

**Analysis on Mechanical Properties of High-Density Polyethylene (HDPE) in
Aluminum Joining Process**

Submitted in partial fulfilment of the requirements for the award of a Bachelor of
Engineering degree In Mechanical Engineering By

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DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade “A” by NAAC 12B status by UGC I Approved by AICTE

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APRIL-2023



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DEPARTMENT OF MECHANICAL ENGINEERING
BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of **G. LAWRENCE** (39150072) who carried out the project entitled "**Analysis on Mechanical Properties of High-Density Polyethylene (HDPE) in Aluminum Joining Process**" under my supervision from December 2022 to MAY 2023.

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I G. LAWRENCE (39150072) hereby declare that the project report entitled “**Analysis on Mechanical Properties of High-Density Polyethylene (HDPE) in Aluminum joining process**” Done by me under the guidance of **Dr. V. Sivaprakash., M.E., Ph.D.,** is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree In Mechanical Engineering.

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PLACE: CHENNAI

A handwritten signature in black ink, appearing to read 'G. Lawrence', is positioned above the printed name.

1. LAWRENCE.G

SIGNATURE OF THE CANDIDATES

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to Board of Management of **SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my sincere thanks to **Dr. S. PRAKASH, M.E., PhD.**, Dean, School of Mechanical Engineering and **Dr. G. ARUNKUMAR, M.E., PhD.**, Head of the Department, Dept. of Mechanical Engineering for providing me necessary support and details at the right time during the progressive reviews.

I would like to express my sincere and deep sense of gratitude to my Project Guide **Dr. V. Sivaprakash, M.E, PhD.**, for his valuable guidance, suggestions, and constant encouragement paved way for the successful completion of my project work. I also express my thanks to all Teaching and Non-teaching staff members of the Department of Mechanical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

In recent days materials and their corrosion analysis are highly approached by researchers. Aluminium and its alloy materials are attracted by researchers for their superior properties like light weight and strength ratio. Orientation between two metal pieces is varied for each condition and the nano composite binding has been carried out under a constant load and temp. High density polyethylene (HDPE) is a material that is widely used in today's industrial and commercial products. HDPE has not only excellent tensile strength, but also high impact strength and high melting point. There is no doubt that plastic is very convenient. Still, the problem with plastic is that most of it is not biodegradable and takes 100 years to break down. In this research work, analysis of the Aluminium 6 series with High- density polyethylene sheet bonding. The deposition of high-density polymer nano composite on Aluminium which is used to highly encourage the tailor-made binding which is applicable in various fields. The purpose of this study is to analyze and compare the mechanical properties of HDPE binding strength with aluminum. This study uses tensile and Sem tests to demonstrate the lower mechanical properties of r HDPE compared to. All results therefore suggest that the HDPE should be supplemented with another fiber to strengthen the bond in aluminum joining process.

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CHAPTER 1

INTRODUCTION

1.1 Back ground study

Plastics have become an integral part of our modern lives, and over the last 50 years, global plastic production has increased significantly. This contributes significantly to the generation of plastic-related waste. In addition, plastics are widely used in a wide range of products due to their excellent properties such as high toughness, low density, ease of design and manufacture, high strength-to-weight ratio, and low cost. Today, polymer-type plastic products are used in almost all industries, especially in packaging, construction and infrastructure, automotive, electrical and electronic, agriculture, and other sectors.

High-density polyethylene (HDPE) is a common polymer widely used in today's industrial and commercial products due to its properties. HDPE has excellent tensile strength and also has high impact strength and high melting point. HDPE is also a thermoplastic type and can be melted and reformed into a solid state repeatedly. It is made by bonding ethylene molecules (that is, "poly" "ethylene") that are primarily obtained from US natural gas sources. To classify HDPE, look for the number 2 surrounded by an arrow printed on the daily bottle. Due to the many advantages of HDPE plastic, its production has increased significantly over the past decade, with more than half of that volume being wasted on his single-use, single-use consumer products, leading to plastic-related waste generation. contributes greatly to.

In addition, these forms of plastic are not biodegradable and no chemical reaction; therefore, these polymeric products have not broken down for decades, if not centuries. Therefore, plastic waste is considered a serious environmental problem. Since the use of plastic cannot be avoided, along with the development of new technologies, the problems posed by the increasing use of plastics, especially HDPE, must be sought for practical solutions. To achieve this, a study of HDPE waste is carried out to know its mechanical and chemical properties. The mechanical and chemical properties of this material will be studied and discussed in the following chapters.

1.2 OBJECTIVE:

The goals of this project are:

1. Make the HDPE material with high-quality binding between Al6 series.
2. Improve the quality of material attachment with load condition.
3. Involvement of temperature to make the material as high bonding strength.
4. Molecular level material bonding increases the tensile strength of the material.

1.3 PROBLEM STATEMENT:

Polyethylene thermoplastics have been widely recognized in various industries such as automotive, household and food packaging. There is no doubt that plastic is very useful. The problem with plastic, though, is that it's largely non-biodegradable and takes hundreds of years to break down. This is because the intermolecular bonds that make up the plastic ensure that the structure does not corrode and break down. Efforts have been made to recycle and reuse HDPE plastic to reduce the impact on the environment. However, the mechanical properties of recycled HDPE have not been extensively analysed yet due to the lack of information on the material. Therefore, the author decided to study the strength of HDPE plastic in aluminium joining process.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

Aluminium and high-density polyethylene (HDPE) are widely used materials in various industries due to their unique properties. Aluminium is a lightweight, strong, and corrosion-resistant metal, while HDPE is a thermoplastic material with high impact strength, excellent chemical resistance, and low moisture absorption. Joining these two materials has gained increasing interest in recent years due to the potential benefits in various applications, such as automotive, aerospace, and construction.

In this literature survey, we will explore the various methods of joining aluminium and HDPE, including adhesive bonding, mechanical fastening, welding, and hybrid joining techniques. We will also review the recent developments in the field, such as the use of surface treatments and additives to improve the joint strength and durability. Furthermore, we will discuss the challenges and limitations associated with each joining method and the factors that affect the joint performance, such as material properties, joint design, and environmental conditions.

The use of lightweight materials, aluminium and magnesium alloys, and thermoplastic materials in engineering, especially in the automotive industry, is expanding due to their improved stress-weight ratio and durability. Although plastics offer great design freedom and machinability, the production of larger and more complex parts usually requires joining techniques, 1 such as friction stir welding (FSW). Friction welding is a rapidly developing solid state assembly process that shows promise as an environmentally friendly welding method that can be used to reduce material waste and avoid radiation and harmful gas emissions. with composite welding techniques. 2,3 The main process parameters affecting material flow and welding quality include tool rotation speed, tool travel speed, tool vertical pressure, tool tilt angle and tool geometry.4,5 During processing, a non-wear tool was attached to the butt. . connect and push the edges of the plates with a specially designed pin. The shoulder

of the tool had to touch the surface of the plate. In this situation, the tool was rotated and guided along the joint line. Thus, frictional heat was generated. The rotation and transverse direction of the tool accelerates the movement of material from the front to the back of the pin, and welds are formed. The process was suitable for joining plates and sheets; However, it can be used for pipe and hollow parts and position welding. Friction welding is designed for demanding structural applications to ensure high performance in industry.

Modern thermoplastic materials such as polyethylene are used in expanding engineering applications due to their stronger joints, high stress-to-weight ratio, flexibility, weathering, abrasion and chemical resistance. High density polyethylene (HDPE) is a thermoplastic polymer with the general formula CH_2 and low molecular weight. It has good chemical resistance to almost all acids and bases, detergents and hot water. HDPE has good insulating properties and is easy to weld. The permeability of HDPE to water and inorganic bases is very low. HDPE is brittle and breaks under minimal stress without twisting the neck. Today, the majority of water pipes installed in the world are made of HDPE.

