HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCE

Development of a small-scale plastic recycling technology and a special filament product for 3D printing

PhD Dissertation

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NOMENCLATURE AND ABBREVIATION

ABS	**:**	Acrylonitrile butadiene styrene
PET	**:**	Polyethylene terephtalate
rPET	**:**	Recycled PET
PP	**:**	Polypropilene
RPM	**:**	Revolution per minute
PE	**:**	Polyethylene
HDPE	**:**	High Density Polyethylene
LDPE	**:**	Low density Polyethylene
FDM	**:**	Fused Deposition molding
Z 100	**:**	Zwick 100 testing machine
Mpa	**:**	Megapascal
AM	**:**	Additive Manufacturing
ASTM	**:**	American Society for Testing and Materials
BCG	**:**	Boston Consulting Group
BoP	**:**	Bottom of Pyramid
CE	**:**	Circular Economy
CP	**:**	Cleaner Production
EU	**:**	European Union
FDM	**:**	Fused Deposition Modelling
HDPE	**:**	High density polyethylene
IT	**:**	Information Technology
IoT	**:**	Internet of Things
LDPE	**:**	Low density polyethylene
MFI	**:**	Melt flow Index
NAPC OR	**:**	National Association for PET Container Resources
PET	**:**	Polyethylene terephthalate
PLA	**:**	Polylactic Acid
PP	**:**	Polypropylene
PS	**:**	Polystyrene
PS	**:**	Polycarbonate
PVC	**:**	Polyvinyl chloride
RPET	**:**	Recycled Polyethylene terephthalate
SD	**:**	Standard Deviation
STL	**:**	Stereolithography
UNEP	**:**	United Nations Environment Programme
USD	**:**	United Stated Dollar
VC	**:**	Variance Coefficient
3DP	**:**	3 Dimensional Printing
EBM	**:**	Electron Beam Machining
FDM	**:**	Fused Deposition Modelling
FFF	**:**	Fused Filament Fabrication

I. INTRODUCTION, OBJECTIVES

This chapter presents the background and the importance of the study as well as the objectives of the research.

1.1 Introduction

Plastic has long been considered a manmade material with many benefits. It has lightweight properties and is easily shaped to the designer's desires. Its versatile properties have led to its widespread use. Since 2016–2017, plastic consumption has increased from 335 million tons to 348 million tons and reach 370 million tons in 2019 (Rakesh Kumar et al., 2021). This demand is expected to reach 485 million tons by 2030 (EEA Report., 2019).

The downside of plastic use is the waste generated and the environmental pollution caused because many plastics are not biodegradable and can take between 500 and 1000 years to decompose. The pollution risks from the toxins released can impact groundwater quality, animal/human health, food-chain poisoning, and reduction in soil fertility (Rinku verma et al., 2016). Furthermore, if burnt in an open space, plastics produce carbon monoxide (a greenhouse gas). If disposed of in waterways, plastics can cause siltation and impede water flows, thereby creating a flood risk (Tim van Emmerik et al., 2019).

In 2018, processing plastic waste for energy used 43% of all of the collected post-consumer waste stream. Furthermore, the insufficient processing and management of plastic waste worldwide face the challenge of insufficient plastic waste treatment facilities at all stages of collection, separation, and disposal. By 2050, it is projected that about 12 billion metric tons of plastic litter will end up in landfills and the natural environment (Roland Geyer et al., 2017).

Waste components produced in the additive process reveal various phenotypes. Low cost, rapid, and stellar accessibility are among the strengths of additive manufacturing. Additionally, parts that are usually disposed can be utilized, as well. Acrylonitrile butadiene styrene is one of the ingredients within plant material or petroleum that is used in 3D thermoplastic (Gibson et al., 2015; Berman et al., 2012). The easy-to-use nature of the technology is one of its greatest strengths, where the general production process and layering of materials using a computer-guided tool is made simple. By streamlining the processes, tools, and parts involved, needless effort and toil by the user is averted while giving an ample scope for designers to create. These improvements profoundly impact production costs within mechanization and line production, elevating the profit margin by USD 5 billion by mitigating inflated production costs. From the opening quarter of 2020, 3D printing was forecasted to increase to between USD 7 and 23 billion (Huang et al., 2013; Kira et al., 2016), while the global market of 3D printing is predicted to jump to USD 51.77 billion by 2026. In addition, 200 million users are forecasted to be reached due to the demand of injection moulding plastic. The continuously evolving technology and adaptability of 3D printing has seen it grow in the present market, contrasting with injection moulding (Columbus et al., 2015).

