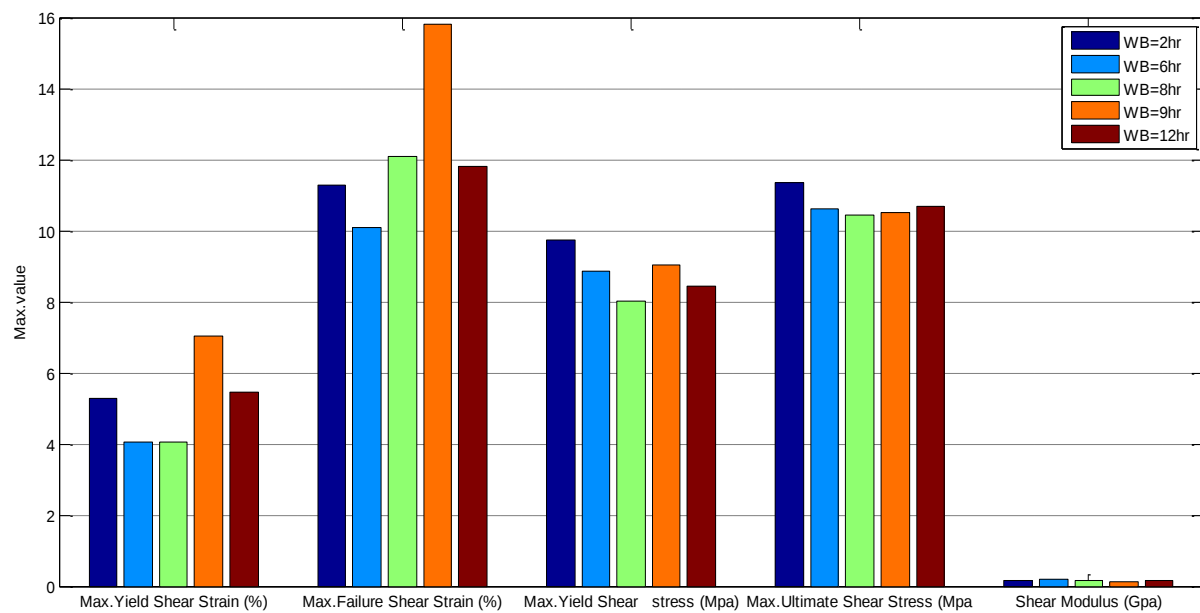


Fig.4.12 Comparison of the effect of water bath duration (moisture) on shear strength adhesively bonded single strap joint

4.2.7 Effect of Heat/Temperature on shear strength of the joint

By varying the temperature, the adhesively bonded single strap joint were exposed to shear loading. As depicted by fig.4.13, both the yield shear strain and stress increases as the joint exposure to temperature increase to 40 °C, after which it decreases. While both the failure shear strain and ultimate shear stress increases up to 35 °C, after which it decreases. And the maximum yield shear strain and stress, and maximum failure shear strain and ultimate shear stress are seen at 40 °C and 35 °C temperature respectively. This result agrees with the manufacture's data sheet of the adhesive for which sandblasted and degreases aluminum that cures for 16 hours at 40 °C have maximum lap shear strength at 35 °C [33].

4.2.8 Effect of Adhesive Thickness on shear strength of the joint

By varying the adhesive thickness, the adhesively bonded single strap joint were exposed to shear loading. Fig.4.14 shows that As adhesive thickness increases from 0.12mm to 0.48mm the maximum yield shear strain, yield shear stress and ultimate shear stress decreases. While the maximum failure shear strain increases as adhesive thickness increases from 0.12m to 0.36mm. and the maximum failure shear strain and ultimate shear stress are seen at 0.6mm. What is observed from the decreasing trend is that the joint can support maximum shear load at 0.12mm adhesive thickness.

