RECYCLING OF THERMPOPLASTIC WASTE BOTTLES

A final year project report

Presented to

SCHOOL OF MECHANICAL AND MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment

of the Requirements for the Degree of

Bachelors of Mechanical Engineering

by

Syed Basir Raza Zaidi

Mohsin Masood Quddusi

Haseeb Khan

June 2017

EXAMINATION COMMITTEE

We hereby recommend that the dissertation prepared under our supervision by:

Syed Basir Raza Zaidi NUST201304605BSMME1113F

Mohsin Masood Quddusi NUST201304644BSMME1113F

Haseeb Khan NUST201305580BSMME1113F

Titled: "Recycling of Thermoplastic Waste Bottles" be accepted in partial fulfillment of the requirements for the award of Bachelors in Mechanical Engineering degree.

Supervisor: Colonel Naveed Hasan	____________________ Dated:
Committee Member:	____________________ Dated:
Committee Member :	____________________ Dated:

______________________ ____________

(Head of Department) (Date)

COUNTERSIGNED

Dated: ________________ ________________

(Dean / Principal)

ABSTRACT

Plastics are widely used these days for multiple purposes. They offer a variety of benefits. It is price competitive with other materials that offer similar advantages in industrial applications. But there are some problems associated with the disposal of plastics. Every year, nearly 8 million metric tons of waste plastic enter the oceans. So, plastic recycling is one of those methods that can be adopted at higher level to reduce the high rates of plastic pollution. Majority of plastics can be recycled and made into useful products. The most commonly available plastics in the society are High Density Polyethylene (HDPE) and the Polyethylene Terephthalate (PET), so we have gone through the properties of these two types of plastics and their ability to recycle.

The major components of the machine used for the said purpose are shredder and compression molding setup .Initially plastic bottles (shampoo bottles etc.) are cut down into small flakes with the help of the shredder. The flakes are then placed in a compression mold to make the desired product (plastic pot). This mold is heated with the help of an Electric collar heater with constant temperature monitoring using thermocouple. After suitable heating and pressure being applied through the mold itself, the collars are removed and the setup is cooled. After a while, the re-opening of the mold delivers the final product in the form of a plastic pot.

PREFACE

This thesis is presented to the NUST School of Mechanical and Manufacturing Engineering (SMME), Islamabad in partial fulfilment of the requirement of the degree BE Mechanical Engineering for the student authors and describes in detail all the efforts that led to completion of their Final Year Project titled "Recycling of Thermoplastic Waste Bottles". This thesis elaborates extensively all the stages that this project went through from conception phase all the way to the finalization phase and also sheds some light on the methodology and calculations that were adopted in order to design the machine and the mold. While organizing this thesis, care has been taken to strictly keep it in accordance with the recommended format provided by the SMME. The authors have made a conscious method to use simple and lucid diction and explain the major concepts of plastic recycling to the readers in a simple yet comprehensive manner. Visual aids like pictures, drawings, tables and graphs etc. have been used wherever necessary to add to the overall clarity of the report. Furthermore, design calculations and formulae have also been written. A dedicated chapter at the end identifies certain areas in which there is some room for improvement to make this machine even better and more useful. This chapter also points out the aspects on which our juniors can work to get better results from this machine.

ACKNOWLEDGMENTS

We would like to express our deepest appreciation to our Creator and Sustainer, Allah Almighty, The Most Beneficent and The Most Merciful, who provided us the possibility to complete the report and helped and guided us through each and every step of the project. Indeed nothing is possible without His divine decree. Furthermore, we would also like to acknowledge with much appreciation the crucial role of our parents and siblings who lent us their valuable support through all the ups and downs of our life. We are highly indebted to our Project Supervisor Col. Naveed Hassan for his guidance and constant supervision as well as for providing necessary information regarding the project and also for his support in completing the project. He has been a source of continuous support and assisted us wherever possible. We would also like to pay special thanks to the entire staff of the Manufacturing Resource Center (MRC) who have been really helpful. Special mentions for Mr. Faisal, Mr. Zahid, Mr.Faraz and Mr. Rizwan. Services of these people are commendable. Without their precious help, we could not have completed our project on time. Finally, we would like to thank all the individuals who helped in the completion of this project in one way or the other. Some of them include Mr. Taha Sharif, Mr. Usman Khalid, and Mr. Mahmood Quddusi.

ORIGINALITY REPORT

FYP Report

ORIGINALITY REPORT

12%	8%	6%	10%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Gulf University for Science & Technology Student Paper	1%
2	coep.vlab.co.in Internet Source	1%
3	Submitted to University of New South Wales Student Paper	1%
4	mechanicalinfo.wordpress.com Internet Source	1%
5	henrysbench.capnfatz.com Internet Source	1%
6	www.azocleantech.com Internet Source	1%
7	Submitted to University of Wolverhampton Student Paper	1%
8	www.slideshare.net Internet Source	1%
9	en.wikipedia.org	

COPYRIGHT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

PET	Poly Ethylene Terephthalate
HDPE	High Density Polyethylene
PlastECO	Project's Commercial Name
SS	Stainless Steel
MS	Mild Steel
EDM	Electric Discharge Machine
CNC	Computer Numerical Control
CAD	Computer Aided Design

NOMENCLATURE

$P = Power$

M-Ohm = Mega Ohm

MPa = Mega Pascal

$\tau = Torque$

$\omega = RPM$

$F_{Sh} = Shear\ Force$

$mm = Millimetre$

CHAPTER 1

INTRODUCTION

With the increasing world population, the demand for consumer products has been on the rise. Whereas increased manufacturing and production of goods has been done to cope up with this increasing demand, this has led to enhanced usage of plastic products. Be it packaging of the consumer products or the actual usable commodity, plastics have carved out an undeniable and irreplaceable place within the consumer sector.

The main reasons for the usage of plastic lie in its functionality, its aesthetic nature and its sustainability. Plastics find their usage in a wide variety of usable items. Their usage is not limited to just outdoors or indoors, food grade or non-food grade items, agricultural sector or gift items, building constructions materials or lab equipments, furniture pieces or toy items, clothes and footwear or automotive industry, packaging items or as a part of designing process, plastics are widespread, have multi-purpose usage and fulfill human needs very effectively.

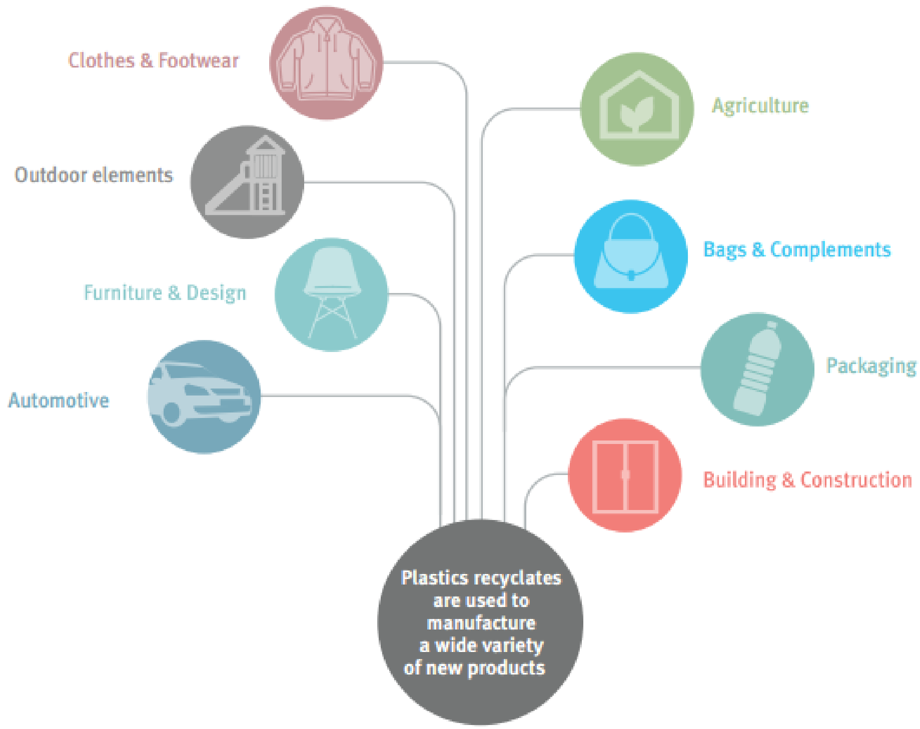


Figure 1 Various Sector of Plastic Usage

One of the key reasons of the widespread usage of plastic products is the aesthetically pleasing effect that they possess along with their sustainability and their material strength. This is complemented with the easy adaptability upon heating and application of pressure. This makes plastics the prime material for widespread usage. Because not only is the area of application broad but it brings alongside the concept of recycling and reusing the plastics in different forms and shapes.