Nevertheless, regarding quality and the standardization of the finished product, the injection moulding process remains superior to 3D printing. While 3D printing can create roughly 5000 distinct sizes and shapes for components, it is typically used for small production units in competitive settings. The standard practices and technology implemented by a specific organisation or country determine which materials are used for 3D printing. Whether making bottle caps, jugs or plumbing pipes, using HDPE or bottle manufacturing and fiber using PET, plastic wastes are usually recyclable. PET is considered the optimal recyclable material when 3D printing. Prior to the extrusion process, the PET is dried. HDPE, ABS, and PET are moulded into pellets after being shredded when a plastic pellet formation is sought. While sheets are frequently constructed using injection moulds, the creation of 3D printers occurs through laments being formed after additional processing of the pellets. Similar to any manufacturing technology, difficulties and obstacles persist, yet the various methods mentioned to recycle plastics are both affordable and easy to use (Al salem et al., 2009). Through the presence of polylactic acid, losses to the tensile strength were found, yet were negligible after the extruded PET was recycled over 10 times. A marginal loss in the mechanical properties of polypropylene (PP) and polybutylene terephthalate (PBT) was found after mixing the polymers at distinct ratios. Prior to use in component fabrication, the mechanical properties of a 3D printed PET filament remained unaffected after being recycled five times, as per a study in the field. Nonetheless, at the fracture point, a 10% reduction in elongation was observed (Community for plastics professionals., 2020).

Gases are released at high temperatures due to 3D printing thermoplastic. Hydrogen cyanide, carbon monoxide, and other instable organics were identified as outputs when using ABS (ASTM D638-14., 2020). There are potential health risks when using ABS which emits a higher quantity of ultrafine particles than the PET filament. Contaminates and pollutants linked to health risks are a principal cause of this. Prior to further research, these risks should be taken into account. Thus, the process of 3D printing must include an adequate ventilation system to avert these risks. Presently, the next generations of 3D printers may include HEPA filters to mitigate these risks, as these filters are tried and tested within desktops in the current market (R. Joseph et al., 1986).
Sixty percent of plastic materials stemming from synthetic fibers meet the world-wide requirement of 30%. Polyethene (PE) and polypropylene (PP) are the largest usable polymers, while PET comes third, also known as polyester, making up 18% of the global polymer production (Stephens et al., 2013). In 1973, Nathaniel Wyeth removed the patent of the first PET bottle. Solar cells and thin films are additional materials made using PET (Perkins et al., 2020).

The objective of this thesis is to examine the feasibility of utilising recycled polymers for the production of 3D printed components, while also investigating the specific conditions that facilitate this process. Additionally, the study will explore the impact of mechanical qualities on the suitability of these parts for various applications.

1.2 Objectives

Having studied the applied plastic recycling technologies, materials for 3D printing and the 3D printing technologies I realized that the quantity and quality of plastic waste differs from country

to country and from company to other. In the case of waste plastics that are recyclable and reusable, the most widely used are polyethylene terephthalate (PET, used for synthetic fibers and water bottles), and second high-density polyethylene (HDPE, used for jugs, bottle caps, water pipes)

The current utilisation of recycled plastics in fabrication and design is relatively restricted. At a small scale, plastics like ABS, HDPE, or PET are shredded and transformed into pellets. These pellets are then either extruded into filament for use in existing 3D printers or injection moulded into small parts and pieces of larger components. On a significant scale, high-density polyethylene (HDPE) that has been recycled is melted and transformed into sheets. These sheets are then either immediately utilised in building or further moulded into construction components through the application of heat. The utilisation of recycled plastics in these manufacturing methods is common due to their cost-effectiveness and uncomplicated procedures. However, each method still lacks some intricacy.