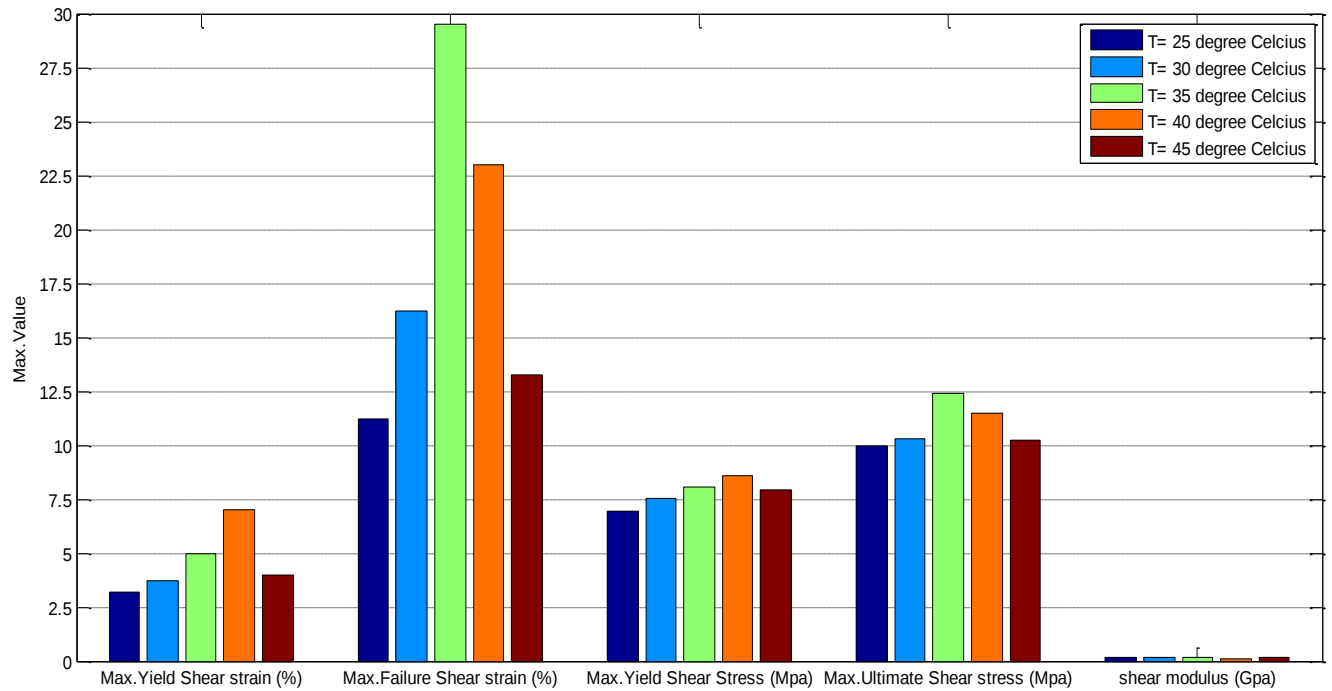


Fig.4.13 Comparison of the effect of temperature ($^{\circ}$ c) on shear strength adhesively bonded single strap joint.

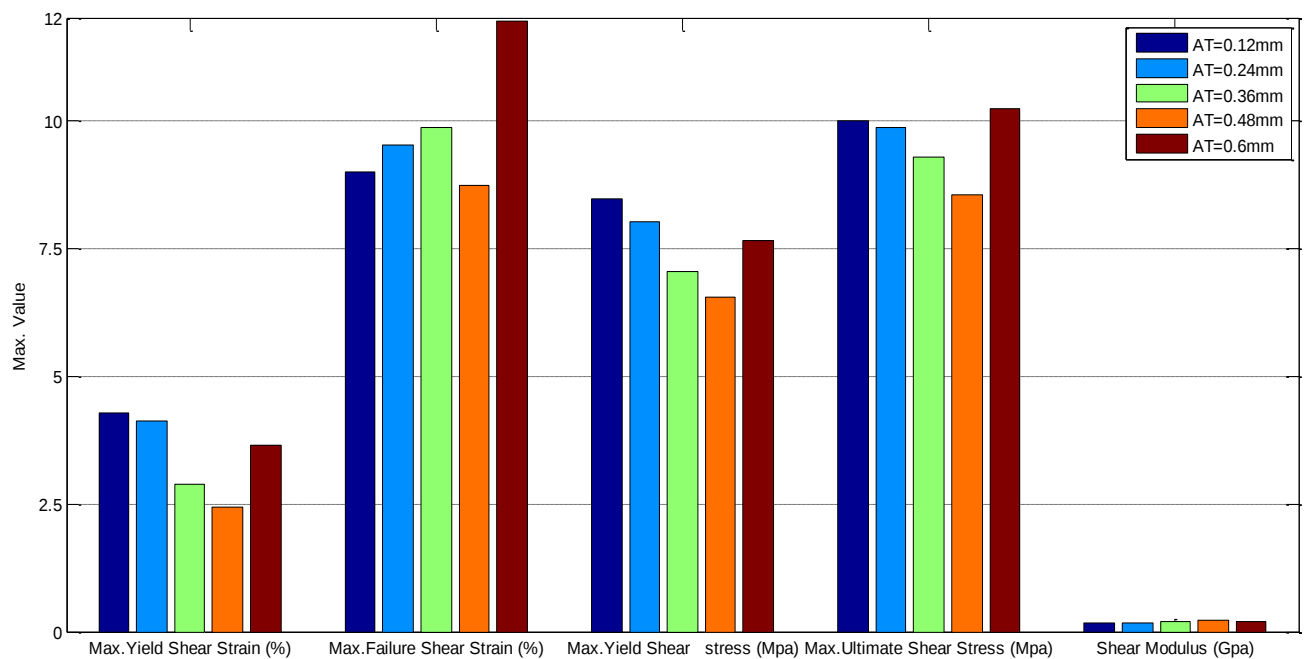


Fig.4.14 Comparison of the effect of adhesive thickness (mm) on shear strength adhesively bonded single strap joint.

4.2.9 Effect of Overlap Length on shear strength of the joint

By increasing the overlap length or the shear area along the shear load axis, the adhesively bonded single strap joint were exposed to shear loading. Fig.4.15 shows that as the overlap length increases from 7.5mm to 11.25 mm maximum yield shear strain, failure shear strain, yield shear stress and ultimate shear stress decreases, and the maximum value is noticed at 7.5mm.

4.2.10 Effect of Overlap Width on shear strength of the joint

By increasing the overlap width or the shear area orthogonal to the shear load axis, the adhesively bonded single strap joint were exposed to shear loading. Fig.4.16 shows as the overlap width increases from 15mm to 22.5 mm maximum yield shear strain and maximum failure shear strain increases, and the maximum value is noticed at 22.5mm. While maximum yield shear stress and ultimate shear stress decreases over this range, and the maximum value is noticed at 15mm.

4.2.11 Effect of Surface Finish on shear strength of the joint

By varying the surface finish, the adhesively bonded single strap joint were exposed to shear loading. Fig.4.17 shows that as the surface roughness increases both the maximum yield shear strain and stress shows decreasing trend while both the maximum failure shear strain and ultimate shear stress shows the decreasing trend only for some extent, after which it increases. And the joint supports maximum shear load for the roughness that is provided by the sand paper of grade 120 i.e. the sand paper of smallest average grit diameter.