The compositional make up of the plastics shows them to be consisting of strands of various chemical nature. There are two major divisions of the plastics family namely :

1. **Thermoplastics** : The kind of plastics that become pliable or moldable above a certain temperature and re-solidify upon cooling without any loss in its polymer chain.
2. **Thermosetting Plastics** : The kind of plastics that synthetic materials that strengthen during being heated, but cannot be successfully remolded or reheated after their initial heat-forming.

Thermosetting plastics are not suitable for molding purposes and hence cannot be recycled either. On the other hand, thermoplastics are very well suited for molding, shaping and reusing after subjecting them to the recycling process. Within these thermoplastics, there are 7 different grades of plastic resins, each having their own physical and chemical properties. The resin chart has been listed below :

Table 1Plastic Resin Chart

CODE	MATERIAL	APPLICATIONS
1 PET OR 1 PETE	Polyethylene terephalate	Clear softdrinks and beverage bottles, food packaging
2 HDPE OR 2 PE-HD	High density polyethylene	Bottles (especially for food products, detergent and cosmetics), Industrial wrapping and film, sheets, plastic bags
3 PVC OR 3 V	Polyvynil Chloride	Bottles, packaging film, credit cards, water containers, water pipes
4 LDPE OR 4 PE-LD	Low density polyethylene	Cling film, plastic bags, flexible containers and food wrap
5 PP	Polypropylene	Packaging such as yoghurt and margarine pots, sweet and snack wrappers, medical packaging, milk and beer crates, shampoo bottles
6 PS	Polystyrene	Disposable hot or cold drink cups and plates, fast food clamshells, dairy product containers
7 OTHER OR 7 O	All other resins and multi-materials not otherwise defined	Other resins, complex composites and laminates

With regards to their recycling nature and their re-usability, these plastics have been assigned resin codes. Out of these 7 resin types, only 1^{st},2^{nd}, 4^{th} and 5^{th} are chemically safe for recycling purposes. The remaining 3 resin types release release toxins and carcinogens during the recycling process which renders them unsuitable for re-usage.

Need Analysis – Global Outlook

According to the recent statistics published by Environment Protection Agency (EPA), the global plastic consumption exceeds 322 million metric tonnes per year. The annual increase in the plastic usage has been depicted as follows :

Figure 3 Global Plastic Conusumption (Million Metric Tonnes)

Whereas the concept of recycling has been inculcated in the people by spreading awareness amongst the masses through campaigns encouraging them to make the most of the plastic products, yet only 35% of the plastic products are recycle1d, leaving behind 65% that ultimately become a part of landfill and cause destruction of the environment in one form or the other.

There are multiple processes of recycling that have been implemented globally, over the years, in a bid to reduce the plastic waste . Whereas most of these campaigns and recycling setups are government sponsored and are well established businesses of industrial scale, the significance of the small scale indigenous recycling setups cannot be ignored. Such setups play the most vital role in not only educating the people regarding recycling but by offering them incentive of Do-It-Yourself attitude in this perspective. One specific project in this regard that has inspired many around the world is by Mr. Dave Hakkens. The project's name is Precious Plastic. This initiative has gone a long way in helping people develop a sense of confidence towards embarking on this journey of recycling plastic waste bottles.

Need Analysis – Pakistan Scale

Pakistan generates over 20 million metric tonnes of solid waste /annum. This equals to about 54,888 tons of solid waste/ day or scaling down these figures, accounts for 2kg of solid waste per house per day. Of this total solid waste, 60% consists of waste plastic products and packaging materials which include wrappers, covers, bottles etc. Of this huge quantity of plastic waste that is generated on a daily basis, Pakistan only has the capacity to recycle 15% whereas the remaining 85% plastic waste goes on to contribute to the degradation of the environment.

The significance of encouraging the concept of plastic bottle recycling in Pakistan is evident from the following table :

Table 2 Plastic Waste Generation Across Pakistan

S. No	Cities	Generation Kg/c/day	Rate Kg/h/day	Waste Tons/day	Generated Tons/year
1	Gujranwala	0.469	3.424	824.0	300,760
2	Faisalabad	0.391	2.737	924.3	337,370
3	Karachi	0.613	4.291	6,450.0	2,354,250
4	Hyderabad	0.563	3.941	975.7	356,131
5	Peshawar	0.489	3.423	809.3	295,395
6	Bannu	0.439	2.941	36.0	13,140
7	Quetta	0.378	2.646	378.0	137,970
8	Sibi	0.283	1.896	17	6,205
	Total			**10,414.3**	**3,601,221**

Addressing the Need

Although some work is being done in Pakistan on the industrial level by companies such as Green Earth Recycling and Balochistan Glass, yet its not sufficient and needs more support from the masses to improve the utilization of the waste plastic bottles. In this regard, the existing companies and setups are either only generating the flakes and not giving out a finished product or are simply utilizing the already made flakes.

The need, here again , is to introduce the idea of a cost effective recycling setup that would not only be portable, low maintenance but also user-friendly and rewarding to the owner in the sense of offering some incentive . This is precisely what the aim of the project 'Recycling of Thermoplastic Waste Bottles: PlastECO' is.

CHAPTER 2

LITERATURE REVIEW

Plastics are economical, lightweight and tough materials, which can promptly be shaped into an assortment of items that discover use in an extensive variety of uses. As a result, the creation of plastics has expanded extraordinarily in the course of the most recent 60 years. Nonetheless, current levels of their utilization and transfer produce a few natural issues. Around 4 percent of world oil and gas creation, a non-sustainable asset, is utilized as feedstock for plastics and a further 3–4% is utilized to provide energy for their manufacture. A noteworthy segment of plastic created every year is utilized to make expendable things of bundling or other fleeting items that are disposed off inside at the time of produce. These two perceptions alone demonstrate that our present utilization of plastics is not practical. Likewise, due to the strength of the polymers included, considerable amounts of disposed off end-of-life plastics are gathering as garbage in landfills and in characteristic living spaces around the world. [1]

Recycling is a standout amongst the most essential activities at present accessible to lessen these effects and represents the most powerful regions in the plastics business today. Recycling gives chances to lessen oil utilization, carbon dioxide discharges and the amounts of waste requiring transfer.

While plastics have been reused since the 1970s, the amounts that are reused differ topographically, as indicated by plastic sort and application. Recycling of packaging materials has seen quick extension in the course of the most recent decades in various nations. Progresses in advancements and frameworks for the accumulation, sorting and reprocessing of recyclable plastics are making new open doors for reusing, and with the consolidated activities of the general population, industry and governments it might be conceivable to redirect the dominant part of plastic waste from landfills to reusing throughout the following decades.

Plastics are utilized generally in many sorts of items. The achievement of plastics and their development in various applications have brought about ecological and wellbeing concerns, which must be managed and their development turned around through forbidding of a few plastics. Packaging represents 35% of plastics utilization and is a noteworthy wellspring of plastic transfer and recycling issues. Around 7% of the family waste in the UK is plastics. Most of this plastic usually ends up in landfills and incinerators.

Table 3 Consumption of Plastics and Waste Generation by sector in UK in 2000

	usage		**waste arising**	
	ktonne	**(%)**	**ktonne**	**(%)**
packaging	1640	37	1640	58
commercial andindustrial	*490*			
household	*1150*			
building and construction	1050	24	284	10
structural	*800*		*49*	
non-structural	*250*		*235*	
electrical and electronics	355	8	200	7
furniture and housewares	335	8	200[a]	7
automotive and transport	335	8	150	5
agriculture and horticulture	310	7	93	3
[illegible]	425	10	255[a]	9

If we have a look at our own country, Pakistan's yearly utilization of plastic resins is more than one million tons and demand may additionally develop on the back of new improvements in plastic innovations and a quickly growing business sector for plastics because of its more extensive application in the building and development, transportation, packaging, electrical and gadgets, furniture and decorations.

Types of Plastics:

Generally speaking, there are two main categories of plastics which are discussed below;

1. *Thermoplastics*

These types of plastics can be formed into other products by re-melting or processing into different shapes by applying heat and pressure. They are similar to an ice cube. It can be melted and then freeze again to get back the original product. E.g. PET, PVC, HDPE etc.

2. *Thermosets*

Such plastics do not soften with heat and hence cannot be formed into shapes.