Regarding the recycling technology, we mention the previous methods of recycling and recovery routes for solid plastic waste. The main routes of PSW treatment are detailed and discussed covering:

- re-extrusion
- mechanical treatment
- chemical treatment
- energy recovery
- schemes and technologies.

We will examine the prior study on the utilisation of ABS filaments in MakerBot 3D printers for filament materials. Additionally, we will provide a portion of the literature review that focuses on the incorporation of particles, resins, and fibres. Firstly, it is essential to thoroughly examine the material properties and production methods used in the sector. Additionally, consider the environmental parameters that influence the selection of a printing mode. Perform an investigation on the various classifications of plastics and the currently available methods for recycling and 3D printing. Formulate a hypothesis and establish a systematic method for analysing and developing recycling technologies. Develop a comprehensive system plan for the advancement of 3D printing filament materials, utilising systems engineering theories to guide technological progress. Finally, conduct field and laboratory testing to assess the physical, mechanical, and application characteristics of the materials.

The aim of this paper is to evaluate the mechanical properties of the samples fabricated from the initial PET filament. The original 3D samples are utilised to fabricate the specimens utilising the PET filament, which are subsequently contrasted with the findings of the study. The recyclability of PET was the determining factor for its selection in this work.
The primary objective of the research is to perform a thorough examination of the utilisation of waste plastic bottles (PET) and tanks (low density polyethylene) as a constituent in concrete, without any additional processing other than grinding. This is done with the intention of reducing the overall cost of the final material.

The specific research aims are as follows:

Researching recycling technologies, materials, and 3D printing technologies. Examined and investigated the impact of varying waste proportions on the physical and mechanical properties of the novel material, specifically in relation to concrete. Assessing the mechanical characteristics of samples made from virgin PET filament and comparing them to recycled materials, specifically in relation to their impact on concrete

II. LITERATURE REVIEW

In this chapter, the related studies on the subject are reviewed, laying bare the existing knowledge gaps in terms of the challenges encountered by previous researchers and their recommendations for 3D printing and recycling technologies. The intensions of this study in filling the knowledge gaps are also enumerated.

2.1 3D printing technologies

The objective of humanity is to eliminate the production of any waste made of plastic by means of production cycles that are both regenerative and cost-effective. The use of 3D printing as a potential solution for the implementation of waste polymers to the maximum extent possible is one area that might be addressed. (Jones et al., 2011)

A technology that falls under the category of additive manufacturing (AM) and is more frequently referred to as 3D printing is called fused filament fabrication (FFF). (Zhu et al., 2021)

Three-dimensional (3D) printers are gaining popularity as rapid prototyping and small-scale manufacturing devices. The development of low-cost desktop versions has made this technologywidely accessible for use in home and office settings. The majority of commercially available 3D printers utilize an additive manufacturing technique known as molten polymer deposition (Siraj et al., 2021)

(MPD), whereby a solid thermoplastic filament is forced through a computer-driven extrusion nozzle (Bumgarner, 2013). The heated nozzle melts the thermoplastic feedstock and deposits streams of extruded plastic in thin layers across a moving baseplate. As the material hardens and the baseplate moves to the next layer, a three-dimensional solid shape is rapidly formed.

The story of 3D printing—or additive manufacturing—was initiated as a "rapid prototype development" tool, which is one of its major applications, and which led to advanced 3D printing technology in the application of a wide range of diverse fields, such as manufacturing, medicine, architecture, custom art, design, and the list goes on. This new volume, 3D Printing Technology and Its Diverse Applications, explores the exciting and diverse applications of threedimensional printing in a variety of industries, including food processing, environmental sciences, biotechnology, medical devices, energy storage, civil engineering, textiles and fashion industry, and more. 3D printing is rapidly transforming the way products are designed and manufactured across complex supply chains. (Kamran et al., 2016)

Over the past decade, newer challenges are being addressed by 3D printing, and a technology that was once popular in the aerospace and automotive industries is today an integral part of jewelry design, architecture, medical, storage devices, biotechnology, shop floor innovation, to name a few. This book explores many of these diverse applications and describes the various 3D printing methods, the commonly used materials, and the pros and cons. (Al-maliki et al., 2015)

The book also includes an overview of the historical development and modern-day trends in additive manufacturing as well as an exploration of the prospects of 3d printing technology in promoting academic education. The informative volume gives readers a thorough understanding of the versatile applications of 3D printing in various domains of engineering & technology and beyond (3D printing technology and its diverse applications., 2022).