The use of polymeric materials and their compounds has grown rapidly in various industries, such as the automotive industry, due to their advantages such as lighter weight and resistance to corrosive environments compared to metals [1-3]. Polyethylene is the most widely used polymer in the world by volume. Compared to other polymers, polyethylene has excellent properties such as durability, abrasion resistance, impact resistance, low (almost zero) water absorption, low cost and recyclability. Polyethylene has three main categories; low density, medium density and high-density polyethylene (LDPE, MDPE and HDPE), depending on the molecular density and crystallinity of the polyethylene structure. High density polyethylene (HDPE) has high stiffness, strength and better flow behaviour. Global demand for HDPE resins increased from 11.9 million tons in 1990 to 43.9 million tons in 2017, with an annual growth rate of 3.3 percent [4].

Molecular structure and microstructural aspects such as degree of crystallinity, crystal size, crystal thickness and crystal orientation can affect the physical and

mechanical properties of polyethylene. It is a polymer that crystallizes rapidly at high temperatures, where thermally activated crystallization becomes important. The amount of crystallinity affects the mechanical properties of semi-crystalline polymers such as HDPE. The mechanical properties and morphological changes of HDPE also depend significantly on the direction of the deformations with respect to the molecular and crystalline arrangement. Line tension and lamellar thickness are proportional to crystallinity and increase linearly according to the crystallinity index.

Based on experimental observations, the tensile strength depends on the degree of crystallinity but is independent of the molecular weight [9]. However, Karasev et al. [8] found that the tensile strength depends on the molecular weight distribution at high temperatures (80-100 °C). On the other hand, the yield strength below -100 °C is not sensitive to the structure and depends on factors such as the strength of van der Waals bonds but not on the details of the morphology. High molecular weight comes with higher strength because the molecules slide over each other. In addition, increasing the molecular weight decreases the crystallinity. The stiffness of thermoplastics is governed by crystallinity and secondary bond strength, while the strength of thermoplastics is governed by intrachain, interchain, secondary bond, and crystallinity. As mentioned, the degree of crystallinity plays a more important role than the molecular weight in the mechanical properties of HDPE. Processing conditions can also affect the microstructural parameters and thus the mechanical properties. The temperature gradient during the production process can affect the crystallinity, and a higher mold temperature leads to a lower crystallization rate and a better modulus.

HDPE can be made either virgin or re-milled (recycled). Regrind HDPE is excess material from the production line (slicing or cutting) that is reused in the production line to reduce material waste. The regrind HDPE material has more than one thermomechanical history compared to the primary material. The physical and mechanical properties of the grinding material are often not published because there are too many variables involved. Dasari et al. [28] evaluated the tensile behaviour of injection moulded HDPE (density = 0.95 g/cm³, crystallinity = 67%) at room temperature and three strain rates of 0.016, 0.04 and 0.08 s⁻¹. A linear relationship

was observed between ultimate tensile strength and strain rate in a semi-logarithmic curve. SEM imaging of the broken surfaces showed that polyethylene behaves hard at low strains and that the fracture is due to the fibrillation of the polymer chains. At intermediate strain rates, the predominant fracture mode at the edges was splitting or tearing, while at intermediate thicknesses, chain damage was the dominant mode. At high tension, the percentage of vibration was small compared to low tension. Addiego et al. [29] also found that the tensile strength (true stress) increased linearly with the logarithm of the true strain rate of HDPE (density = 0.962 g/cm³, crystallinity = 78%) at 23 °C.

Merah et al. [30] investigated the effect of temperature on the tensile properties of HDPE (PE-100 pipe-grade HDPE with density = 0.96 g/cm³) at a constant strain rate of 0.0006 s⁻¹. A significant decrease in tensile strength and modulus of elasticity was observed when the temperature was increased from -10°C to 70°C. At temperatures of -10 °C, a foggy fracture surface was observed. The effect of temperature and strain on tensile properties was investigated using injection-molded HDPE at temperatures of -40, 23 and 70 °C in the strain range of 0.01-10 s⁻¹ in [31]. Again, with increasing strain, the elastic modulus and fracture strength increased linearly at each temperature tested. It was also found that the trend of decreasing tensile properties with increasing temperature is linear [12]. X-ray diffraction images of stretched polyethylene films showed that the elastic modulus of polyethylene crystals is almost independent of temperature up to 145 °C, while the Young's modulus (E) of the films decreased with increasing temperature.

The world's most popular plastic is polyethylene (PE). This polymer is a multifunction material as it can create food containers, shampoo bottles, kid's toys, and even use in kitchen utensils. It has the simplest of all commercial polymers, a very simple structure. Polymers are high molar mass substances in their molecules and consist of a significant number of rep-eating units. There is nothing more than a long chain of carbon atoms in a polyethylene molecule connected to each carbon atom by two hydrogen atoms as shown in Figure 1. There are polymers that are both natural and synthetic. Proteins, starches,

cellulose and latex are among the naturally occurring polymers.

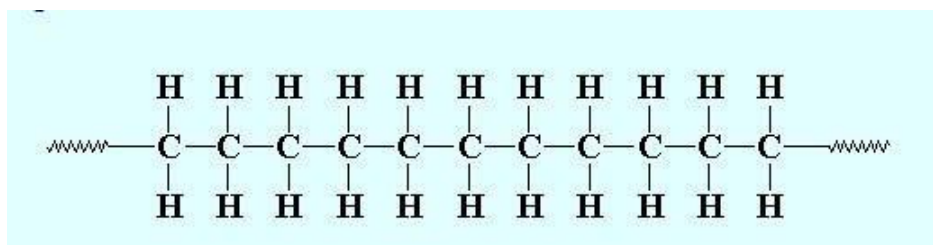


Figure 1: HDPE Structure

Also known as a "thermoplastic," polyethylene and the name is related to the material's heat response. Thermoplastic products will become liquid at some point of melting. A great useful feature of thermoplastics is that they can be warmed, cooled, and heated to their melting point without any degradation and molded again to reuse it.

Polyethylene is made from ethylene gas. Ethylene gas is derived by products from the cracking of natural gas feedstock or petroleum. Ethylene is still a gas at this stage and requires stress and a catalyst to convert it into a resin called polyethylene as shown in Figure 1. The process used to produce polyethylene from ethylene is called polymerization. Ethylene usually polymerizes under broad range of stresses, temperatures and catalysts (depending on the type of PE) to form very long polymer chains. Different techniques will produce different types of PE resins. The ability to produce so many varieties of a raw material make it possible for the manufacturer to modify PE resins for different applications.

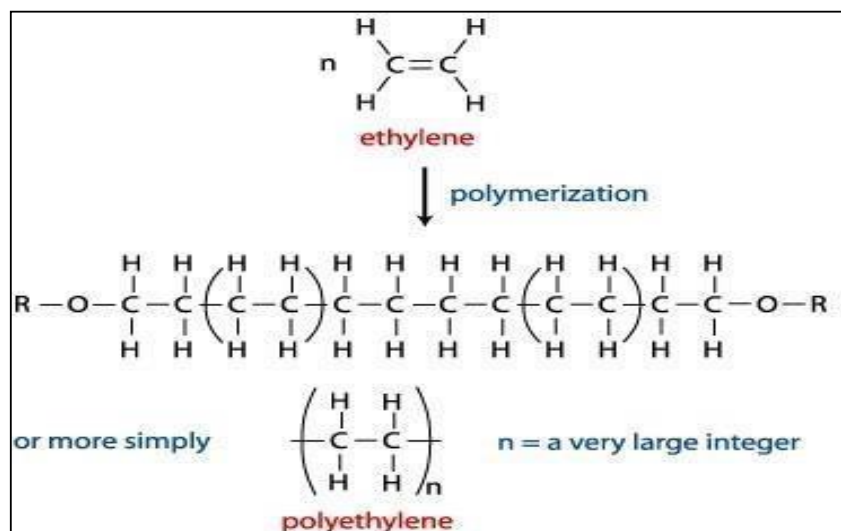


Figure 2: The Polymerization of Ethyl to Produce Polyethylene

There are various kinds of PE such as low-density polyethylene (LDPE) and high-density polyethylene (HDPE). Figure 2 shows LDPE has shorter and many branching compare to HDPE. Produced by free-radical polymerization, in its crystal form, the branching comprises tightly packed molecular chains, so that LDPE has less tensile strength but more ductility. This remarkable "formability" makes LDPE extremely useful for a variety of applications, from sturdy objects such as plastic bottles, detergents and bowls to non-sturdy ones such as trash bags.