Considering these two types, only Thermoplastics can undergo recycling.

Limiting ourselves to just two plastic resins for the purpose of research and demonstration, namely **Polyethylene (PET)** and **High Density Polyethylene (HDPE)**.

Types of Recycling:

1. *Feedstock Recycling*

In this case, the plastic monomers are broken down which can be used in refineries and chemical production.

2. *Mechanical Recycling*

This method is usually adopted in the industries and we will also be going with this type of recycling. It basically includes the cleaning, shredding and melting of plastic. Quality products can be manufactured when the material is devoid of contaminants, sorted into a single type of polymer and if necessary, segregated according to the color required at the end.

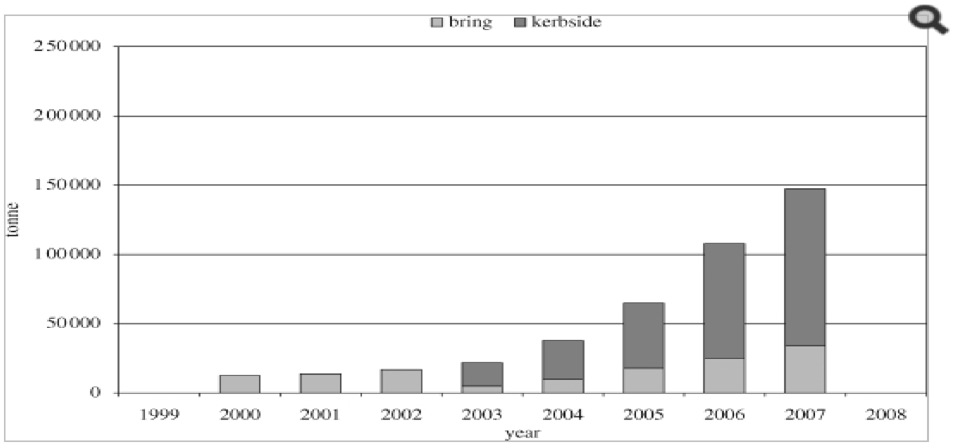
Feedstock Recycling does not ensure that a plastic will remain environmental friendly over its whole life cycle. The supportability advantages of utilizing renewable feed stock may not be adequate if the material can't be reused. To concentrate the recyclability of the polymeric materials including bio plastics and their subsidiaries, it is an all-around attempted practice to reproduce the mechanical recycling by doing different extrusions and to find out the durability or service life.

Due to the reasons mentioned above, Mechanical Recycling is given a preference over the former one. The four phases include collection, separation, processing, and manufacturing and marketing. It is very necessary that the plastic resin is clean and homogenous because that will ensure that the highest quality recycled plastic product is formed . [2]

There are several technologies such as automatic sorting, gravity separation, and electrostatic separation that can be used for the separation of waste plastic, but due to various limitations, we had to do that by hand. PET bottles is the aim of every recycling setup but owing to their chemical composition and their high melting point, they're not readily recyclable.

Plastic bottles which include shampoo bottles, milk jugs, cleaning agents, laundry detergents etc. are usually the main point of focus for the experiment [3]. There has been a huge increase in these products and naturally, the bottles have been going to waste more than anything. This can be visualized by the following survey which was carried out in UK:

Table 3 Waste Generation Statistics



What stands out from the studies so far is that HDPE is most suitable for recycling demonstration purposes. After their collection, their cleaning by water is carried out. Different cleansing methods are adopted in the industry, which usually include machines.

Shredding/Grinding

After the cleaning has been done, shredding of the plastic bottles is carried out. For this , different machines are available in the market, through the desired results can be achieved. They differ from each other on the basis of design and the user requirements. Like the one shown below is a double shaft shredder machine.

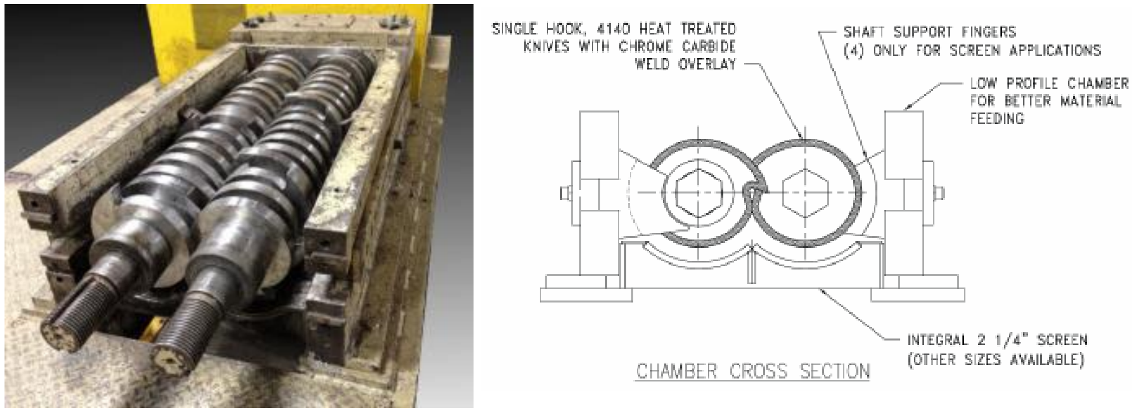


Figure 2 Double Shaft Shredder Machine

Just like a shredder machine, grinders are also used to serve the purpose. They too shred the plastic into very small granules which can then be further used.

After the shredding of plastic, different moulding methods that can be utilized to make the given product. It usually depends on the end product which one procedure to follow. Discussed below are each one of these methods :

1. *Compression Molding Machine*

Plastic is warmed inside the stove/oven and gradually squeezed into a shape with a carjack. Appropriate for making substantial and stronger items. The stove/oven itself is additionally an incredible machine for prototyping and making plastic tests. [4]

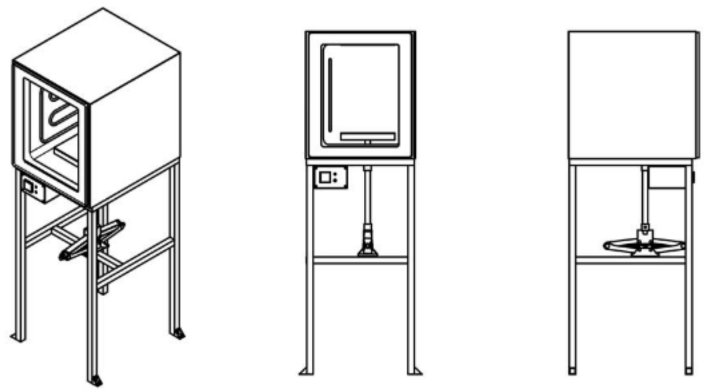


Figure 1 Compression Molding Oven

2. *Injection Molding Machine*

Plastic drops are warmed and infused into a shape. It's a moderately fast process which is appropriate for making little objects over and over again. You can make the molds yourself utilizing CNC plants or machines, or by essentially welding them. [5]

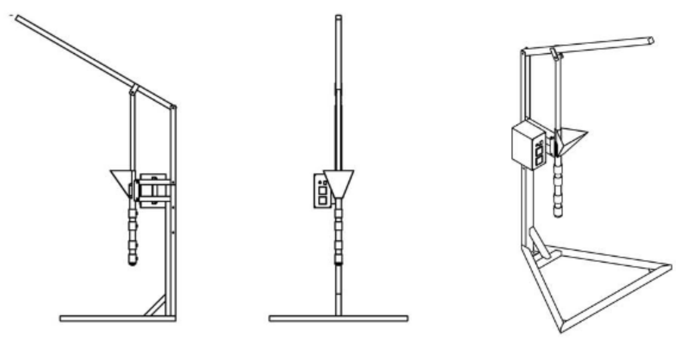


Figure 2 Injection Molding Machine

3. Extrusion Molding Machine

Extrusion is a constant procedure where plastic pieces are embedded into the container and expelled into a line of plastic. These lines can be utilized to make new crude materials, for example, 3d printing filament, make granulated plastic, spun around a shape, or utilized by you in new and innovative ways. [6]

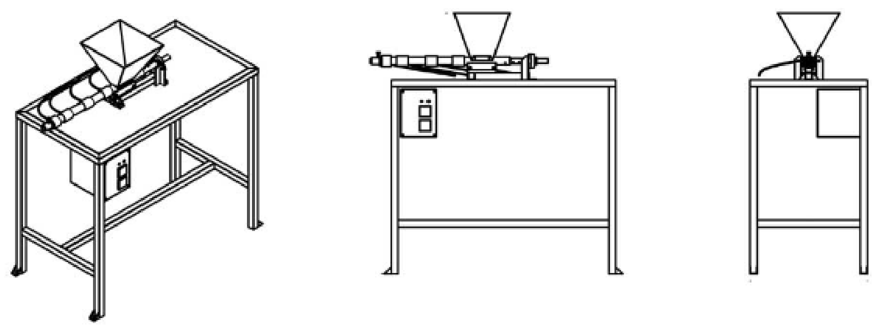


Figure 3 Extrusion Molding Machine

Each of these methods is capable of making a different sort of a product. Since the more reasonable approach for demonstration and testing is compression molding, so we will be going ahead with compression molding machine. We plan on using the weight of the mold as the compression and made out the required stuff.