Manufacturing and technology environments are fuelling a new generation of engineer, scientist and designers. Just as it made at home polymer 3D printers a commonality today, theworld could eventually see a metal or ceramic 3D printer become common in an averagehousehold. To achieve this goal, future inventions in next generation structures using existingmaterials via AM will surely need to revolve around cost reduction, improved performance andadvanced structural design (Arup Dey et al., 2021). The study conducted for 3DP ofmultilateral component of acrylonitrile butadiene styrene (ABS) and thermoplasticpolyurethane (TPU) reveals with support of 3D imaging that interface properties are found incontrol with good layers connectivity.

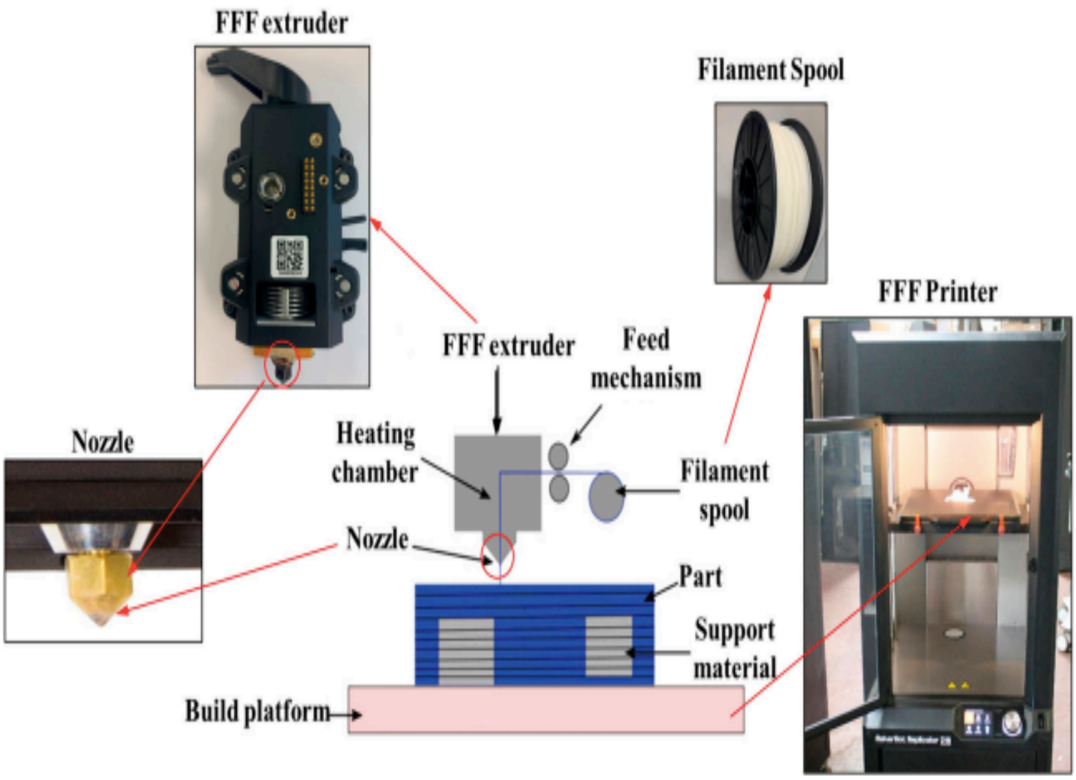


Figure 1 - A schematic diagram of the fused filament fabrication (FFF) process (Ala'aldin Alafaghania et al., 2017)