On the opposite side of the polymer chain, HDPE has minimal branching of polymer chains. Less branching means that during crystallization the linear molecules are packed together which makes HDPE even more compact and rigid.

Besides, it also improves intermolecular strength hence result in higher tensile strength compared to LDPE. As HDPE has a tougher structure, it is often used as a plastic to produce detergent bottle, pipes, and garbage bins. Lesser branches in its structure will enables the polymer chains to attach tightly together. This will lead to strong-structure of HDPE that can withstand repeated exposure at 120 ° C and a melting point above 20 ° C compared to LDPE.

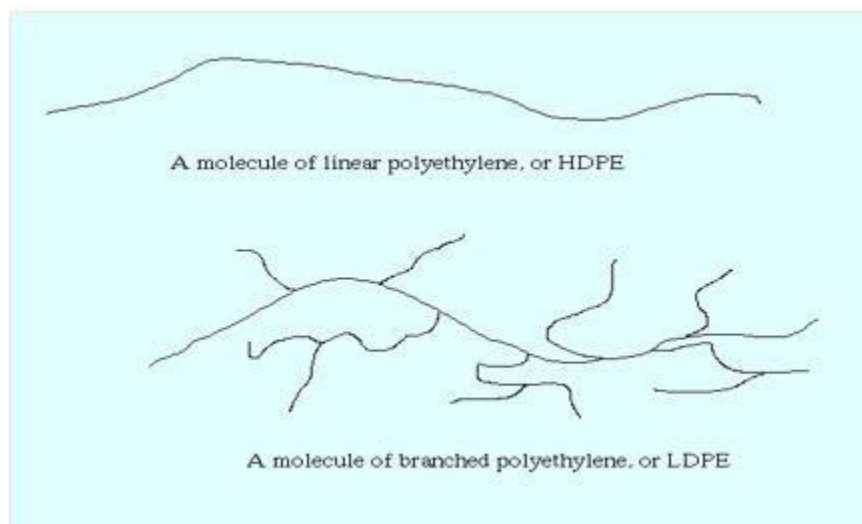


Figure 3: HDPE VS LDPE Structure

2.2 High Density Polyethylene (HDPE)

High density polyethylene is a resin whose monomer is ethylene, also abbreviated as HDPE. It is a thermoplastic with a density ratio of very high strength. HDPE is a highly versatile material with a wide range of applications, from tubes to bottles for storage. The melting point of high-density polyethylene is relatively high compared to other plastics. HDPE is the most popular type of polyethylene plastic which makes up more than 34 percent of the global plastics market. This polymer consisting of a large number of repeating units (known as monomers), and can be generalize the chemical formula as $(C_2H_4)_n$. The branching is relatively low in high-density polyethylene (as opposed to other polyethylene categories). The general HDPE structure is shown below.

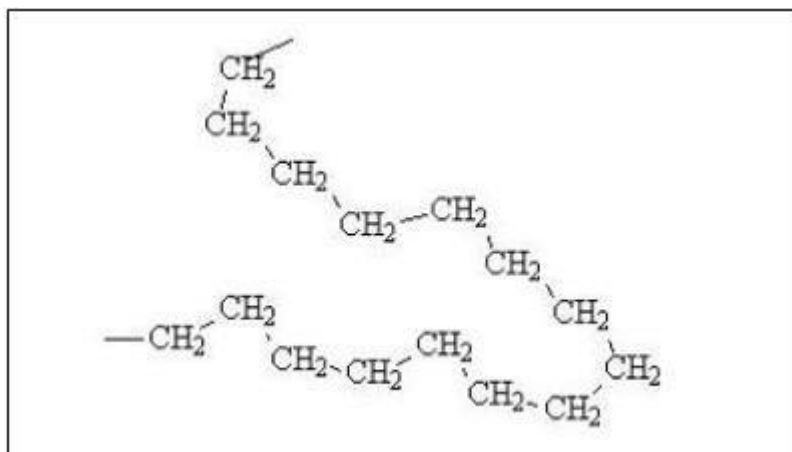


Figure 4: HDPE Structure

In addition, HDPE is a hydrocarbon polymer, which can be made from ethylene through a catalytic reaction. Some of the popular catalysts used here are catalysts for Ziegler – Natta, catalysts for chromium / silica (Phillips catalyst), and catalysts for metallocene. Such catalysts typically attract free radicals in the polymerization phase at the end of the through polyethylene molecules. At the end of the molecules, they also add new ethylene monomers to form a long linear chain.

Table 1: HDPE Thermophysical Properties

Mechanical Properties	Units
Density	940 kg/m ³
Melting Point	130.8 °C
Temperature of Crystallization	111.9 °C
Latent Heat of Fusion	178.6 kJ/kg
Thermal Conductivity	0.44 W/m. °C at °C
Specific Heat Capacity	1330 to 2400 J/kg-K
Specific Heat (Solid)	1.9 kJ/kg. °C
Crystallinity	60%

2.3 Mechanical Properties

2.3.1 Tensile Test

By using tensile test, mechanical properties of material can be determined. It is conducted by applying uniaxial load along the axis of a specimen until it deformed. Once a specimen is pulled beyond its ultimate tensile strength (UTS), a specific cross-sectional will starts to decrease. It is also known as necking deformation where the specimen experience greatest stress at this stage. With continued loading, necking deformation will keep increasing and finally split the specimen into two pieces.

Nevertheless, for tensile testing, the specimen shapes must be acceptable for standardization, in compliance with ASTM D638. Figure 5 shows the stress-strain nature of every plastic polymer and several useful properties of the material can be determined from the curve.

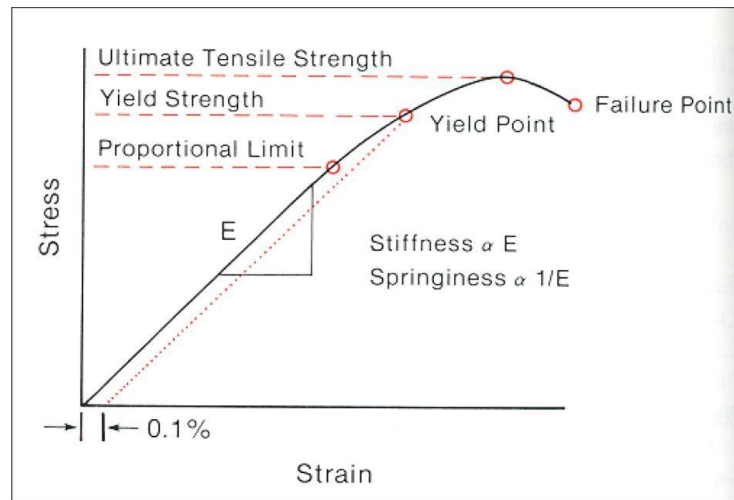


Figure 5: Stress -Strain Curve

The details shown in Figure 5 for some characteristics are explained as follows:

1. Fracture point: Specimen reaches its limit of stretching and breaks into two parts.
2. Elastic region: A point before the specimen reach its yield point where the load is removed, the material returns to its original state.
3. Yield point: Represents material's elastic limit. In another word represents the end of elastic nature and the beginning of plastic nature. By removing

the specimen before its yield point, the material can return to its original form. Plastic region: A stage after the specimen reach its yield point of the material and the material will not be able to return to its original shape.