It is necessary to study the properties of the plastic that is undergoing the operation. Its melting point and other characteristics should be known, so that temperature is increases in accordance with the need.

So by keeping in mind the increasing rate of plastic, and the waste it produces, we at PlastECO probably think such a machine should be built which can be used at a small scale level as well as on an industrial scale. The one we intend to build will be very economical and can be used by small scale industries. This will help to reduce the plastic waste as well as obtain very useful daily use products at a much cheaper rate.

Apart from the initial cost of the machine, the other charges should be pretty nominal. This includes the electric power for running the shredder and for heating purposes.

Although this concept of recycling is still new in our country, but a lot of advancements have been made in the other countries in the recycling of plastics.

CHAPTER 3

METHODOLOGY

In order to go about achieving the set objectives and aims of the project, the approach that we adopted was a very systematic one. The major tasks were sub-divided into smaller tasks. Which, according to the need, were further divided into smaller levels of work. In this way, the formation of a Work BreakDown Structure (WBS) was the first step in our approach.

WORK BREAK DOWN STRUCTURE

1 PlastECO

1.1 Plastic

1.1.1 Type and Grade

1.1.2 Properties

1.1.3 Additives and Fillers

1.1.4 Post-Processing Strength

1.2 Process

1.2.1 Cleaning

1.2.2 Drying

1.3 Shredder

1.3.1 Blades number and type

1.3.2 Blade Design

1.3.3 Manufacturing Method

1.3.4 Body Design and Flake Size

1.3.5 Capacity

1.3.6 Electrical Connections

1.4 Compression Molding

1.4.1 Type

1.4.2 Temperature Control

1.4.3 Volumetric Variations

1.4.4 Mold Design

1.5 Testing

1.5.1 Prototype Design

1.5.2 Design Approval

1.5.3 Manufacturing of Prototype

1.5.4 Testing

1.5.5 Results and Deductions

Figure 6 Descriptive WBS of PlastECO

The tree diagam of the WBS of PlastECO is listed below :

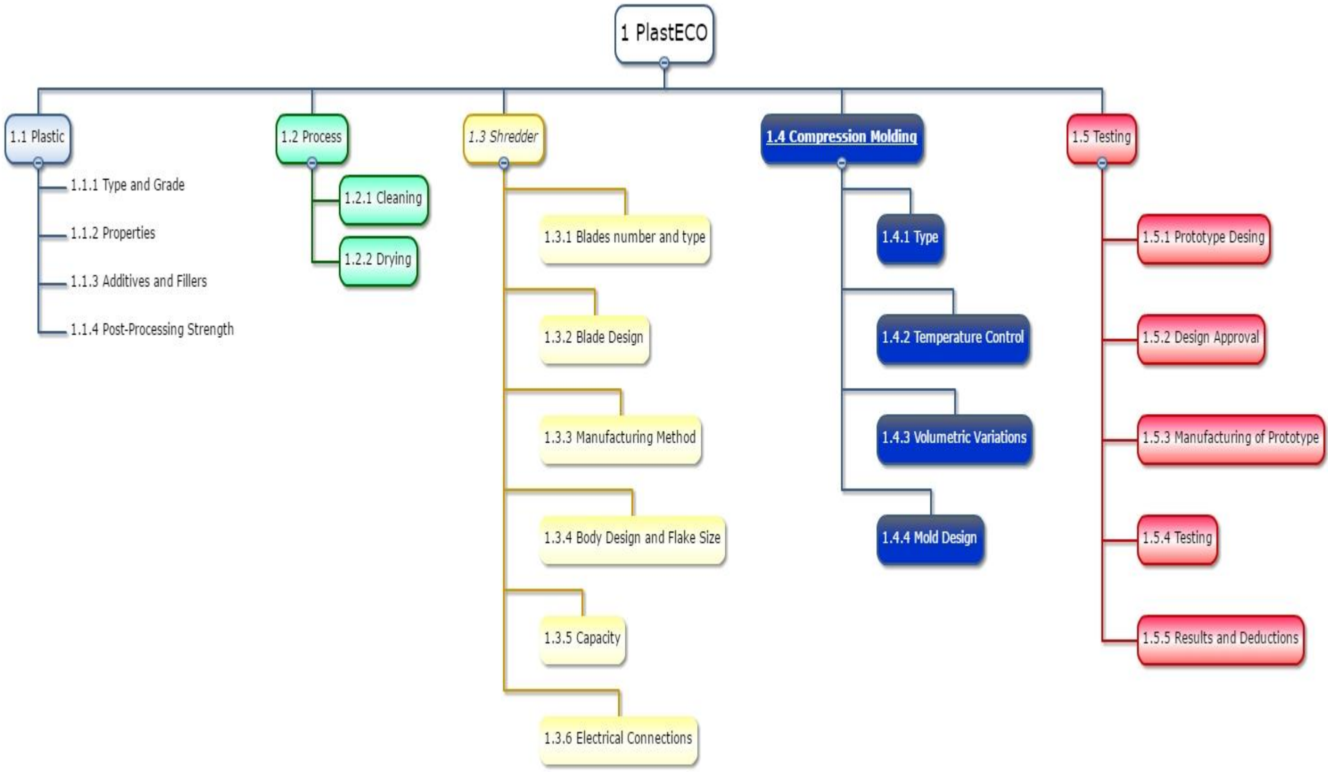


Figure 7 WBS Tree-diagram of PlastECO

TYPES OF PLASTICS FOR RECYCLING

Types of Plastics:

Generally speaking, there are two main categories of plastics which are discussed below;

3. *Thermoplastics*

   These types of plastics can be formed into other products by re-melting or processing into different shapes by applying heat and pressure. They are similar to an ice cube. It can be melted and then freeze again to get back the original product.

   E.g. PET, PVC, HDPEetc.

4. *Thermosets*

   Such plastics do not soften with heat and hence cannot be formed into shapes.

   Since we're mainly concerned with the recycling of waste plastic bottles, nearly 80% of all the plastic bottles used worldwide are made of PET and HDPE, the 1st and 2nd plastic types according to the plastic resin chart. The properties of PET and HDPE have been laid out below in details for the purpose of comparison as well as detailed information in terms of recycling knowledge, melting points and adaptability in the molding process.

Properties of Polyethylene Terephthalate (PET)

Some of the properties have been mentioned below:

- May exist both as an amorphous (transparent) and as a semi-crystalline material
- Semi-crystalline material might appear transparent (particle size < 500 nm) or opaque and white (particle size up to a few microns)
- Monomer in PET is bis-beta-hydroxyterephthalate which can be synthesized by the esterification reaction between terephthalic acid and ethylene glycol with water as a byproduct
- Repeating unit: $C_{10}H_8O_4$
- Young's Modulus (E) = 2800-3100 MPa
- Tensile Strength = 55-75 MPa
- Elastic Limit = 50-150%
- **Melting Point = 260 degree Celsius**
- Boiling Point > 350 degree Celsius
- Intrinsic Viscosity: Dependent upon the length of its polymer chains. Longer the chains, higher the viscosity

  0.70 - 0.78 dL/g   Water bottles (flat)

  0.78 – 0.85 dL/g   Carbonated soft drink grade

- Can be semi-rigid to rigid, depending on how it is processed
- Lightweight
- Good gas and fair moisture barrier
- Strong and impact resistant
- Becomes white when exposed to chloroform
- Hygroscopic (absorbs water from its surroundings)

Be that as it may, there were a few reasons and issues confronted because of which we needed to change our kind of plastic. Right off the bat, PET softened at around 260-270 degree Celsius and the electric heaters that were accessible to us couldn't accomplish the required temperature in the said time. Likewise, water bottles being not all that thick, stuck in the middle of the sharp edges in the shredder box. This did not accomplish the required destroying. So, owing to the design and manufacturing limitations of the prototype setup, we chose to opt for HDPE as an alternative.