2.2 Waste management and recycling

In the 21st century, rapid growth of the population, urbanization, industrialization, modernization and digitalization results in the increase in wastes such as Domestic, Industrial, Commercial, Mining, Radioactive, Agricultural, Hospital, Electronic wastes, etc. Managing these wastes are becoming more biggest problem in the world. Waste management is the process of collecting, transporting, segregating, discarding, destroying, processing, recycling, controlling, monitoring and regulating the garbage, sewage and other waste products. Main objective of the waste management is to save the environment from detrimental effects, free from pollution and also to protect the people's health from the hazardous effects. To manage these wastes, many modern methods are adopted in the worldwide. They are biological reprocessing, recover through recycling, dumping in sanitary landfill, composting, waste to energy, bioremediation, incineration, pyrolysis, plasma gasification, disposal in ocean/sea, etc. These waste management techniques make the environment a better place for the living creatures to survive. This also paves the way for the future generation to live in the peaceful and healthy environment (Kumar et al., 2021)

Saving our earth planet from the contamination became a giant challenge for us. To conserve our natural resources, wastes should be maintained properly. So that all living beings on this earth can live safely and get benefits from it. The process of managing waste is called as waste management (Vijayalakshmi Murugesan., 2020).

Figure 2 - Solid Waste Management Proces (prepp Solid waste management)

Waste management consists of a series of steps such as collection of the waste, segregating it on the basis of its nature, transporting carefully and labelling them, undergoing various types of treatment in order to reduce the its hazardous effect and disposing it by burning, burying and recycling methods, etc. These steps prevent the spread of pollution, reduces the hazardous effects and keeps the environment clean. So, the environment became a good habitat for all living creatures. (Sonjaya et al.,2022)

2.3 Recycling technolgies

Plastics recycling is complex and sometimes confusing because of the wide range of recycling technologies and recovery activities. These include four categories: mechanical reprocessing into a product with equivalent properties, secondary mechanical reprocessing into products requiring lower properties, and recovery of chemical constituents and quaternary recovery of energy.

Biodegradable plastics can also be composted, and this is a further example of recovery of chemical constituents and is also described as biolgical recycling.

2.3.1 Primary recycling

2.3.1.1 Re-using recycling

Before 40 years, re-utilization of post-buyer bundling as glass containers and jugs was normal.

There are restrictions to the excessive and extensive usage of inflexible compartment re-utilization; which are at any rate usually estimated. The dissemination and accumulation focus is generally far away from unified item filling manufacturing plants and would bring about impressive back-pull separations.

Also, the extensive variety of compartments and packs for marking and promoting purposes makes coordinate reclaim and refilling less practical. Reclaim and refilling plans do exist in a few European nations (Institute for Local Self-Reliance 2002), including PET containers and also glass, however they are somewhere else for the most part considered a specialty movement for neighborhood organizations as opposed to a sensible vast scale procedure to lessen bundling waste.

The exhaustive availability of variety of these compartments and packs for marking and promotion purposes makes the co-ordinates reclaim and re-filling less practical. There are existing reclaim and re-filling plans in some European nations (Institute for Local Self-Reliance 2002) such as the PET containers and the glass; but these are usually considered part of the specialty movement for the neighborhood organizations; in contrast, to the sensible vast scale procedure of lessening the bundling waste.

There is potential scope for re-usage of plastics used for the transport of goods; and; for reuse or re-manufacture of some plastic components used in high-value consumer goods such as vehicles and electronic equipment.

This is precedence in the industrial scale about the re-use of containers and pallets in haulage (Thompson, Moore, vom Saal, & Swan, 2009). Some move far from using single-utilize plastic transporter sacks to reusable packs and likewise been observed, both in the view of willful conduct change programs, as in Australia (Environmental Protection and Heritage Council, 2007) and as a consequence of legislation, such as the plastic bag levy in Ireland (DPER, 2017), or on the other hand the current restricting of lightweight bearer sacks, for instance in Bangladesh and China.