4. Ductility: A measure of how much pressure the specimen of material can put on before splitting into two. Even so, material with low ductility will simply break once it has been deformed, which also known as brittle material.
5. Young's Modulus: Also known as tensile modulus to measure elastic stiffness. It is an interpretation of reading the ratio of uniaxial stress to uniaxial strain in the range of stress in which Hooke's Law holds. Have to occur before the specimen reach its Yield point.

$$E = \frac{\Delta \text{Stress}}{\Delta \text{Strain}} \quad \text{Eq. 1}$$

6. Resilience: Material's capability to retain energy when elastic region is deformed, and let go that energy when unloaded. Whereas, resilience modulus is described as the energy limit that can be absorbed with no degradation per unit volume. By integrating the stress-strain curve from null to elastic max, it can be measured. Resilience.

$$U_r = \frac{\sigma_y^2}{2E} \quad \text{Eq. 2}$$

7. Toughness: It's the amount of energy a substance will consume per volume before rupture to measure the region underneath stress-strain curve.

$$\frac{\text{Volume}}{\text{Energy}} = \int_0^{E_f} \sigma dE \quad \text{Eq. 3}$$

By using tensile test, tensile strength of the material can also be determined. Tensile strength refers to how much stress the material can hold before it rips into two pieces. The specimen will undergo a stretch and elongation until it splits. HDPE's tensile strength is usually between 3,000 and 3,500 pounds per square inch (psi), which in SI unit is approximately 20 to 32 MPa. This also enables it to handle the transport of high-pressure substances and to be easily

manufactured into shapes without the risk of damaging the structure of the materials. The range of mechanical properties of HDPE is shown in Table 2

Table 2: Tensile Test Range for HDPE

Quantity	Values	unit
Youngs modulus	600-1400	Mpa
Shear modulus	700-800	Mpa
Tensile strength	20-32	Mpa
Elongation	180-100	%
Fatigue	18-20	Mpa
Bending strength	20-45	Mpa

Mechanical properties of HDPE from ASTM D638:

Table 3: Tensile Yield Stress based on ASTM D638

Material	Test Speed in./ min	Average (psi)
HDPE	2	4101
HDPE	2	3523

Table 4: Tensile Yield Elongation based on ASTM D638

Material	Test Speed in./ min	Average (psi)
HDPE	2	9.27
HDPE	2	9.63

2.3.2 Scanning electron microscope (SEM)

Scanning electron microscope (SEM) is a powerful imaging tool used to study the surface structure of materials. It works by scanning an electron beam on the surface of the sample and detecting electrons that are scattered or emitted from the surface. Electrons are accelerated by an electromagnetic field that concentrates them into a narrow beam. The beam is then directed at the sample, which is placed in a vacuum chamber to prevent electrons from colliding with air molecules. When the beam hits the surface of the sample, it interacts with the atoms, causing them to emit secondary electrons, which are detected by a special detector. SEM produces high-resolution images that can show the surface morphology and topography of the sample, as well as the composition of the material. It is widely used in fields such as materials science, nanotechnology, biology and geology to study the structure and properties of materials at the nanoscale. SEM is a valuable tool in surface analysis of materials, as it provides a very detailed view of the topography, morphology and composition of the material. Its high resolution, magnification and imaging capabilities make it an essential tool in many fields of research.

The scanning electron microscope (SEM) is a powerful tool for studying the microstructure and topography of materials. In mechanical engineering, SEM can be used in many applications, including:

1. Failure Analysis: SEM can be used to examine the surface of damaged mechanical components to identify the root cause of the failure. This can help engineers design more reliable components in the future.
2. Characterization of materials: SEM can be used to study the microstructure of materials and identify defects such as cracks, holes and inclusions. This information can be used to optimize material properties and performance.
3. Surface analysis: SEM can be used to study the surface topography of materials, including roughness, structure and surface properties. This information can be used to improve the performance of materials in applications such as friction, wear and adhesion.
4. Quality control: SEM can be used to check the quality of manufactured

components to ensure they meet design requirements. This may include examination of surface finish, dimensional accuracy and defects. In summary, SEM is a versatile tool that can provide valuable information about the microstructure and surface properties of materials in mechanical engineering.

2.4 SUMMARY

High-Density Polyethylene (HDPE) is a popular thermoplastic material used in a variety of applications, including piping, containers, and packaging. Combining HDPE with other materials, such as aluminium, can be difficult due to differences in material properties. However, there are several techniques for joining HDPE to aluminium, including bonding, mechanical bonding, and thermal bonding.

Thermal bonding, also known as hot gas welding, is a common method for joining HDPE to aluminium. In this process, a hot gas, such as nitrogen or air, is directed directly to the surface of the HDPE and aluminium to melt and fuse the materials together. The temperature, pressure and velocity of the gas flow are carefully controlled to ensure a stable and long-lasting bond.

One challenge with thermal bonding between HDPE and aluminium is that the melting point of HDPE is much lower than that of aluminium. Therefore, it is important to carefully control the temperature and pressure to avoid damage to the HDPE and to ensure a tight bond.

In summary, HDPE can be joined to aluminium by a variety of techniques, including thermal bonding. Careful control of temperature, pressure and other parameters is necessary to ensure a strong and durable bond between the two materials.

CHAPTER 3

Aim and scope of work

3.1 AIM

In recent days materials and their corrosion analysis are highly approached by researchers. Aluminium and its alloy materials are attracted by researchers for their superior properties like light weight and strength ratio. In this research work, analysis of the Aluminium 6 series with High- density polyethylene sheet bonding. The deposition of high-density polymer nano composite on Aluminium which is used to highly encourage the tailor-made binding which is applicable in various fields. Orientation between two metal pieces is varied for each condition and the nano composite binding is carried out under a constant load and temp.

3.2 SCOPE OF WORK

This project will focus on designing a dog bone mould, which is the shape of a test specimen in accordance with ASTM 638. After that, the high-density polyethylene (HDPE) will be tested for its mechanical properties. Tensile tests were carried out to check the tensile strength of these HDPE attached to the aluminium dog bone shape. The tensile test results of each type are tabulated and then compared. The SEM analysis will be performed in SEM lab to perform the test. The location if this study was conducted in the laboratory of the Department of Mechanical Engineering at IIST Bangalore

3.3 PRESENT INVESTIGATION

This investigation was carried out to evaluate the efficiency of thermal bonding to bond high-density polyethylene (HDPE) to aluminium. The purpose of the investigation is to determine the strength and durability of the bond created by thermal bonding and to identify any factors that may affect the quality of the bond.

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 METHODOLOGY

This chapter will cover the process flow diagram of the project process. The focus will then change to the mechanical property testing, tensile test, SEM analysis.

4.2 MATERIALS USED

4.2.1 High Density Polyethylene (HDPE) Plastic

High-density polyethylene (HDPE) is a lightweight, super-strong material that is widely used in household items such as detergent and milk bottle. The HDPE bottles will be labelled as shown in Figure 7. HDPE bottles such as shampoo bottles and drinking water were recycled and processed into pellets. For this project, HDPE bottles will be collected at nearby waste. Mineral bottle cap, detergent bottle and milk jug are used to test the material properties.



Figure 6: Symbol Used in Recycling Waste of Plastics for HDPE

4.2.2 Tensile Test Machine



Figure 7: UTP's Tensile Test Machine

Tensile or stress testing is one of the basic mechanical tests conducted on a material which is conducted by applying pressure on the material and measuring the material's reaction to the forces applied to it. The pull applied on the material leads to the elongation of the surface. The material's pressure and elongation will be measured, and data will be obtained. If the material is no longer able to withstand the stress it causes failure or extreme deformation.

The stress-strain curve was obtained using this tensile test. The results of the tensile analysis provide details on the mechanical properties of the material. Pulling the material before breakage helps to get the material's entire tensile characteristic. The values of the yield stress, tensile strength and elongation at break were also displayed at the end of the experiment.

The breakpoint is the ultimate strength of the object, or what is called UTS. The resulting graph also shows UTS for the material. Analysis of the material under the force of elongation by stress-- graphs reveal several material characteristics and helps predict the material behavior. Tensile testing is carried out using ASTM D638, a standard test method for polymer plastic tensile properties.

Tensile Test Procedure

- 1) The product is cut or inserted into a "dog bone" shape below 14 mm thickness.
- 2) The specimen was load into tensile grips.
- 3) The test was begun by separating the tensile grips at a constant rate of speed.
- 4) The speed was set up 50mm per minute.
- 5) Time taken for the specimen to break was taken which is from 30 seconds to 5 minutes.