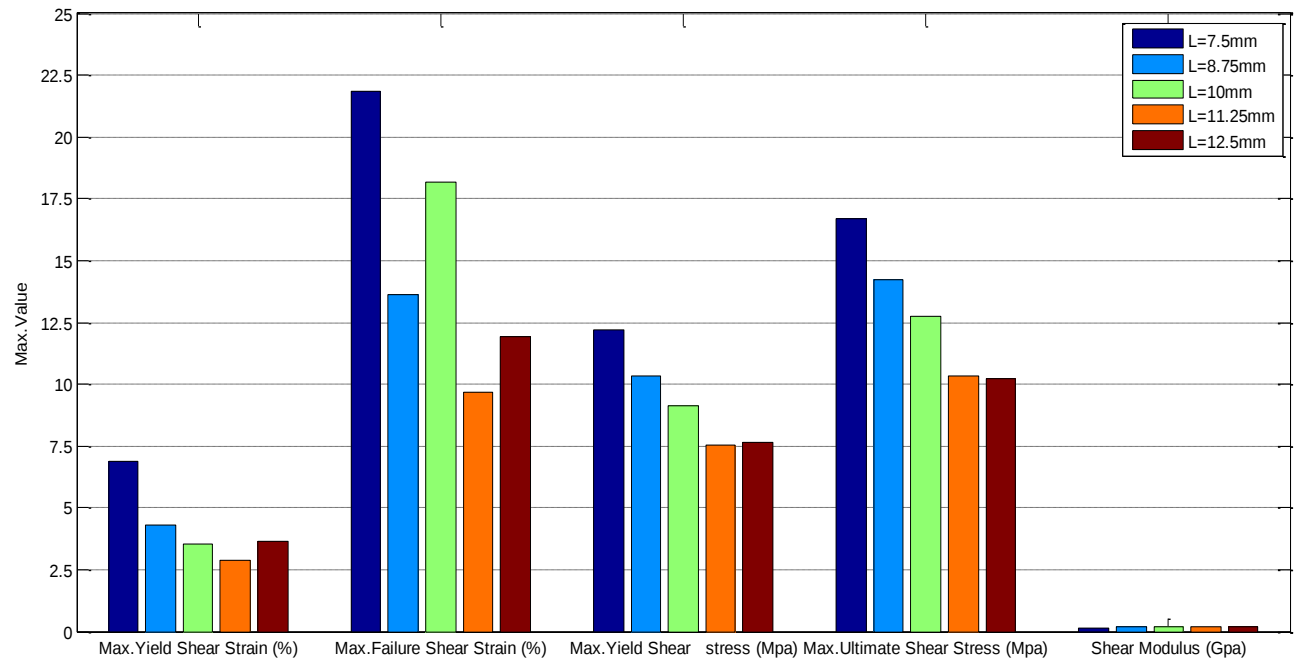


Fig.4.15 Comparison of the effect of overlap length (mm) on shear strength adhesively bonded single strap joint.

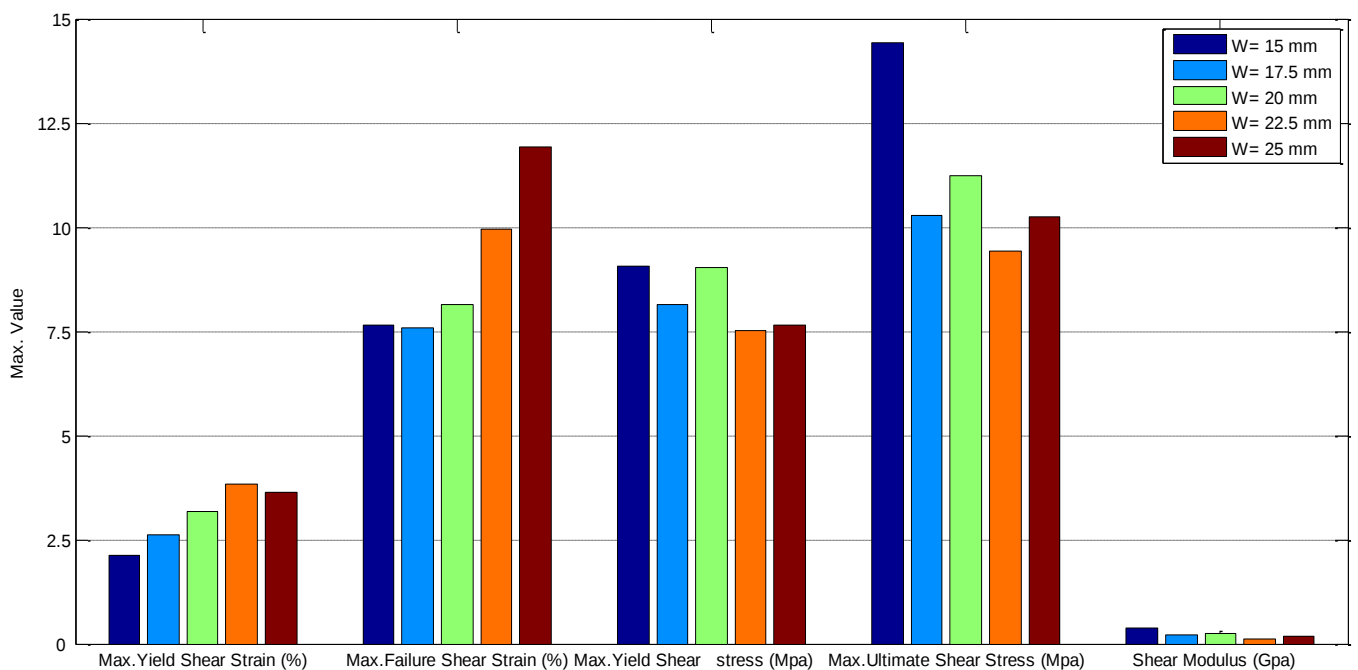


Fig.4.16 Comparison of the effect of overlap width (mm) on shear strength adhesively bonded single strap joint.