There are many advantages of re-consumptions of plastics; as they are utilized as a part of various applications every day. However, some plastic things land up in the waste stream after a single utilization just like having a single-life or cycle or a brief span after buying, e.g. sustenance bundling. Re-utilizing plastic is desirable over reusing as it utilizes less vitality and less assets. Recently, the multi-trip plastics have turned into a more favorable decision; promoting thr PSW decrease in the MSW last stream. This problem further worsened in the starting of the year due to China; stop accepting the foreign waste. In the current scenario , China has taken up 500,00 tons of plastics from the United Kingdoms in a year(“UK could adopt strict Norway plastic bottle recycling system,” n.d.).

Re-use involves products which have been designed and produced to fulfil a minimal amount of rotations over their life span. Mostly these products are selectively collected, reconditioned and reprocessed for the same purpose. The best known example is the multi-trip plastic crates and pallets. Other examples include refillable drink bottles and reusable plastic containers (Laurens Delva et al., 2019)

2.3.1.2 Sorting recycling

Re-utilizing plastics has various favorable circumstances, portrayed by (i) preservation of non-renewable energy sources since plastic creation utilizes 4– 8% of worldwide oil production, i.e. 4% as feedstock and 4% amid change (Perdon, 2004; JCR, 2006); (ii) diminishment of vitality and MSW, and (iii) reduction of carbon-dioxide (CO2), nitrogen-oxides (NOx) and sulfur-dioxide (SO2) emissions. Various procedures and protocols have been created with a specific end goal to discrete and sort PSW (Environment and Plastics Industry Council (EPIC), 2004). In the reusing business, arranging and recognizable proof must be endeavored inside a brief timeframe to decidedly influence a recycler's funds. (Veit et al 2002)

Primary recycling, usually defined as re-extrusion, is the re-introduction of scrap, industrial or single-polymer plastic edges and parts to the extrusion cycle in order to produce products of the similar material. This process consumes those scrap plastics that have similar characteristics to the original products (Al-Salem, 2009). Primary recycling is only feasible with semi-clean scrap, therefore making it an unpopular choice with recyclers. An ideal example of primary recycling is the injection moulding of out of specification LDPE crates .Crates that do not meet the specifications are palletized and reintroduced into the recycling loop or the final stages of the manufacturing.(Grigore, 2017). Currently, most of the PSW being recycled is of process scrap from industry recycled via primary recycling techniques. In the UK, process scrap represents 250,000 tonnes of the plastic waste and around 95% of it is primary recycled(Report, 2007). Primary recycling also involves the re-extrusion of post-consumer plastics. Mainly, households wastes are the prime source of such waste stream. However, recycling household waste requires a number of challenges, namely the need of selective and segregated collection. Kerbside systems are required to collect relatively small quantities of mixed PSW from a big number of sources. This poses a resource drain and involves significant operating costs in many countries, especially considering the current market situation. Taking into account current market prices for virgin resins, a 0.45$ is the return on average from every converted kg of polyolefin (European commission, 2011).

2.3.2 Energy recovery

The process of incineration reduces the demand for landfill of plastics waste, however, in the process releases various dangerous substances into the atmosphere that are a matter of concern. For example, PVC and halogenated additives are typically present in mixed plastic waste leading to the risk of dioxins, other polychlorinated biphenyls and furans being released into the environment (Gilpin et al. 2003). As a result of this, perceived pollution risk, incineration of plastic is less favorable than landfill and mechanical recycling as a waste-management strategy. Japan and some European countries such as Denmark and Sweden are notable exceptions, with extensive incinerator infrastructure in place for dealing with MSW, including plastics.

Incineration can be used with recovery of some of the energy content in the plastic. The useful energy recovered can vary considerably depending on whether it is used for electricity generation, combined heat and power, or as solid refuse fuel for co-fueling of blast furnaces or cement kilns. Liquefaction to diesel fuel or gasification through pyrolysis is also possible. (Arvanitoyannis & Bosnia 2001)

There is an increasing interest in this approach to produce diesel fuel, presumably due to the rising oil prices. Energy-recovery processes may be the most suitable way for dealing with highly mixed plastic such as some electronic and electrical wastes and automotive shredder residue.

2.3.3 Chemical recycling

Chemical (tertiary) recycling is a terminology generally used for referring to advanced technology processes which deal with converting plastic materials into smaller molecules, usually liquids or gases, which are adapted for usage as a feedstock for the production of new petrochemicals and plastics (Mastellone, 1999).