Properties of High Density Polyethylene (HDPE)

General characteristics of HDPE include:

- Usually rigid.
- Can be formed by a wide variety of thermoplastic processing methods.
- Impact resistant from -40 to 90 degree Celsius.
- Moisture Resistant.
- Chemical Resistant.
- High thermal expansion.
- Density up to 0.97 g/cm^3.
- Melting Point around 170 degree Celsius.
- Large strength to density ratio.

Table 4 Typical Properties of HDPE Plastic

Typical Properties of High Density Polyethylene

Property	Value	Range / Comments
Density, g/cc	0.95	0.941-0.97 g/cc
Hardness, Shore D	65	60-70 Shore D
Tensile Strength, Yield, MPa	30	20-40 MPa; ASTM D638
Tensile Strength, Ultimate, MPa	50	20-70 MPa
Modulus of Elasticity, GPa	0.8	0.4-1.2 GPa; In Tension; ASTM D638
Flexural Modulus, GPa	1.4	0.7-2 GPa; ASTM D790
Coefficient of Thermal Expansion, linear 201C, µm/m-°C	22	ASTM D696
Melting Point, °C	130	

Pre-Processing

Before the plastic bottles are brought to the machine for recycling, there are some steps to be followed to make the bottles clean and pure. This includes

- Bottles are sorted by hand and unwanted materials are removed so that only bottles are left.
- Bottles are cleaned inside and out to remove any residual liquid or dirt to prevent contamination.
- Bottles can be sorted by infrared radiation techniques, to determine the polymers present (not being followed in our process)
- Bottles are usually shredded into 1mm x 1mm to 6mm x 6mm flakes.
- These flakes are then washed again.
- The shredded plastic is then melted to produce plastic granulates or pellets.

Technical Construction and Working

For the purpose of structured accomplishment of the project , the project was divided into 2 main modules , namely :

1. Shredder Machine
2. Compression Molding Oven

The complete process from the recycling of plastic bottles to the production of a finished product has been laid out in the following figure :

Figure 8 PlastECO Recycling Process

Shredder

Shredder is used to convert plastic bottles into flakes. The size of the flakes is determined by the blades and the size of the pores of metal strainer beneath them.

Difference between granulator, shredder and grinder:

Since the project is based around the recycling of thermoplastic waste bottle, so, the first step in this entire process is the conversion of waste plastic bottles into flakes. For this stage of size reduction, there are three different machines that are generally used, namely Shredder, Granulator and Grinder.

Table 5 Difference Between Shredder Types

DEVICE	FLAKE SIZE(MM)	TORQUE	SPEED
SHREDDER	20-100	High	Low
GRINDER	12-18	High	Low
GRANULATOR	6-12	High	Low

The primary difference between shredder, grinder and granulator lies in the flake size as well as the output requirement. Shredders are high torque and low speed machines whereas in contrast to this, grinders and granulators are high speed and low torque. The main difference between grinders and granulators is that they have different rotor designs. Granulators normally have an open rotor design whereas grinders usually have closed rotor designs. This is the reason granulators can handle light materials a lot easily and efficiently than the grinders. Also, the final flake size from the granulator is mostly smaller than the output of the grinder.

Since granulators operate on relatively lower torques with high speeds, it is generally not considered a wise choice from operational perspective to feed high density and big sized material in the granulator. Otherwise chances are that it would create a lot of noise, may even jam and damage the rotor of the granulator. Shredders are quite the opposite of this. The heavier the feed is, the better it is for the shredder to reduce into smaller sizes, as the weight of the feed further forces it into the hopper. One particularly important feature of the shredders in this regard is that the motor can rotate the shaft and the blades attached to it in both the directions, thereby , clearing up any jammed scrap plastic as well. Also, for shredders, feeding is quite a straight forward process through the hopper.

Keeping in view the above presented comparisons, for the purpose of reducing the waste plastic bottles into small sized flakes, shredders are the most suitable machine to be used.

Shredder Design:

There are two major designs in use for shredders:

1. Single Shaft Shredder
2. Double Shaft Shredder

There is another third type as well which is the multi shaft shredder with screen as well.

Both these shredder designs have their respective advantages and disadvantages.

Double Shaft Shredder:

- Used mainly for small to large sized relatively light or hollow products.
- Once the material is fed into the hopper, the two shafts of cutting blades hook the material and bite it until it's fully swallowed and shredded down in size.
- There is no screen underneath the shafts to regulate the flake size.
- Used for shredding composting, municipal solid waste, tires, metals, industrial waste, electronic scrap, plastics and paper.

Single Shaft Shredder:

- Used mainly for thick and solid materials.
- Once the material is fed into the hopper, the side plate ensures that it goes into the single shaft with cutting blades for proper size reduction and efficient shredding.
- There is a mesh screen underneath the rotary shaft to regulate the flake size. The material will be repeatedly shredded by the rotary blades until it is fine enough to pass through the screen mesh.

- Used for shredding plastic purging, foam, fiber, paper, rubber, plastic bottles etc.

Table 6 Comparison of Single And Double Shaft Shredders

	Double Shaft	**Single Shaft**
Applications	For shredding composting, municipal solid waste, tires, metals, industrial waste.	For shredding plastic purging, foam, fiber, paper, rubber
Motor Speed (RPM)	10-20	70 -110
Flake Size	Quite random since no screen mesh.	Can be controlled using screen mesh.
Materials	Small to large sized relatively light and hollow products.	Thick and solid materials.

On the basis of the comparisons presented above between the single and double shaft shredders, the requirements of our project were more specified to the single shaft shredders.

So naturally as per our requirements, we opted for a single shaft shredder.

Our requirement is to have a motor that has less RPM but generates greater torque in order to ensure that the shredder rotary blades don’t get stuck because of the plastic pieces between them. Blades assembly length or the shaft length has been set keeping in view the longitudinal length of a standard 500ml drinks bottle.

Components of the Shredder:

Shredder consists of the following components:

1. Shredder Box
2. Motor and Gearbox
3. Blades (Static and Rotary)

Shredder Box:

The box of shredder is critical in the sense that the side plates and the screen mesh form a part of it. Side plates and screen mesh are pivotal for the shredding operation as the former ensures appropriate force on the material between the blades and the side plate whereas the latter is responsible for regulating uniform sized plastic flakes.

A shaft passes through in between the side plates , upon which are placed the rotary blades along with the spacers. On both ends of the side plates are placed two bearing blocks for the purpose of keeping the shaft aligned and in its proper position.

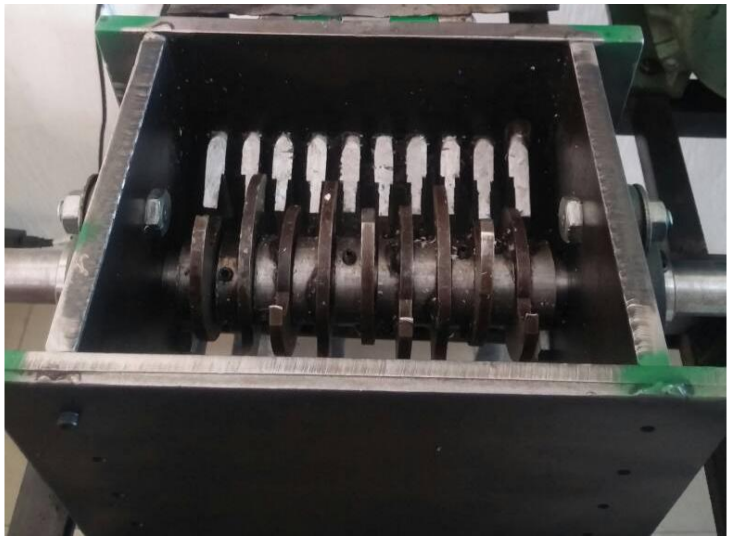


Figure 9 Shredder Box

Motor and Gearbox :

The power calculations for the motor required for smooth operation of the shredder is given below :

- Sus = 0.577 x 55 Mpa
  = 31.73 Mpa
- Shear Area (Effective Area w.r.t blades) = 164mm^2
- Assuming a safety factor of '2', **Fsh = 31.73/2 Mpa * 77 mm^2**
  Shear Force = 1.22 kN
- Torque = 2 x 1.22 kN x 25mm (radius)
  = 61 Nm
- Shaft Power = 61 Nm x 7.33 rad/s
  = 0.64 hp = 1.0 hp approx.