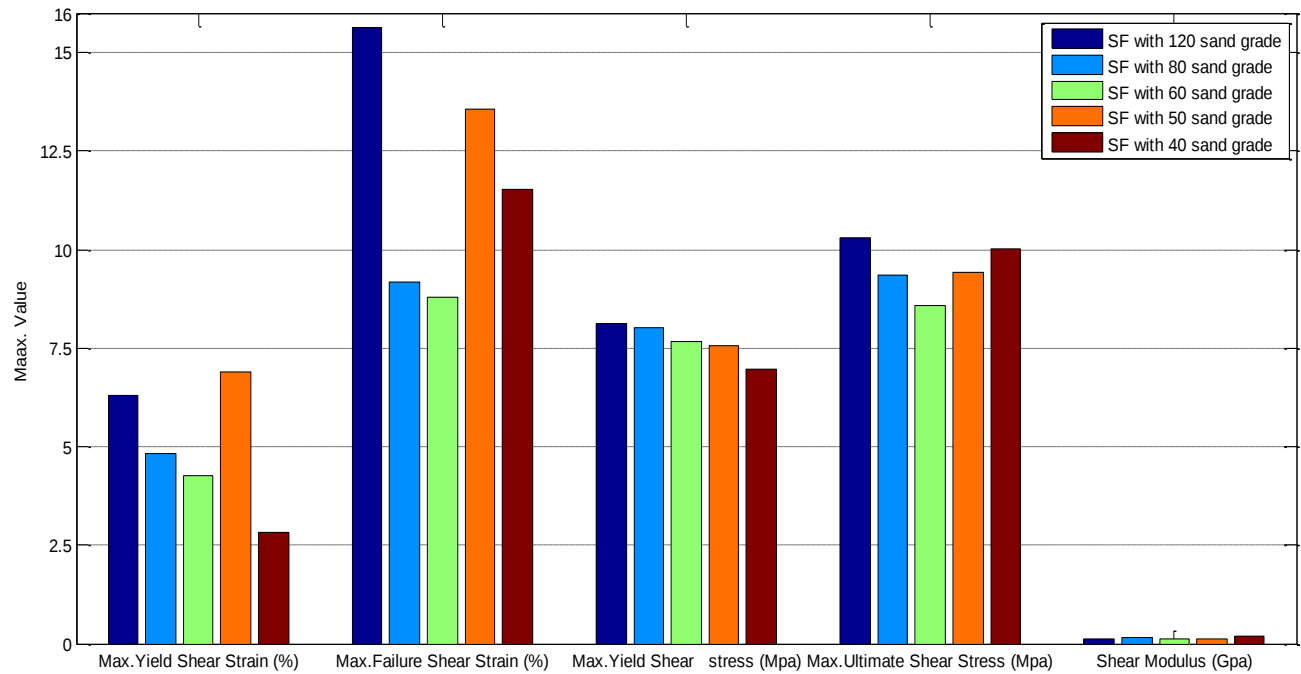


Fig.4.17 Comparison of the surface finish on shear strength adhesively bonded single strap joint.

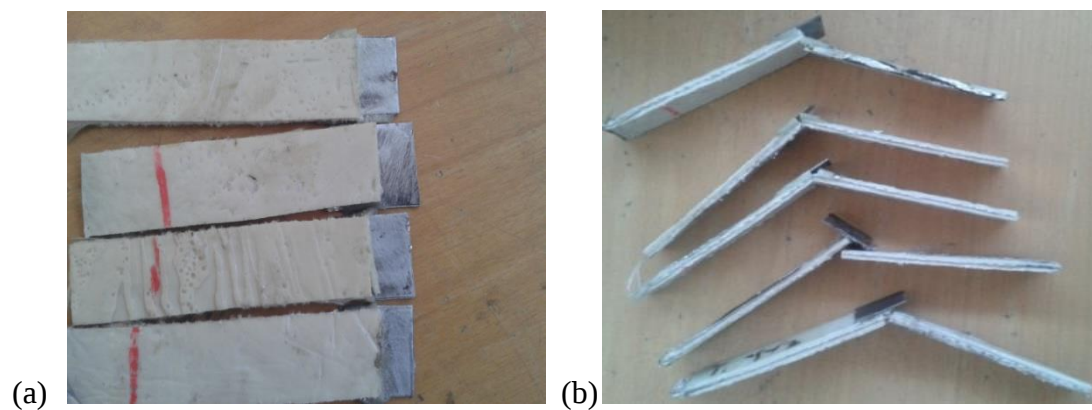


Fig.4.18 The failure modes of adhesively bonded single strap joint under shear loading

4.2.12 Failure Modes of the shear test specimens

Also, as shown by above fig.4.18, almost the entire adhesively bonded single strap joint have failed under shear loading in the same fashion, the separation at the adhesive-strap interface i.e. adhesive failure (sometimes referred to as interfacial failure). [26] And, it was observed that almost all separation at the adhesive-substrate interface is not noticed i.e. as opposed to the fear to use this adhesive for low surface energy plastic such as HDPE, the adhesive bonds strongly to

the substrate than the strap. This increase in adhesion to the composite is either due to enhanced surface treatment than that of the strap or the effect of more offset of the lap shear area from the shear load axis.