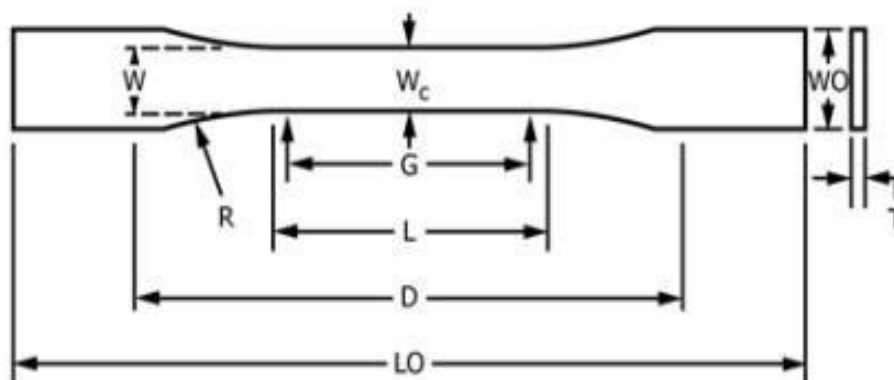


Figure 8: Dog Bone Shape and Dimension for Types I, II, III & IV from ASTM D638



Figure 9: Sample of Al after CNC cutting

Table 5: Specimen Dimension for Thickness, T, mm (in.) Based on ASTM D638

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl		4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV ^B	Type V ^{C,D}		
W—Width of narrow section ^{E,F}	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02) ^{B,C}	
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02) ^C	
WO—Width overall, min ^G	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)	
WO—Width overall, min ^G	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)	
LO—Length overall, min ^H	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)	
G—Gage length ^I	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010) ^C	
G—Gage length ^I	...	...	...	25 (1.00)	...	±0.13 (±0.005)	
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5) ^J	25.4 (1.0)	±5 (±0.2)	
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04) ^C	
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)	

4.2.3 Surface morphological studies

Scanning electron microscopy (SEM) is a powerful analytical technique for studying the morphology and microstructure of materials at high magnification. An electron beam is used to scan the surface of the sample and the resulting signal is used to create an image of the sample. When performing his SEM analysis of aluminium, the following steps are typically followed. Sample preparation: Aluminium samples should be prepared for SEM analysis. This includes cutting the sample to the appropriate size and shape, mounting it in a sample holder, and polishing the surface to remove contaminants and imperfections. Coatings: Aluminium surfaces are often coated with a thin layer of conductive material such as gold or carbon to improve the quality of SEM images and prevent sample charging during analysis. Instrument setup: Place the sample holder into the SEM chamber and set up the instrument for analysis. This involves adjusting electron beam parameters such as beam energy and spot size to optimize image quality. Imaging: An electron beam is scanned across the surface of the aluminium sample and the resulting signal is captured and used to create an image of the sample. SEM images can provide information on the surface morphology, crystal structure, and elemental composition of aluminium.

Coatings: Aluminium surfaces are often coated with a thin layer of conductive material such as gold or carbon to improve the quality of SEM images and prevent sample charging during analysis. Instrument setup: Place the sample holder into the SEM chamber and set up the instrument for analysis. This involves adjusting electron beam parameters such as beam energy and spot size to optimize image quality. Imaging: An electron beam is scanned across the surface of the aluminium sample and the resulting signal is captured and used to create an image of the sample.

Analysis: Once the SEM image is obtained, further analysis can be performed to examine the microstructure of the aluminium. For example, electron backscatter diffraction (EBSD) can be used to determine the crystallographic orientation and grain size of aluminium. Overall, SEM analysis is a useful technique for studying the microstructure of aluminium and can provide valuable information for material characterization and failure analysis.

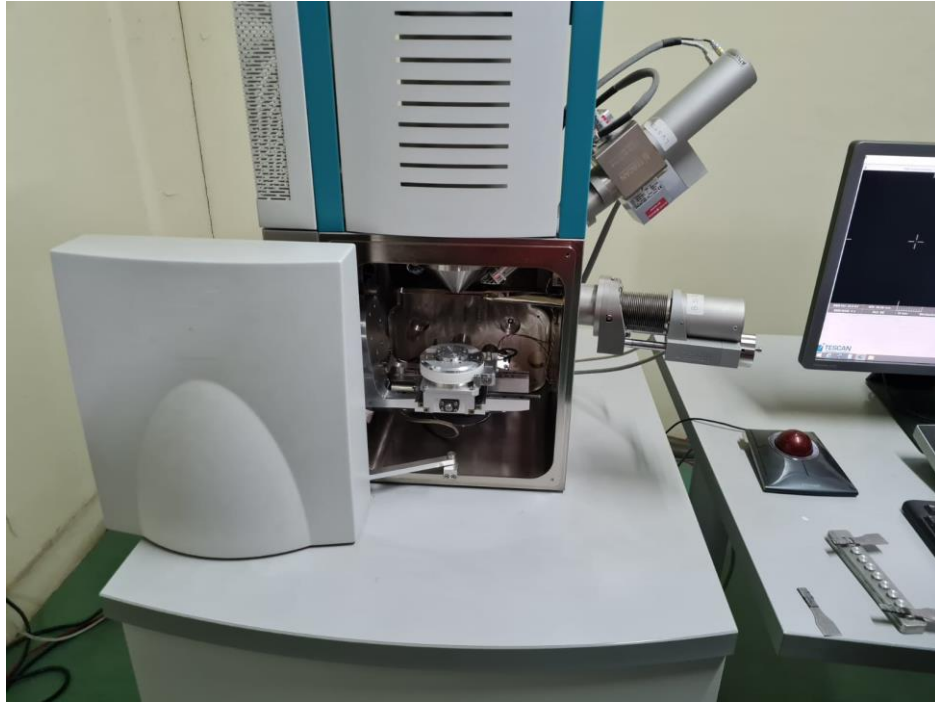


Figure 10: Sem analysis testing machine



Figure 11: sample placement in SEM machine

4.3 experiment Process

This is an experiment process that need to be done to check the mechanical properties of HDPE and aluminum. A process called "hot pressing" can be used to join two pieces of aluminum using HDPE (high density polyethylene) as a spacer. The following is a general experimental process that can be used to join two pieces of aluminum using HDPE, heat and pressure: Materials: Two aluminum parts to connect HDPE sheet Heat source (e.g., stove) Pressure source (e.g., hydraulic press) Thermocouple or temperature sensor Protective equipment (e.g., gloves, goggles)

Actions: Cut a piece of HDPE sheet to the same size as the aluminum pieces to be joined. Clean the surfaces of the aluminum parts and the HDPE sheet with a solvent (e.g., isopropyl alcohol) and let them dry. Place the HDPE sheet between the two aluminum pieces, making sure the edges are lined up. Place the aluminum-HDPE-aluminum sandwich on the cooker and heat it to the desired temperature. The temperature depends on the thickness of the HDPE sheet and the properties of the aluminum, but usually it should be between 160-190 °C. When the sandwich has reached the desired temperature, put it in the hydro press and press it. The pressure should also depend on the thickness of the HDPE sheet and the properties of the aluminum, but usually it should be in the range of 10-20 MPa. Keep the sandwich under pressure and at the desired temperature for a certain time, usually 5-20 minutes. When the desired time has passed, remove the sandwich from the press and let it cool to room temperature. After the sandwich has cooled, remove the aluminum pieces from the HDPE layer. Inspect the joint surfaces for possible defects and test the strength of the joint with a tensile or shear test.

Note. The exact parameters of the test can vary depending on the materials used and the desired properties of the joint. Careful selection of temperature and pressure settings is important to ensure a strong and reliable joint.