Hence, keeping in view the above calculations, the motor that we used was of 1 HP, 1450 RPM and single phase AC Induction.

Now, for the purpose of shredding effectively, the motor requires its RPM to be less but the torque to be maximized, as given by the following relation :

$$P = \tau \times \omega \quad \Rightarrow \quad \tau = \frac{P}{\omega}$$

So, a gearbox was attached with the motor for the purpose of reducing the RPM. The specifications of the gear are that it operates on 1:20 , thereby reducing the output to 71 RPM.

Blades :

The major components needed in this regard would be:.

Rotary Blades

The designing of rotor blades was indeed a big challenge for us. It had to be made in such a way that they could crush the plastic that is being fed into the hopper, into very small flakes. However, a total of 10 blades of 5mm thickness were agreed upon. The manufacturing of these blades took places on Electric Discharge Machine (EDM). Each of these 5mm stainless steel blade is alternatively placed on the shaft with a spacer in between. The spacers used have a thickness of 12mm and are made of Mild Steel.

Figure 10 3D Printed Sample Blade

The actual rotary blade manufactured using EDM machine was a lot sharper and had fierce edges because of the design changes that were made after the 3D manufactured sample blade.

Figure 11 Rotary Blade Manufactured through EDM

Static Blades

On one end are the rotary blades but to engage the plastic bottles in between two sharp edged corners, we used a set of 10 static blades on one of the opposite walls to the shaft. These static blades were 7mm in thickness initially but owing to the limitations in the manufacturing and misalignment of the assembly, they had to be trimmed down to 5mm in thickness each.

Figure 12 Static Blades For Shredder Box

Side-Plate

The side plate is made from 6mm sheet of Mild Steel and their slots are milled in one of the plates of the shredder box. The static blades are then fixed in these slots. Lesser the distance, smaller will be the size of the flakes.

Manufacturing Method for Shredder Blades

One of the primary difficulties that we were faced with whilst opting for and designing the shredder was the manufacturing of the shredder blades and how we would go about doing that. For this purpose, we had two major choices which were:

1. To get the blades and parts laser cut.
2. To get them manufactured using the EDM machine.

Laser cut parts would not only have cost us a lot but would also have taken 4-6 weeks for delivery, rendering it unfeasible for usage given our time and budget constraints.

On the other hand, the EDM machine was already available in DMRC, SMME, so not only was the manufacturing time reduced by half but also made it feasible in terms of costing and finances involved.

Once the rotor blades were designed, they had to be fixed on the regular shaft with spacer blades in between. These spacer blades were welded to the rotor blades. A key way was also developed to ensure smooth rotation.

Compression Molding Machine

Second phase of the project is remolding the shredded plastic into our desired product i.e plastic pot. This was done using compression molding technique.
As this part of the project is in prototype phase, so we created a mini wooden oven using thermal electric collars (Resistance bands) for heating the mold and recorded the test results before crating a standard machine . The tests were conducted using different thermal bands positions and temperatures settings through Arduino and thermo-couple . For compression molding instead of using an automated compression mechanism, mold was designed with such characteristics of weight so as to compress the plastic upon melting.

Compression Molding is a method of molding in which the molding material is first placed in an open, heated mould cavity. The mold is closed with a top force or plug member, pressure is applied to force the material into contact with all mold areas, while heat and pressure are maintained until the molding material has cured. The process employs thermosetting resins in a partially cured stage, either in the form of granules or flakes .

The advantage of compression molding is its ability to mold large, fairly intricate parts. Also, it is one of the lowest cost molding methods compared with other methods such as transfer molding and injection molding; moreover it wastes relatively little material, giving it an advantage when working with expensive compounds.

However, compression molding often provides poor product consistency and difficulty in controlling flashing, and it is not suitable for some types of parts. Fewer knit lines are produced and a smaller amount of fiber-length degradation is noticeable when compared to injection molding. Compression-molding is also suitable for ultra-large basic shape production in sizes beyond the capacity of extrusion techniques.

Shredded Plastic State

The Plastic bottles were shredded and turned into flakes. The size of flakes depends on the length of the cut of blade. The blades were designed to achieve a 10mm by 5mm of flakes.

The size of the flakes cannot be controlled but re-shredding helps in reducing the size of larger flakes to increase efficiency of shredder. During the first time of shredding, a certain bottle size of flakes varies due to position of bottle whilst being struck by the blades.

Components

The components used to achieve remolding of shredded plastic to flower pot are :

1) Oven Prototype

A wooden box with an internal size of 8*8*8 inch was used . The box was internally lined with heat resistant aluminum tape . There were handles on the side and on the top cover to allow for safe handling. A hole for thermocouple was created to control and record the internal temperature of the oven. The aluminum tape and wood can withstand the temperature up to 400^{O} C.

Figure 13 Prototype Wooden Oven

2) Thermocouple

A K- type thermocouple with range from -50^{O} to 500^{O} was used with a MAX-6675 module for arduino. Thermocouple was used to record the change in temperature with respect to time and for controlling the thermal collars to maintain a specific temperature range.

Figure 14 K-Type Thermocouple

3) Mold

Flower pot mold consisted of two parts ; an upper part with an extra weight for compression and a lower part. The material used for mold was Mild Steel due to its high specific heat , thereby helping in gradual heating and cooling of the plastic.

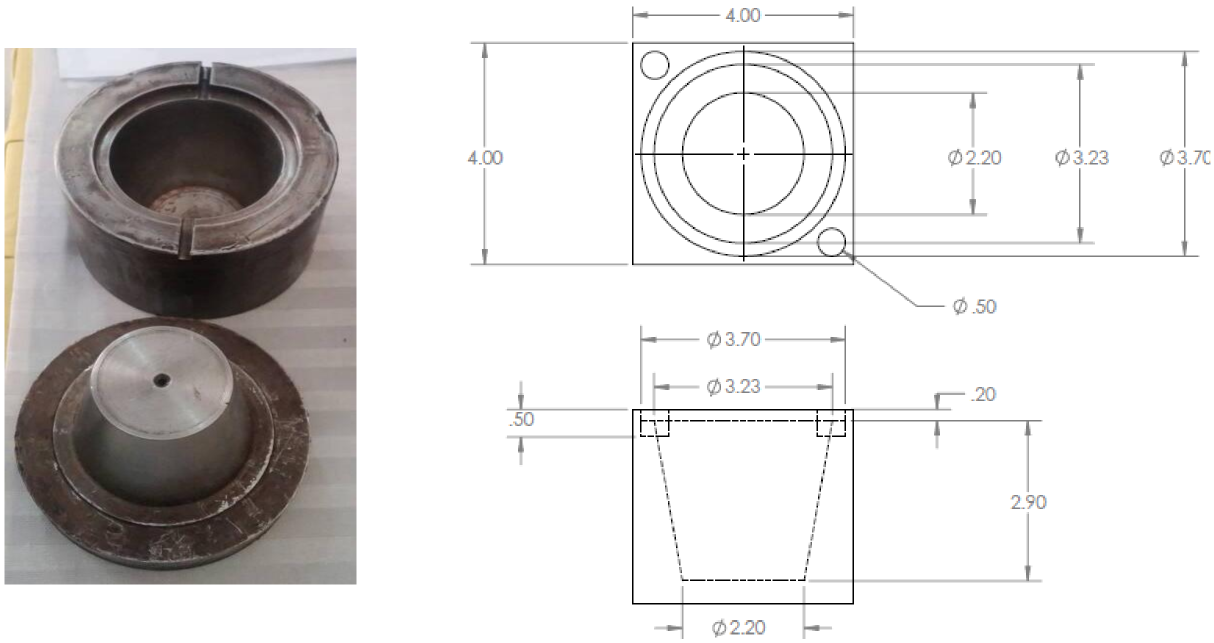


Figure 15 Mold

4) *Thermal Collars*

Thermal collars were our primary source of heating. Mold was placed in the center of the collar for uniform heating. Initially, single thermal collar was used but later two collars were used with mold in between for uniform heating from all directions.