4.2.13 Average lap shear strength of the adhesively bonded joint

The average lap shear strength (among similar substrates) of typical joints of some common materials is depicted on fig. 4.19, those cured for 16 hrs at 40 °C and tested at 23 °C. The pre-treatment used is abrasion followed by degreasing and sand blasting followed by degreasing for plastic and metals respectively. But, the joint used in this study is cured for 72 hrs at room temperature and tested at room temperature. The pre-treatment used is sand abrasion and degreasing for both metal strap and reinforced plastic. As seen from the stress-strain curve plot of adhesively bonded joint for all the parameters, the average lap shear strength of this joint is 10 Mpa. Ignoring the effect of curing temperature and duration this average lap shear strength is greater than that of ABS and PVC. But, these two plastics have higher surface energy than HDPE. This happened possibly because of as HDPE is recycled and reinforced its surface energy is increased. Again, the depth of surface treatment also have its own influence. This result shows that the effect of the surface parameters of the substrate material in varying the lap shear strength is noticeable.

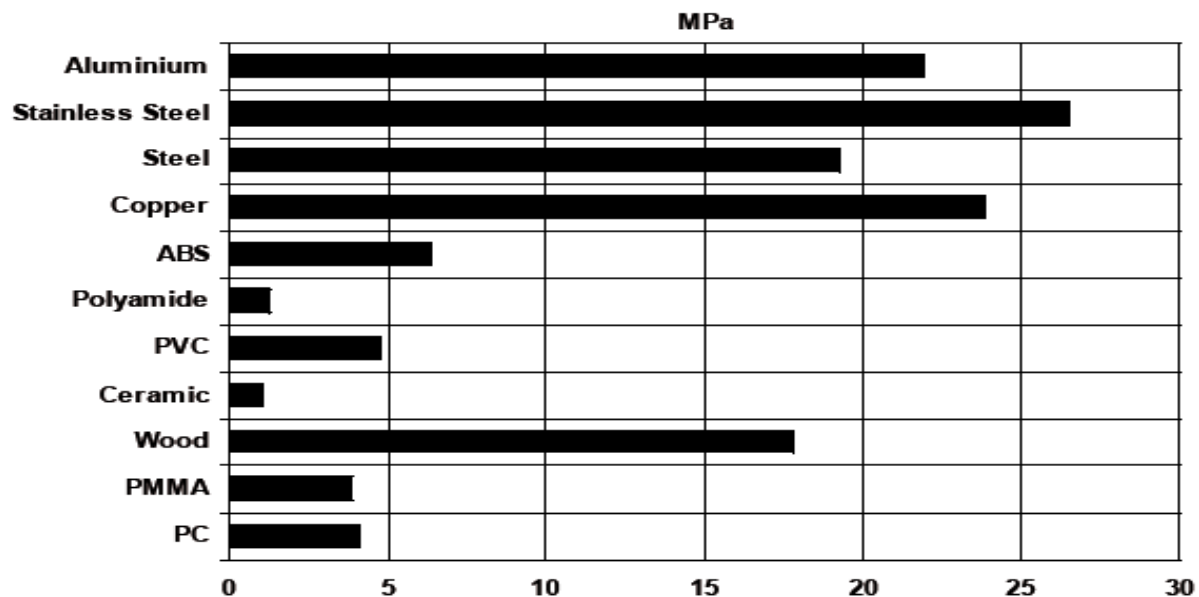


Fig.4.19 Average lap shear strength of typical joints of some common substrate materials [31]

4.2.14 Significance of Test Results

As seen from the test results, these results are significant in:

- Contributing to the improvement of the locally built automotive body in reducing the weight.
- Enabling the designers to design light weight automotive body and predict the static strength of its adhesively bonded joint.
- Using as stepping board for those interested in manufacturing the thermoplastic composite in such manner for both academic and commercial purposes.
- Creating awareness's about recycling and reuse of thermoplastic products that are abundantly available.
- Unlocking the dependency of local car body work on fasteners and welding which in turn increases assembly rate, and
- Solving a challenge on the strength prediction of the adhesive bonded single strap joint.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The matrix used for this study is verified to be high density polyethylene (HDPE) using Spectroscopy Attenuated Total Reflectance (ATR) analysis. Woven E-glass fiber which is compatible with it and that can allow through penetration of this high viscous matrix is used. Reinforced HDPE was manufactured by injection molding. And, adhesively bonded single strap joint was manufactured using reinforced HDPE as substrate, mild steel as strap and Araldite ® Rapid: Two components fast curing adhesive as adhesive.

Reinforcing HDPE with the woven E-glass fiber improves its ultimate tensile stress by 46.7 %. Under the same elongations for lower loads, HDPE supports higher axial load than the reinforced HDPE. Reinforced HDPE of fiber to matrix ratio of 48.7% ($\approx 50\%$) has highest ultimate tensile stress of 32.5 Mpa. Thus, fiber to matrix ratio is known to be one of the factors that determines the tensile strength of reinforced HDPE. So, this reinforced plastic can be used as automotive side panel after the justification that will be made by the future works.

Comparatively, the adhesively bonded single strap joint developed for this research has higher shear strength with adhesive thickness of 0.12 mm, overlap length of 7.5 mm, overlap width of 15 mm and surface roughness that is provided by sand grade 120 at 2hrs water bath, and 35 °C temperature. It is seen also that it is the surface parameters of the substrate material that matters in varying the lap shear strength of the joint than the substrate material itself.

The shear strength of these joint decreases as surface roughness, overlap length, overlap width and adhesive thickness increases. And, the exposure of this joint to moisture increases its shear strength to some level after which it decreases and remains constant. While its exposure to temperature increases its shear strength to some level after which it decreases.