4.4 flow chart

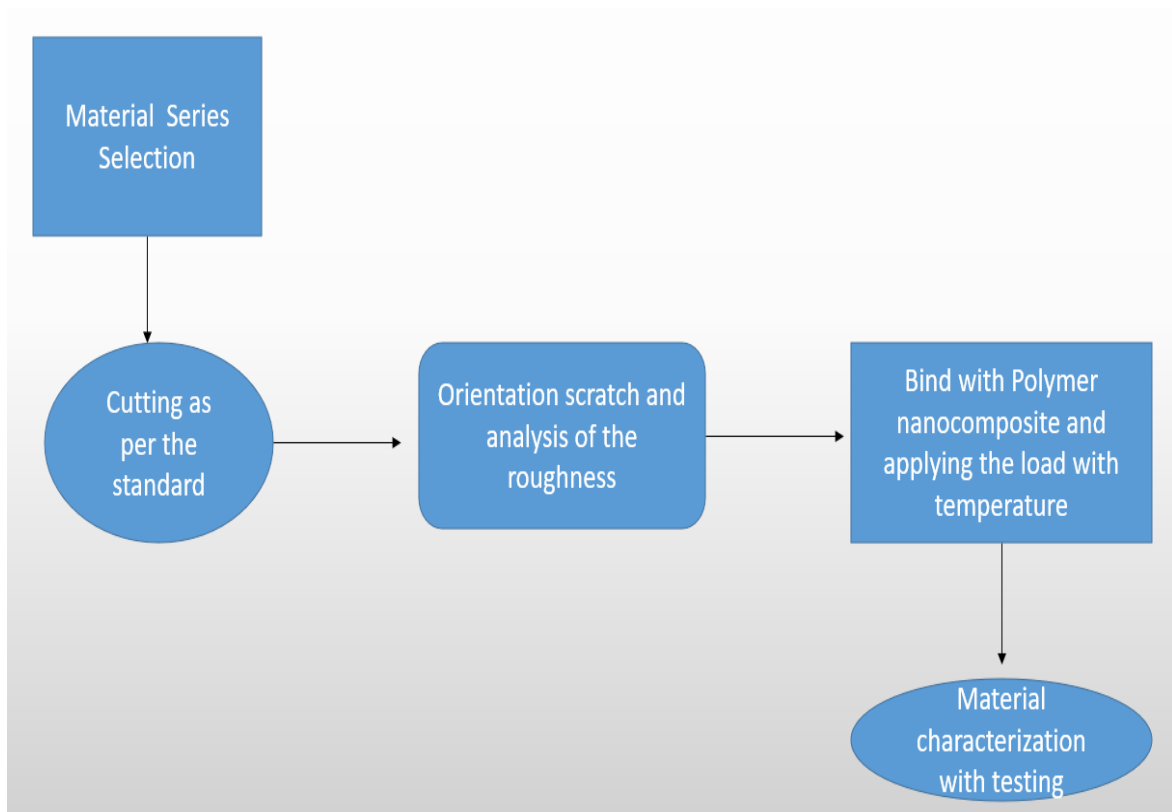


Figure 12: flow chart of experiment performed

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Results for Tensile Test

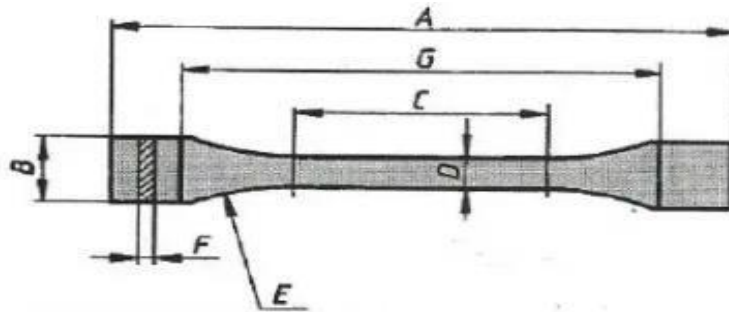


Figure 13: specimen undergo vernier caliper measurement

Specimen parameter was determined by using a Vernier calliper. A mean value was taken of three measurements.

Table 6: Measurement of Specimen from ASTM D638

Type of Specimen	HDPE
A	164 mm
B	19 mm
C	50 mm
D	13 mm
F	3.2 mm
G	57 mm

For the measurement of stress, strain and Young Modulus, E of specimens the formula applies as follows:

Specimen 1: High Density Polyethylene (HDPE) Five specimens were tested under condition of 50mm/min for the speed of testing and the average is taken.



Figure 14: Specimen Undergo Tensile Test

The cross-sectional area and initial specimen length are measured as below: Area = $0.013 \text{ m} \times 0.0032 \text{ m} = 4.16 \times 10^{-5} \text{ m}^2$

Initial length of specimen = 0.057 m

Stress and strain data calculated for HDPE:

Table 7: Results for HDPE Tensile Test

Test No.	Thickness mm	Width mm	Max. Load N	Elastic Modulus MPa	T.Strength MPa	Yield Load N	Yield strength MPa	Elongation@Break mm
1	3.220	12.75	1054	1365	25.67	644.053	15.688	187.07
2	3.250	12.75	1085	1606	26.18	671.958	16.216	207.79
3	3.230	12.75	1084	1311	26.31	717.656	17.426	104.77
4	3.250	12.75	1103	962	26.61	676.703	16.331	99.14
5	3.260	12.75	1132	21714	27.23	794.696	19.119	95.88
Average	3.242	12.75	1092	5392	26.40	701.013	16.956	138.93
SD(N-1)	0.016	0.00	29	9127	0.57	58.594	1.364	54.00

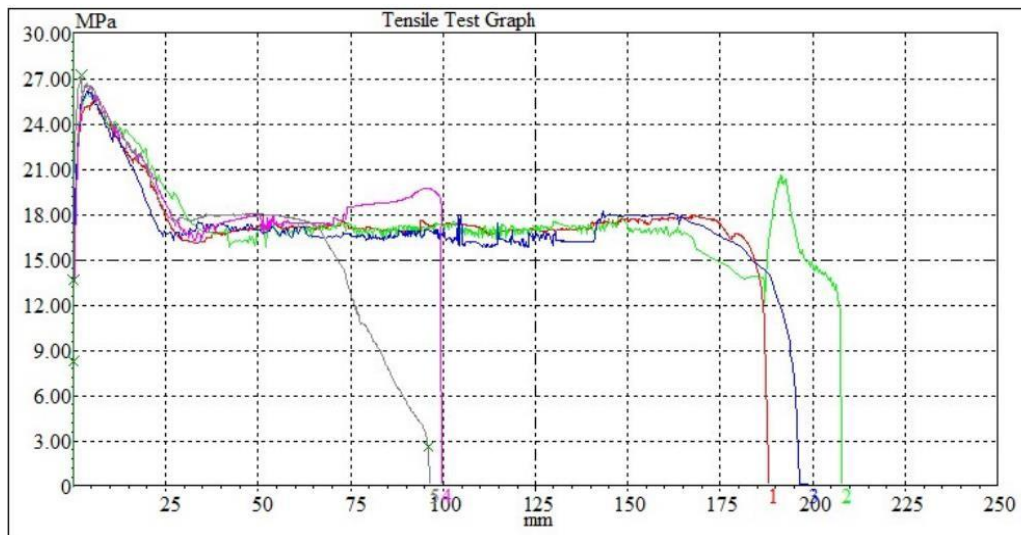


Figure 15: Stress - Strain Curve Obtained from Experiment in Figure 14

The following averages can be determined:

- i. Ultimate Tensile Strength (UTS) = 26.40 MPa
- ii. Yield strength = 16.96 MPa (with 0.002 offset)
- iii. Young Modulus, $E = 5392$ MPa

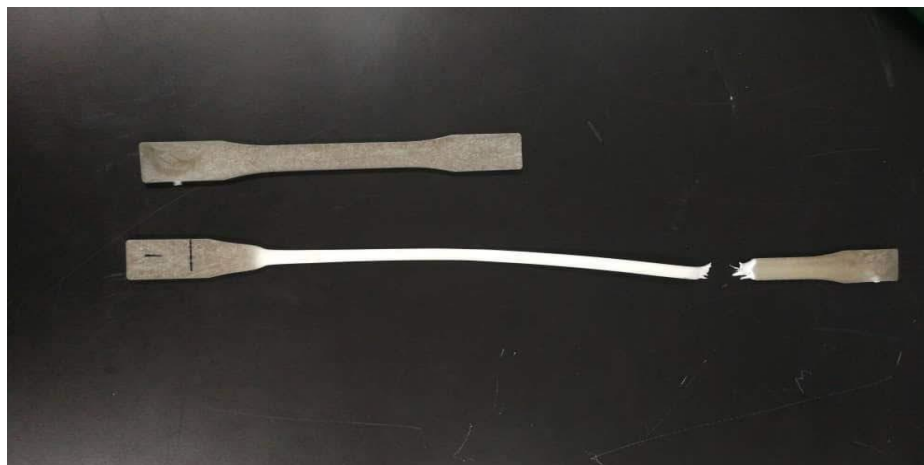


Figure 16: Specimen Before and After Undergoing Tensile Test

Sample Description : Al 6 Series ASTM Sample. Sample : 2.
(as stated by customer)