The term chemical is used, because of an alteration taking place that is bound to occur due to the chemical structure of the polymer. Products of chemical recycling have proven to be useful as a fuel. The technology behind its success is the depolymerization processes that can result in a very profitable and sustainable industrial scheme, providing a high product yield and minimum waste. Under the category of chemical recycling advanced process (similar to those employed in the petrochemical industry) appearing like e.g. Pyrolysis, gasification, liquid–gas hydrogenation, viscosity breaking, steam or catalytic cracking and the use of PSW as a reducing agent in blast furnaces. Recently, more interest has been shown to chemical recycling (mainly non-catalytic thermal cracking (thermolysis), catalytic cracking and steam degradation) as a method of producing various fuel fractions from PSW. Due to their nature, a number of polymers are advantageous for such treatment. Polyethylene terephthalate (PET)and certain polyamides (nylon 6 (PA 6) and nylon 66) can be efficiently depolymerized. Of partical reasons polyethylene (PE) has been targeted as a potential feedstock for fuel (gasoline) producing technologies. (Al-Salem, Lettieri, & Baeyens, 2009)studied the thermal cracking behavior of HDPE. It was published that PE thermally cracks into gases, liquids, waxes, aromatics and char via five primary and two secondary reactions to form five lumped products.

2.3.4 Mechanical recycling

Mechanical recycling (secondary recycling) is defined as the phenomenon of recovering plastic solid waste (PSW) for the re-use in manufacturing plastic products through mechanical means. It was propagated and commercialized all over the world back in the 1970s. Mechanical recycling of PSW can be performed only on single-polymer plastic, e.g. PE, PP, PS, etc. The more the complexity and degree of contamination; more is the difficulty of recycling mechanically. Separation, washing and preparation of PSW are all essential and required steps to ensure production of high quality, clear, clean and homogenous end-products. One of the main problem associated to the mechanical recyclers is the degradation and heterogeneity of PSW. Since chemical reactions that constitute polymer formation (i.e. polymer addition, polymerization and polycondensation) are all reversible in theory, energy or heat supply can cause photo-oxidation and/or generation of mechanical stresses which occur as a result of consequences. There is lengthening or branching of polymer chains occurring from the formation of oxidized compounds and/or harsh natural weathering conditions (Report, 2007).

Due, to previous cited reasons, it is mandatory to have a customer ready to purchase the product to achieve a sensible economic and environmental practice. Mechanical recycling opens new ventures for economic and viable route for PSW recovery, especially for the case of rigid plastics (Zia, Bhatti, & Ahmad Bhatti, 2007).

A number of products found these days comes from mechanical recycling processes, such as grocery bags, pipes, gutters, window and door profiles, shutters and blinds, etc. The quality is the main issue when dealing with mechanically recycled products. The industrial PSW generated in manufacturing, processing, and distribution of plastic products is in requirements for their use as a raw material for mechanical recycling; due, to the conspicuous separation of different types of resins, the low level of dirt and impurities present, and their availability in large quantities.

Mechanical recycling of PSW has also become a compulsory matter of concern in the R&D, where numerous researchers have devoted their efforts to. Recent literature published shows a great interest in utilizing polyolefin that end up in the PSW stream. Table 1 summarizes pervious literature in direct relation to PSW mechanical recycling, utilizing reclaimed and scrap in the studied schemes on bench and pilot scales.

The existing plants and technologies applied in mechanical recycling PSW via mechanical means requires a number of treatments and preparation steps to be taken for consideration. Due to the process being expensive and an intense energy demanding process, mechanical recyclers try to reduce these steps and working hours as much as possible. Generally, the first step in mechanical recycling involves size reduction of the plastic to a more suitable form (pellets, powder or flakes). This is usually achieved by milling, grinding or shredding (Zia et al., 2007).The most general scheme was described by (Aznar, Caballero, Sancho, & Francés, 2006) and is illustrated in Fig. 1. The steps involved are usually the following (Aznar et al., 2006; SubsTech, 2006) :

Cutting/shredding: Large plastic parts are cut by shearing or sawing for further processing into chopped small flakes.