Collar Specifications:

Current - 3A

Resistance – 28 M-Ohm

Diameter - 4 inch

Length - 8 inch

Voltage - 220V

Max. Temperature : $400^{O}C$

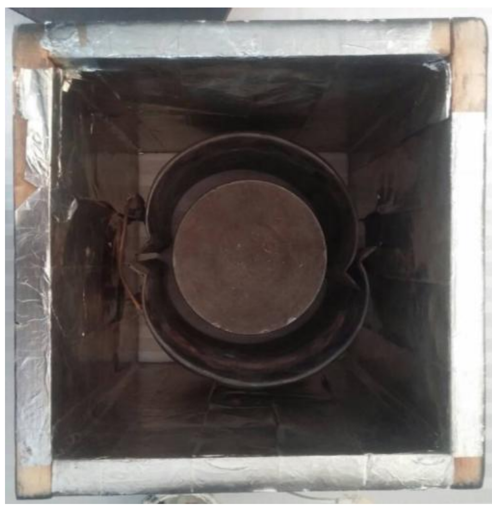


Figure 16 Thermal Collars

Usage Instructions

As this was a prototype, most of the work was done manually to achieve the results for automation and standardization.

Step-1

The mass of the flower pot produced using this mold is 56 grams. First step is filling the lower half of the mold with 65 to 70 grams of shredded flakes that will cover the 80% portion of the lower mold. It depends on the size of the flakes being used , larger flakes will cover larger volume of the mold. Place the upper half of the mold on the top of lower mold and align it. The extra weight of the upper half will compress the flakes. Place the mold in the center of wooden oven.

Step-2

Surround the mold with thermal collars placed facing each other , position the collars to center the mold. Thermal collars are connected in series and then to a 220V power source.

Step-3

Setup the thermocouple with Arduino and place it at its position on the top of the mold through top cover of the oven and start noting the readings. Thermocouple will show readings of the surface temperature of mold.

The melting temperature of HDPE is around 180^{O}C - 200^{O}C.The arduino is set to turn off the thermal collars upon reaching a temperature of 250^{O}C and turn on again at 200^{O}C. This helps in maintaining a uniform heating environment. For the plastic to melt completely and take the shape of the mold takes about 30 – 40 minutes.

Step-4

After heating to the said time, remove the mold from oven and cool the mold using running water for 10 – 15 minutes and remove the molds halves to separate the molded product.

HDPE does not stick to MS if heated below decomposition temperature but for convenience, that can withstand the temperature can be used which will help in removing the molded part.

CHAPTER 4

RESULTS

Since the project was based around building a cost effective plastic recycling setup, so the two main modules of the project namely shredder and compression molding machine had different outputs but the entire system as a whole had one complete finished product in the form of a plastic pot.

Discussion

Shredder :

The desired product of the shredder was in the form of flakes of the plastic bottles utilized. The desired aim was to make plastic shreds not more than 6*6 mm. But owing to the manufacturing limitations and increased blade spacing, this could not be accomplished. However, shreds of unequal dimensions were obtained.

Figure 17 Flakes of Shredded Plastic Bottles

To further enhance their quality and efficiency, however, re-using the shredded plastic as feed is a good choice.

Compression Molding :

This phase of the project i.e obtaining finished product using the flakes was of prime importance. This was so because the entire project rested upon the final outcome of the plastic pot. This required patience and more than one attempts were made. Gradual improvement in the plastic pots obtained took place and by incorporating learnings from all the previous attempts, the final attempt was successful.

We conducted several test samples to achieve our required product. The finish quality and strength of the molded pot was excellent from the first sample but it took us several attempts to achieve the required size in desired time.

First Attempt :

Figure 18 Plastic Pot Obtained in 1st Attempt

- Uneven due to non uniform heating (using only one collar), plastic on the contact side of the collar rose faster compared to the opposite side.

- Brownish top obtained due to excessive heating above decomposition temperature. (The convection currents from collar are at above $300^{O}C$ temperature causing excessive heating of exposed region of plastic in mold. Also, since HDPE plastic was used, this temperature was well above its melting point and was nearing its decomposition temperature.)

Second Attempt:

Figure 19 Plastic Pot Obtained in 2nd Attempt

- Semi Uniformity was achieved due to changing of the position of collar to other side during heating (using only one collar). This was another attempt at obtaining uniformity in heating and plastic spread.

- Brownish top surface due to excessive heating above decomposition temperature. (The convection currents from collar were at above $300^{O}C$ temperature causing excessive heating of exposed region of plastic in mold.

Third Attempt:

Figure 20 Plastic Pot Obtained in 3rd Attempt

- Plastic rose evenly this time due to the use of two collars for uniform heating.
- Brownish top surface due to excessive heating above decomposition temperature. (The convection currents from collar are at above $300^{O}C$ temperature causing excessive heating of exposed region of plastic in mold.)
- In an attempt to prevent the plastic pot from sticking to the surface of the mold, mobil oil coating was spread on the mold's exterior surfaces. But instead of this proving to be helpful in removing the plastic pot from the mold, it did the exact opposite. Oil got burnt and led to the pot sticking to the mold

Final Attempt

Although all the previous attempts had been successful at making the plastic pots too but some sort of incompletion was there because of which the proper finished product essence was missing. To deal with this, a couple of new methodologies were introduced in the process as stated below :

Figure 21 Final Plastic Pot

- Plastic rose evenly this time due to the use of two collars for uniform heating.
- Exposed area of plastic to convection currents were covered through heat resistance tape helped in maintain the temperature below decomposition temperature.
- To ensure that the molten plastic doesn’t stick to the internal surface of the mold upon heating and re-solidification, a thin coating of compressor oil was placed on the inside of the lower part of the mold and the outside of the upper part of the mold. The properties of this oil enable it to withstand temperatures greater than $300^{O}C$.

Comparison with the Similar Works :

Our project was inspired by the recycling setups made by Mr. Dave Hakkens. Judging against those standards that he’s set, we believe that the work we’ve done and the results we’ve obtained in our very first attempt of manufacturing this setup are quite satisfactory.

Given the budget constraints and the manufacturing limitations, the investment of time and money that this project took us was well within our desired goals. Infact , to our surprise as well, it was much lower than the reference project of similar nature.

Figure 22 Comparison of Reference and Manufactured Shredder

Summary

Although the results obtained weren’t exactly perfect in our initial attempts, yet after sufficient working on improving the blade spacing, the motor alignment and assembly in the shredder and multiple attempts at ensuring uniform heating in compression molding process, significant improvements were made .The flakes as well as the plastic pot obtained at the end were quite close to the set target. Both the machines making up the recycling setup, though not in the perfect shape possible, performed their tasks in quite a satisfactory manner to accomplish the laid out task.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

So essentially we chose to run in light of this venture keeping the perils that plastics and the landfills are creating to nature. We do feel that recycling of plastics is one of the most ideal approaches to decrease this mischief and even make openings for work for individuals intrigued by this field. We had this inspiration at the back of our mind that alongside the final year project, we accomplish something that is useful and advantageous for the general public. Our recycling machine expects to diminish the quantity of restrains that end in landfills and are making harm to the Mother Nature. On the off chance that making valuable items out of these bottles is conceivable and that too at a nominal price, then what are we sitting tight for?

Making advances on the machine itself, there were certainly a few weaknesses of course. Which can be overcome later on or enhanced to make the working of the machine more viable. We can examine them one by one to make the working all the more clear. At first we began with the assembling of the shredder box. The static blades were fixed on the plate such that the rotary blades passed through them. That is the reason the cutting of the blades must be done truly accurately so they could be moving without touching each other. In spite of the fact that EDM technology was utilized for the cutting of rotary blades and Gas cutting technology for the static blades, we still couldn't manage to accomplish the exactness. This rose to the issue as said over, that the blades were touching each other. So keeping in mind the end goal to resolve this, we additionally reduced down the thickness of the static blades through milling. This time around, enough crevice was made which helped the revolving blades to pass through them effectively. However, it expanded to such a degree that the plastic began clogging up in the middle of amid the operation. Because of this, the extent of the flakes was additionally much larger than we desired.

In future, we can keep away from this specific issue by utilizing laser cutting technology and making the openings in the plates with more accuracy. This will help us in moving the blades easily between the plates with least spaces. So the flakes will be acquired according to the requirement.

Another issue that we confronted during the second stage that was the compression moulding, was that uniform heating couldn't be achieved. Because of this issue, plastic confronting the electric collar heater was heated more when contrasted with the opposite side. In the underlying trials, when the amount of plastic required for one entire pot was uncertain, the plastic rose rapidly at the neckline side when compared with the opposite side. In spite of the fact that we halfway came over this issue by utilizing two electric collar heaters confronting each other, regardless we believe that a more effective heating system could be concocted. An electric broiler could be a decent alternative however that too would have been exorbitant contrasted with the system we adopted.

Since we were using electric collar heaters, so the power utilization was truly high. This certainly wasn't practical when contrasted with different strategies and thus, other techniques ought to be looked upon.