Mechanical Properties:-		Equipment Used : 25 kN UTM
S. No	Characteristics Test	Findings
1	Breaking Load, N	822

End of Report



For Chennai Mettlex Lab Private Limited

G. PRABAGARAN
Technical Manager
Authorised Signatory

Reviewed & Authorized by

figure 17: Tensile Rest Report

Sample Description : Al 6 Series ASTM Sample. Sample : 4.
(as stated by customer)

Mechanical Properties:-		Equipment Used : 25 kN UTM
S. No	Characteristics Test	Findings
1	Breaking Load, N	1009.6

End of Report



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figure 18: Tensile Test Report

Above result stated that the average of Young Modulus is 5392 MPa whereas the pure HDPE are around 0.565 to 1.50 GPa which means the recycle HDPE is stiffer than the pure one. However, UTS for recycle HDPE is much lower than the pure which is 0.0264GPa compare to the pure HDPE (7.60 to 43.0 GPa). The cause of a low UTS from recycleHDPE may affected from the main chain scissions accompanied by decrease in the molecular weight which came from the possible degradation through the recycling process.

By approximation, plot from the engineering stress-strain plot of each specimen, the yield strength for average recycle HDPE is 16.956 MPa. It is quite lower than the pure HDPE which is around 23.0 to 29.5 MPa. According to Alzerreca M., Paris.M, molecular weight produces

from the recycle HDPE in lower than pure HDPE and recycling method often generate chain scission, branching and crosslinking, resulting from various reactions involving free radicals. Which also mean degradation of the polymer chains caused during the formulation of the recycle can cause quality problems at extrusion for finished models hence results in lower yield strength.

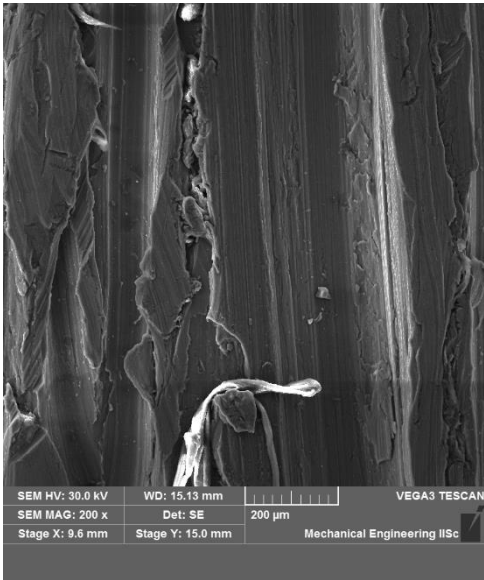
Table 8: Mechanical Properties for Pure HDPE at 23 °C

PROPERTY	UNIT	VALUE / RANGE
Tensile Strength, Yield at 23 C	MPa	23.0 - 29.5
Tensile Strength, Break at 23 C	MPa	30.5 - 33
Elongation, Yield	%	9 - 18
Elongation, Break	%	600 - 1350
Tensile Modulus at 23 C	MPa	900 - 1550
Flexural Strength, Yield	MPa	
Flexural Modulus	MPa	970- 1380
Compressive Strength	MPa	
Izod Notched	J/m (kJ/m ²)	71 - 159 (20)
Izod Unnotched	J/m	No Break

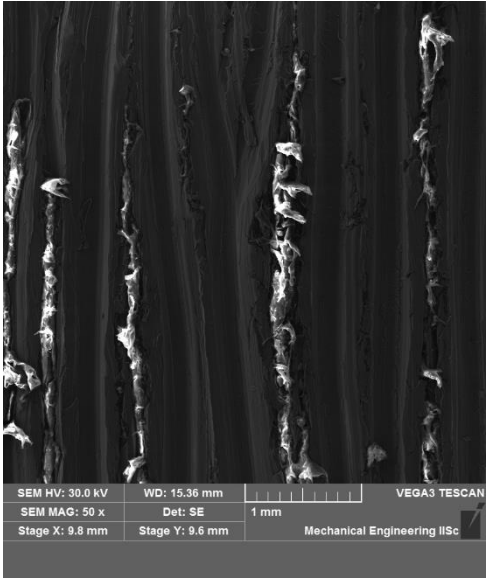
Based on Table 8, the elongation at break of pure HDPE is around 600 to 1350 percent and the elongation for recycle HDPE is 297%. According to Pattanakul and Selke, the higher the percentage of the recycled HDPE, the lower the elongation percent at break will be compared to the pure HDPE. Miltz and Narkis and Ram et al, they found that the mechanical property most affected by deterioration was elongation at break. Therefore, the results of this analysis are identical to their findings.

Overall, recycled HDPE is a material with useful properties that are not substantially different from virgin resin ones. When recycling increases, more of this material will be available at a lower price compare to the pure HDPE resin. Manufacturers may contribute to reduce the country's solid waste crisis by using this recycled plastic. In Dikobe and Luyt study, they stated that Young's modulus will increase and the stress at break will decrease with increasing wood powder (WP) content. Hence, to increase the mechanical properties of HDPE, we can add another composite material to strengthen its bond.

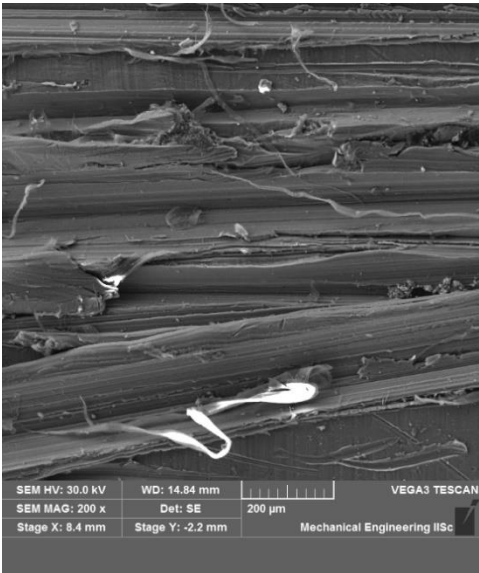
5.2 Scanning electron microscope result



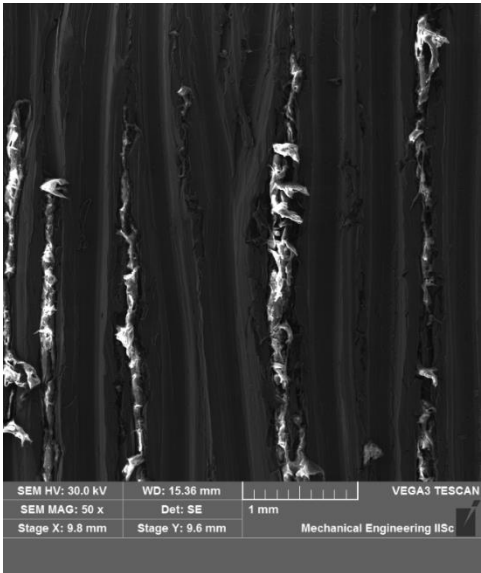
(a)



(b)



(c)



(d)