These results showed that the composite is light enough to substitute other body materials. And, the stress and strain distributions for the joint configurations are more sensitive to changes in adhesive thickness, overlap length, overlap width and surface finish.

5.2 Recommendation

The following recommendations are derived:

- For normal working conditions, the automotive side panel should withstand against the load that is transferred to it by the automotive body frame, the wind drag force and the wind pressure.
- Frankly speaking, the side panel, especially, should withstand against both tensile and bending loading.
- The surface to be bonded with the adhesive should be treated properly with the correct surface treatment before the applying the adhesive.
- During manufacturing the sandwich in the furnace, it should be exposed to equal amount of temperature in all direction to obtain sandwich of uniform property.
- Both the sandwich and the bond should be subjected to even pressure distribution to come up with uniform thickness.
- Before development of the joint, both the hardener and the resin should be mixed equally, according to the manufactures specification.
- Also, correct curing and polymerization duration of an adhesive should be respected
- The standard Universal Testing Machine that is suitable for testing adhesively bonded joint should be used since some compressive force was observed during gripping of the test specimen by the machine used for this research.
- The environmental conditions should be set stable at all during manufacturing of the joint.

5.3 Future work

The following studies should be conducted in the future depending on their importance.

- Both the numerical and experimental studies of adhesively bonded single strap joint, where both the strap and the substrates are of the same material .i.e. woven e-glass reinforced recycled HDPE that will be used for maintenance purpose.
- The numerical studies of adhesively bonded single strap joint that is used for this study.
- The flexural, shear and compressive tests of woven e-glass reinforced recycled HDPE
- The characterization of natural fibers in Ethiopia reinforced recycled HDPE.
- Applications of different adhesives other than Araldite Rapid and surface treatment techniques other than sand abrasion on the join of this study for comparison purpose
- Investigation of effect of addition of virgin HDPE to the recycled HDPE on the strength of woven e-glass reinforced recycled HDPE
- Field tests or laboratory tests of both the material and the joint used in this study on the prototype
- Determinations of effect of fiber orientations and number of sandwich layers on the property of woven e-glass reinforced recycled HDPE
- Exposure of the joint to elevated/lower temperature and long water bath duration other than those stated in this research to further investigate the effects.

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Appendix A: Chemical composition of cooking oil jerycans plastic (Thanks to Elena Verna again. This Test is done by her.)

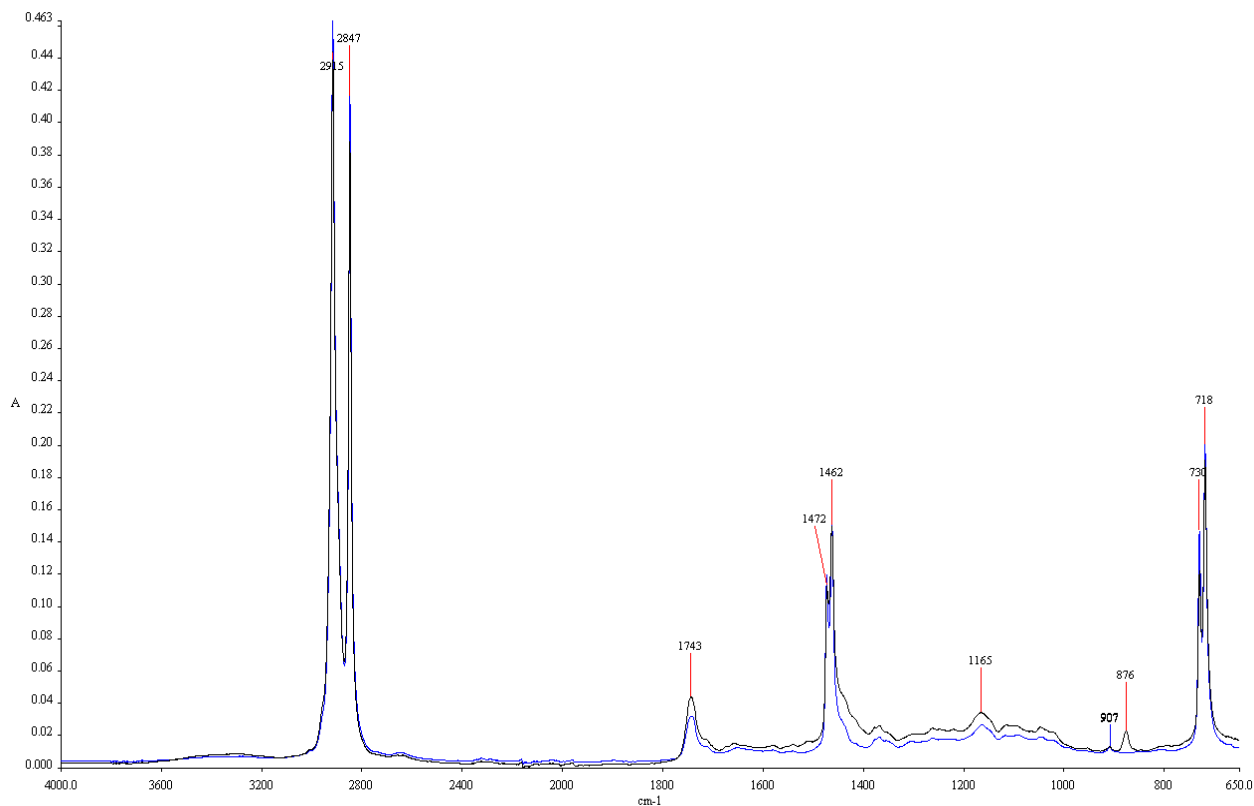


Fig. A.1 The stretching vibration amplitude by Perkin Elmer Spectrum 100.16 scans between 650-4000 cm^{-1} of both sides of HDPE jerycans plastic

In order to verify the chemical composition of this sample, Spectroscopy Attenuated Total Reflectance (ATR) analysis was used. Test was performed at the two surfaces of the sample. The ATR spectroscopy shows the typical spectral results expected for high density polyethylene.