Another issue that we confronted while hearing plastic was that it stuck with the mold. It turned out to be truly hard to take that off, and once in a while it even got damaged. Indeed, even in the wake of utilizing some oil/lubrication, we could eliminate the issue up to some degree yet not completely. Research can be made further by including some added substance or other chemical which keeps the plastic from sticking to the mold.

Recommendations for the Future

PlastECO , because of the idea and the vast variety of plastics involved as well as the methodologies of utilizing this plastic to make assorted products, has huge potential going forward. Our primary focus has just been to demonstrate the do-ability of this project. Ours was just the first step of the journey. Making the prototype for recycling was our biggest accomplishment since we made it out of scratch with our own calculations and numerous hit and trial attempts. Ours was the hard bit of combining the components that were always doubtful. There were points in time when we ourselves lost the confidence and belief that it could be done but we kept going forward. Because of the mission involved and the targets we'd set.

What lies ahead for PlastECO is open avenues for research. Research on the different grades of plastics . For the purpose of demonstration, we stuck to only PET and HDPE grades of plastic resins. But now that the setup exists, this concept can be extended very easily to the other grades of plastics too. As far as the improvements in shredder are concerned, the primary change to be made to it would be the re-manufacturing of the static blades and their proper alignment with the rotary blades in a manner that would enable the inter-space differences between the two to be minimum, thereby greatly improving the shearing potential of the shredder. It would also lead to betterment in the flakes obtained as they would be smaller in size and most optimum for usage in molding operations.

Although the shredder does need further improvements but certainly not as much as the molding operation. The process that we used for the purpose of our project was compression molding and it was accomplished using a custom made wooden oven lined internally with aluminium heat resistant tape. The areas of exploration and discovery, however, are still open not just in terms of betterment of the compression molding process but also expanding it to encompass injection and extrusion molding procedures.

As for the compression molding operation, instead of using this prototype oven, a larger oven made of stainless steel sheets with wool insulation in between subsequent layers can be made. Such an oven would utilize heating coils for the purpose of raising temperature to the melting point of plastic flakes. The capacity of such an oven should ideally be large enough to allow for 5 to 6 molds to be placed in it simultaneously. Energy consumption during heating as well as the efficiency in terms of costs would improve manifolds this way.

Not just this but improvements could also be made along the lines of chemical properties of plastics , keeping under consideration the assorted fillers and additives that can be amalgamated to produce dazzling products , not just attractive from the looks but also resistant and durable.

Fillers/ Additives

The main problems encountered in plastic recycling are:

1. Degradation of plastic during processing and product lifetime.
2. Incompatibility between polymers (when mixed heterogeneous plastics are recycled.

The degradative phenomena is experienced more in homogenous plastics than in virgin polymers due to the formation of oxygenated groups during the processing or during use. The following effects are witnessed due to the degradative processes:

I. Variations in molecular weight (which can also induce changes in crystallinity).
II. Formation of chain branching.
III. Formation of oxygenated compounds, unsaturation etc.

To overcome this, fillers and modifiers are added to reduce the negative effects of recycling steps. It can also enhance the mechanical properties of plastics**.** Plastic additives reinforce fibers to make the base polymer stronger. Conductive fillers build electromagnetic shielding property into plastics. Fillers are both organic and in-organic.

So in short we can summarize the following reasons for the use of fillers:

a. Bulk up plastics to reduce the cost.
b. To improve the stiffness and hardness of plastic hardware.
c. Improve the mechanical properties (modulus and tensile strength).

Some of the classes of the additives are:

A. *Processing Aids*

   It improves the polymer accessibility

B. *Antioxidants and Stabilizers*

   Delay the degradative process

C. *Mineral Fillers*

   Can decrease the cost and enhance some of the properties

D. *Impact Modifiers*

   Increases the impact strength values

E. Compatibilizers

   Improves the compatibility between incompatible polymers

Filler that can be used in our case (HDPE) is Calcium Carbonate**.** It can improve the modulus and tensile strength of HDPE. It can help in reducing the wall thickness without an increase in the bottle weight.

Lastly, one major element that is missing from this project uptill now is the automation bit. With a project of this much attraction for the public and idea of international significance and interest behind it, it would be a shame to not have a fancy control panel attached to it. Basic PLC circuit could be the way to go forward for this automation scheme. The final goal should be to see this recycling setup in as compact a form as a vending machine.

The concept of recycling in Pakistan is only in its pre-mature days. Not only is a boost needed to pace it up and place it on the fast track to raising awareness in the masses but even more than that , public interest and incentive schemes are the need of the hour. With the population of our country increasing at an explosive pace, consumption of commodities is also on the rise exponentially. The only way to save our environment from the menace of landfills is to make the common man involved in the recycling loop and to build up the confidence needed in the people that recycling is not just a possibility but it is indeed a reality. In the short-term goals, we wish to see two of these setups installed at NUST to cater to the plastic bottle waste of the campus. The long-term goals of the project , undoubtedly, are to see the people of this nation realizing the importance of caring for Mother Nature and making a conscious effort to make a difference.

10 months ago, PlastECO was just an idea. A dream of three young boys aspiring to add value to the community. Fast-forward to this day, this idea is now a reality. As the famous saying goes , *"The hardest thing about getting started is getting started".* We've taken the first step. PlastECO is not a destination , it's a journey that needs to continue for the sake of raising awareness about protecting our planet and bringing Pakistan at par with the environmental standards. We conclude our work on this project with the hope that regardless of who chooses to be the flag-bearer of this caravan, the recycling dream will go on.

Reduce. Recycle. Reuse. And Rejoice

WORKS CITED

[1] Anddrady A. L., N. M. (2008). Applications and Social Benefits of Plastics. *Phil Trans. R. Soc.* , 1977-1984.

[2] Arena U., M. M. (2009). Life Cycle Assessment of a plastic packaging recycling system. *Int. J. Life Cycle Assess* , 92-98.

[3] Geo Raju, M. L. (2014). Recent Methods for Optimization of Plastic Extrusion. *International Journal of Advanced Mechanical Engineering* , 583-588.

[4] Huiting Shen, R. P. (1999). A review of plastics wasterecycling and the flotation of plastics. *Elsevier* , 85-109.

[5] Jefferson Hopewell, R. D. (2009). Plastics recycling: challenges and opportunities. *Royal Society Publishing* , 1-12.

[6] Rizwan Mohd Khan, G. A. (2016). Plastic Injection Molding Process and Its Aspects for Quality: A Review . *European Journal of Advances in Engineering and Technology* , 66-70.

APPENDIX I: PHYSICAL PROPERTIES OF PLASTICS

Table 7 Recyclable Plastics – Physical Properties

Plastic	Thermal Properties				Strength		Density
Abbreviation - Brand name	Tm	Tg	Td	Cte	Tensile	Compressive	
	°C	°C	°C	ppm/°C	psi	psi	g/cc
PET - Polyethyleneterephthalate	245 265	73 80	21 38	65	7000 10500	11000 15000	1.29 1.40
LDPE - Low density polyethylene	98 115	-25	40 44	100 220	1200 4550		0.917 0.932
HDPE - High density polyethylene	130 137		79 91	59 110	3200 4500	2700 3600	0.952 0.965
PP - polypropylene	168 175	-20	107 121	81 100	4500 6000	5500 8000	0.900 0.910
PVC - polyvinylchloride		75 105	57 82	50 100	5900 7500	8000 13000	1.30 1.58
PS - polystyrene		74 105	68 96	50 83	5200 7500	12000 13000	1.04 1.05

Tm - crystalline melting temperature (some plastics have no crystallinity and are said to be amorphous).

Tg - glass transition temperature (the plastic becomes brittle below this temperature).

Td - heat distortion temperature under a 66 psi load.

Cte - coefficient of linear thermal expansion.

Tensile Strength - load necessary to pull a sample of the plastic apart.

Compressive Strength - load necessary to crush a sample of the plastic.

Density - aka specific gravitymass of plastic per unit volume.

APPENDIX II: ARDUINO CODE FOR TEMPERATURE MONITORING

```
#include "max6675.h"
 int ktcSO = 8;
 int ktcCS = 9;
 int ktcCLK = 10;
 MAX6675 ktc(ktcCLK, ktcCS, ktcSO);
 void setup() {
 Serial.begin(9600);
 // give the MAX a little time to settle
 delay(500);
 }
void loop() {
 // basic readout test
 Serial.print("Deg C = ");
Serial.print(ktc.readCelsius());
 Serial.print("\t Deg F = ");
Serial.println(ktc.readFahrenheit());
 delay(200);  }
```