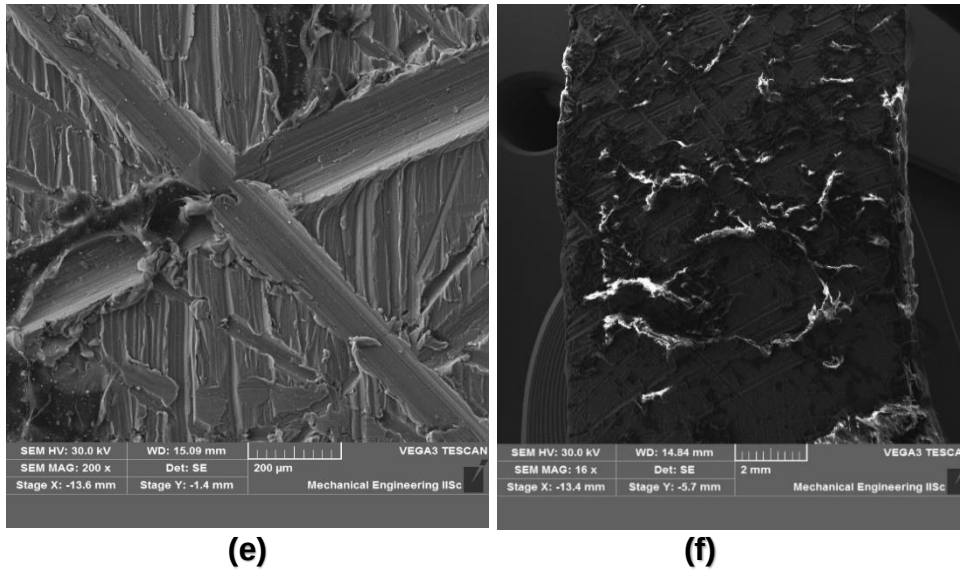


Figure 19 SEM image

Figure 19 Sem images of (a) before HDPE sheet attachment (b) after tensile specimen analysis, (c) before attachment of y direction sample (d) after tensile specimen attachment of HDPE, (e) X- Y direction scratch surface and before Sem analysis and (f) after tensile testing attachment of HDPE attachment.

The surface morphological studies indicates that the before and after the tensile specimen testing the HDPE were highly attach with the aluminium samples and the grip of the specimens were increase the test results. In figure 19 (a) the samples shows that x – direction of scratch surfaces is placing a vital role in the testing part. After the testing the samples were indicates that the HDPE were still attach with the alumina samples and the bonding with sample of aluminium and the bonding agent of HDPE were highly attach with each other. The tailor-made attachments of aluminium and the HDPE were bond with each other by means of pressure and the temperature of the process. The temperature plays a major role in this process that gives a high-quality bonding with each other. When the process without pressure in this research the bond between the material and HDPE were make the poor bond also studied.

Fig.19 (c) indicates that y – direction scratch and the HDPE were delivering the nearest same result. Moreover, the attachment of HDPE on the samples were increase in bonding were increased. The Fig. 19 (d) indicates the surface

morphological results of HDPE bond highly attach with the aluminium sample due to the high temperature applied on the surface while attachment process. Compare between the x- and y axis scratching the samples are highly bond with the aluminium alloy and the HDPE were encourage the attachment. Theoretically the aluminium – HDPE – aluminium alloy attachment with the x – and y – directions are increasing the bonding of the material each other. The surface morphological studies also indicate the same results of different scratch process.

Fig. 19 (e) indicates that the x-y direction of scratching that the samples were possibilities of bonding process. The surface morphological images indicates that the roughness of the samples was increased and the Fig. 19 (f) shows the HDPE were highly bond with each other. Compare to x and y direction scratch surfaces the samples are encourages the attachments of HDPE and that elevates that aluminium-to-aluminium attachments. This process is conducted under the high pressure and the high temperatures that encourages the contact of aluminium to HDPE and aluminium alloy attachments.

CHAPTER 6

CONCLUSION

In this project, tensile and SEM experiments were applied for studying the HDPE's mechanical and fracture properties. The project is integrated fracture study with application calculation, a series of numerical simulation based on a pure HDPE dog-bone shape test were done to obtain the mechanical properties constants.

The initial material constants were obtained directly from experimental data and error correction procedure is then followed to get the true stress-strain curve which used to fine and extrude elastic-plastic material data.

SEM analysis where also done in the specimen to analysis the pattern formation after the breakage points in tensile test and also the analysis of HDPE material in the specimen surface.

Among the test results taken from tensile and SEM analysis the pattern in figure 19 (e,f) shows the highest bonging strength between the sample tested.

Recommendation

This study should be done with experimenting its chemical properties to know how it affected recycle HDPE. Nevertheless, HDPE properties can be further exploited by introducing organic or inorganic particles into the polymer matrix to strengthen its bondingand increase the tensile strength and hardness of recycle HDPE.

- In application part, more accurate numerical test should be operated in the future.
- Different specimen dimension will be considered in the processing of fracture, for example, different thickness.
- In the shear specimen test, the shear combined with tensile model can be investigated deeply with experiments and numerical method.

References:

- [1] N. M. Mehat and S. Kamaruddin, "Optimization of mechanical properties of recycled plastic products via optimal processing parameters using the Taguchi method," *Journal of Materials Processing Technology*, vol. 211, no. 12, pp. 1989-1994, 2011, doi: 10.1016/j.jmatprotec.2011.06.014.
- [2] S. A.H, "The Effect Of Recycled – High Density Polyethylene (Hdpe) Mixing Ratio On The Tensile Strength Of High Density Polyethylene (HDPE) Polymer," 2013.
- [3] N. Singh, D. Hui, R. Singh, I. P. S. Ahuja, L. Feo, and F. Fraternali, "Recycling of plastic solid waste: A state of art review and future applications," *Composites Part B: Engineering*, vol. 115, pp. 409-422, 2017, doi: 10.1016/j.compositesb.2016.09.013.
- [4] D. I. B. D. Praveen P. Rathod, "A Literature Review on Properties of Recycled High Density Polyethylene Composites," *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, vol. 5, no. X, 2017.
- [5] K. A. V. Thakare, Honeykumar G.; Bhawe, A. G., "Experimental Investigation Of Possible Use Of Hdpe As Thermal Storage Material In Thermal Storage Type Solar Cookers," *Engineering and Technology. Bangalore, India: IJRET/Sun Publications*, vol. 04, 2015.
- [6] C. Pattanakul, Selke, S., Miltz, J., "Properties of Recycled High Density Polyethylene from Milk Bottles," *School of Packaging*, p. 4, 2017.
- [7] I. I. N Nursyamsi , V Theresa, "Effect of HDPE plastic waste towards batako properties," presented at the Materials Science and Engineering, Universitas Sumatera Utara, 2018.
- [8] K. A. Nischal, K.A. Abinash, B. Devaraj,E., "Mechanical Properties of HDPE Reinforced with carbon fiber Powder with and without filler addition," *International Research Journal of Engineering and Technology (IRJET)*, vol. 05, no. 07, p. 11, 2018.
- [9] E. K. A. Abo, A.A., "The Mechanical Behaviour of Recycled High Density Polyethylene," *International Journal of Modern Engineering Research (IJMER)*, vol. 3, no. 3, p. 11, 2013.
- [10] M. Alzerreca, M. Paris, O. Boyron, D. Orditz, G. Louarn, and O. Correc,

- "Mechanical properties and molecular structures of virgin and recycled HDPE polymers used in gravity sewer systems," *Polymer Testing*, vol. 46, pp. 1-8, 2015, doi: 10.1016/j.polymertesting.2015.06.012.
- [11] V. O. Huberto, "Engineering Fundamentals Refresh of Strength vs Stiffness vs Hardness," 2011.
- [12] D. G. Dikobe and A. S. Luyt, "Thermal and mechanical properties of PP/HDPE/wood powder and MAPP/HDPE/wood powder polymer blend composites," *Thermochimica Acta*, vol. 654, pp. 40-50, 2017, doi: 10.1016/j.tca.2017.05.002.
- [13] Bonding behavior studies of cold sprayed copper coating on the PVC polymer substrate By Amirthan Ganesan , Jon Affi, Motohiro Yamada, Masahiro Fukumot .
- [14] L. A. Tony, "An Investigation of Recycled High Density Polyethylene Reinforced by Short Glass Fibers," p. 65, 1994.

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