The black spectrum correspond to the darker yellow side of the sample, while the blue one refers to the opposite side, that appears higher yellow.

Peaks between 2600 and 3000 cm^{-1} are associated with the methylene C-H stretching vibrations; the methylene deformations appear at 1,462 and 718 cm^{-1} .

Due to the crystallinity of polyethylene, the 1,462 and 719 cm^{-1} peaks are split, and additional peaks are seen at 1,472 and 730 cm^{-1} . The sharp peak at 730 cm^{-1} corresponded to the C-H deformations (rocking). The stretching of -C=O- bond could be seen at 1743 cm^{-1} .

The 1165 cm^{-1} band is attributed to CH_3 absorption peak. The peak at 909 cm^{-1} is peculiar of HDPE spectrum and refers to vinyl end groups.

The signal at 1350 cm^{-1} isn't so visible and refers to a few CH_3 terminal groups.

The 876 cm^{-1} peak isn't present on light yellow side, and is not typical of polyethylene, probably it refers to a detachment agent, stretching along link.

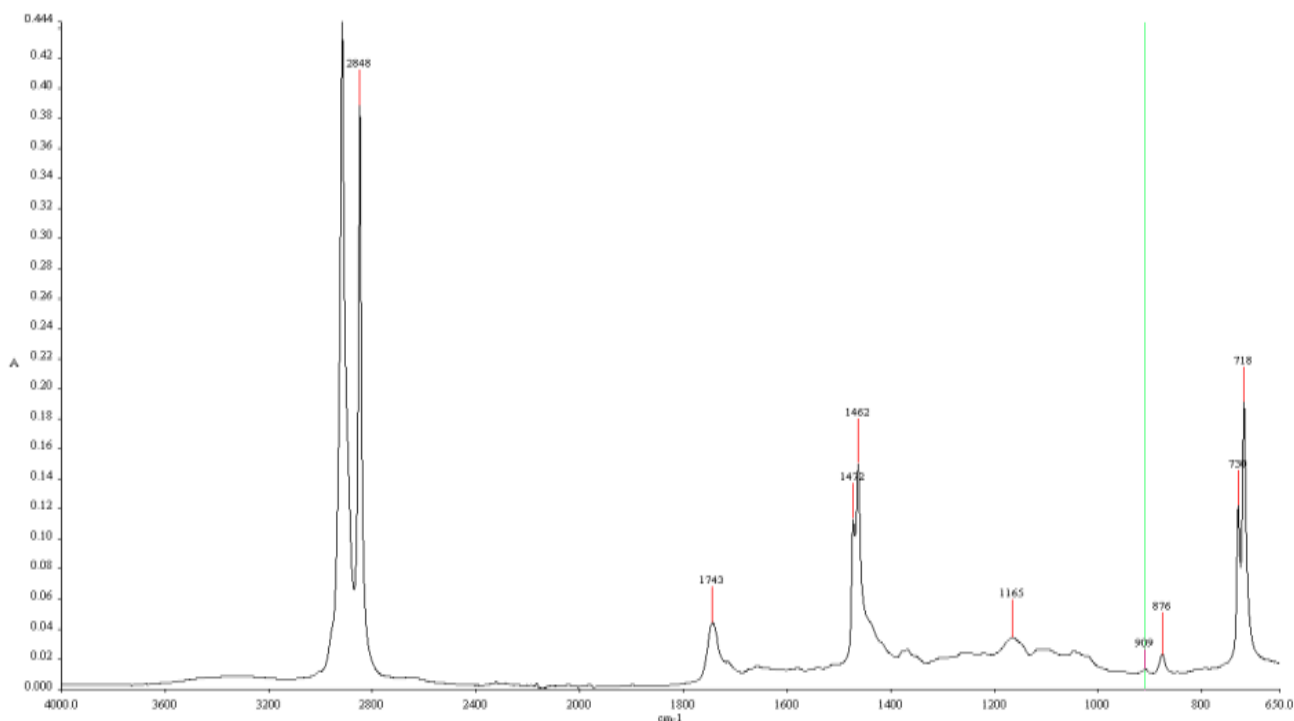


Fig. A.2 The stretching vibration amplitude by Perkin Elmer Spectrum 100.16 scans between 650-4000 cm^{-1} of Dark yellow side of HDPE jerycans

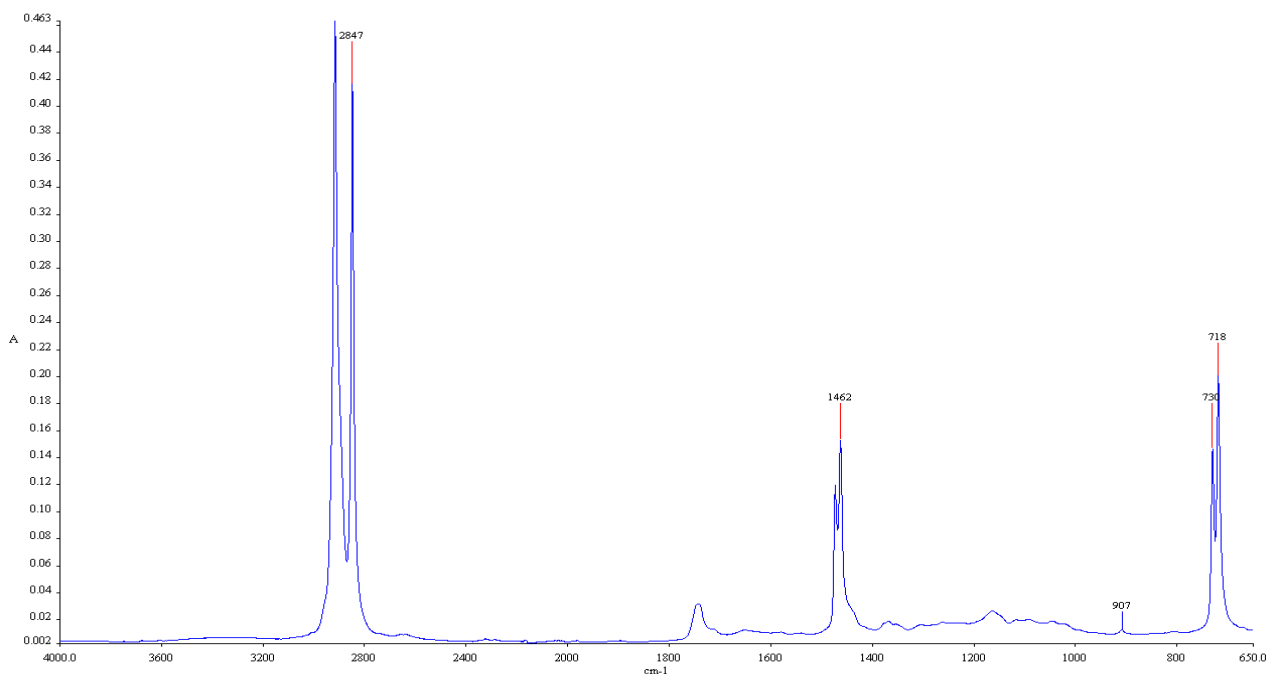


Fig. A.3 The stretching vibration amplitude by Perkin Elmer Spectrum 100.16 scans between 650-4000 cm^{-1} of Light yellow side of HDPE jerycans

Appendices –B: Geometries of the test specimen Samples

Table B.1 Test parameters, samples designations and geometries of the test specimens for tensile test of unreinforced plastic

N _o	Test parameter	Samples designations	Gauge length (mm)	Width (mm)	Thickness (mm)	Cross-sectional Area (mm^2)
1	Tensile strength	URT1	95	13	2.4	31.2
		URT2	95	13	3	39
		URT3	95	13	3.6	46.8
		URT4	95	13	3.8	49.4
		URT5	95	13	4.2	54.6

Table B.2 Test parameters, samples designations and geometries of the test specimens for tensile test of reinforced plastic

N _o	Test parameter	Samples designations	Gauge length (mm)	Width (mm)	Thickness (mm)	Cross-sectional Area (mm ²)
1	Tensile strength	RT1	95	13	2.2	28.6
		RT2	95	13	3.2	41.6
		RT3	95	13	3.6	46.8
		RT4	95	13	4.3	55.9
		RT5	95	13	5	65

Table B.3: Test parameters, samples designations, Sample values and geometries of the test specimens for shear test of the adhesively

N _o	Test parameters	Samples designations	Sample values	Gauge length (mm)	Adhesive thickness (mm)	Overlap length (mm)	Overlap width (mm)	Apparent Shear Area of contact (mm ²)
1	Surface finish as function of sand grade	SF1	120	12.5	0.48	12.5	25	312.5
		SF2	80	12.5	0.48	12.5	25	312.5
		SF3	60	12.5	0.48	12.5	25	312.5
		SF4	50	12.5	0.48	12.5	25	312.5
		SF5	40	12.5	0.48	12.5	25	312.5
2	Temperature (C ^o)	T1	25	12.5	0.48	12.5	25	312.5
		T2	30	12.5	0.48	12.5	25	312.5
		T3	35	12.5	0.48	12.5	25	312.5
		T4	40	12.5	0.48	12.5	25	312.5
		T5	45	12.5	0.48	12.5	25	312.5
3	Moisture/ water bath duration (Hr)	M1	2	12.5	0.48	12.5	25	312.5
		M2	4	12.5	0.48	12.5	25	312.5
		M3	6	12.5	0.48	12.5	25	312.5
		M4	9	12.5	0.48	12.5	25	312.5
		M5	12	12.5	0.48	12.5	25	312.5
4	Adhesive thickness (mm)	t1	0.12	12.5	0.12	12.5	25	312.5
		t2	0.24	12.5	0.24	12.5	25	312.5
		t3	0.36	12.5	0.36	12.5	25	312.5
		t4	0.48	12.5	0.48	12.5	25	312.5
		t5	0.6	12.5	0.6	12.5	25	312.5
5	Overlap length (mm)	L1	7.5	7.5	0.36	7.5	25	187.5
		L2	8.75	8.75	0.36	8.75	25	218.75
		L3	10	10	0.36	10	25	250
		L4	11.25	11.25	0.36	11.25	25	281.25
		L5	12.5	12.5	0.36	12.5	25	312.5
6	Overlap Width (mm)	W1	15	12.5	0.36	12.5	15	187.5
		W2	17.5	12.5	0.36	12.5	17.5	218.75
		W3	20	12.5	0.36	12.5	20	250
		W4	22.5	12.5	0.36	12.5	22.5	281.25
		W5	25	12.5	0.36	12.5	25.4	317.5

bonded joint