Contaminant separation: Paper, dust and other forms of impurities are separated from plastic usually in a cyclone. _ Floating: Different types of plastic flakes are separated in a floating tank according to their density.

Milling: Separate, single-polymer plastics are milled together. This step is usually taken as a first step with many recyclers around the world.

Washing and drying: This step refers to the pre-washing stage (beginning of the washing line). The actual plastic washing process occurs afterwards if further treatment is required. Both washing stages are executed with water. Chemical washing is also employed in certain cases (mainly for glue removal from plastic), where caustic soda and surfactants are used.

Agglutination: The product is gathered and collected either to be stored and sold later on after the addition of pigments and additives, or sent for further processing.

Extrusion: The plastic is extruded to strands and then pelletized to produce a single-polymer plastic.

Quenching: Involves water-cooling the plastic by water to be granulated and sold as a final product.

Reference	Main single-polymer plastics used	Comments
Kowalska et al. (2002)	PP (Malen P F-401) Waste LDPE Waste PVC Reclaimed LDPE films Suspension PVC	• Thermoplastics were mixed and extruded with fillers (waste rubber granulate, whiting, cellulose fibres and wood flour) to obtain an optimum blend composition • The blend contained <50 wt% of secondary LDPE, >50 wt% of comminute rubber scrap and <0.1 wt% of blowing agent • 3–4 l/h of water permutation was achieved with the blend making it a satisfactory mixture
Strapasson et al. (2005)	PP/LDPE blends (0/100, 25/75, 50/50, 75/25 and 100/0 wt/wt%) via injection moulding	• Thermoplastics were mixed and extruded with fillers (waste rubber granulate, whiting, cellouse fibres and wood flour) to obtain an optimum blend composition
Lei et al. (2007)	RHDPE	• Composites based on RHDPE and natural fibres, made through melt blending and compression moulding were studied, so were the effects of fibres and coupling agent (type/concentration) on the composite properties • The use of MAPE, CAPE and TDM improved the compatibility between the fibre and RHDPE, and mechanical properties of the resultant composites compared well with those of virgin HDPE composites
Meran et al. (2008)	LDPE, HDPE and PP	• The tensile strength relation was monitored in PP since the loss of mechanical and physical properties did not exceed 50% in the films studied
Brachet et al. (2008)	PP	• Modification of mechanical properties of recycled PP from post-consumer containers with the addition of stabilizers, elastomer (EOR) and $CaCO_3$ were studied • Results showed limited changes with the addition of elastomer and $CaCO_3$ on the mechanical properties of the recycled PP

Table 1 - Summary of mechanical recycling studies in direct relation to utilizing scrap and reclaimed materials (namely blended with single virgin polymers).

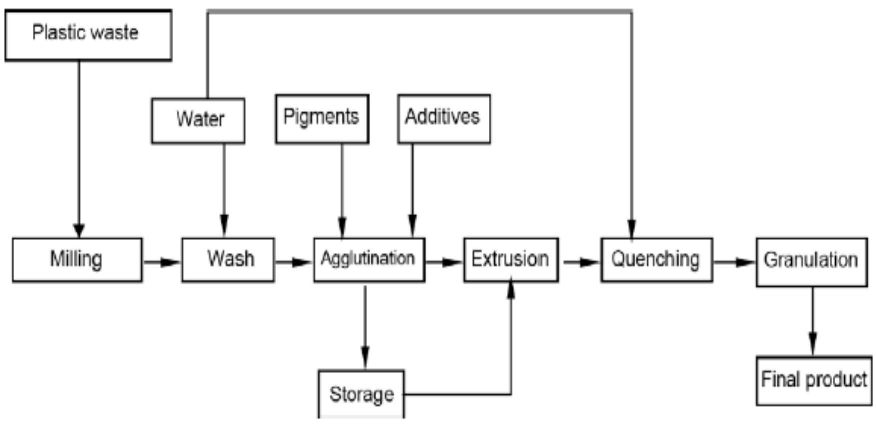


Figure 3 - Mechanical recycling steps as described by Aznar et al. (2006).

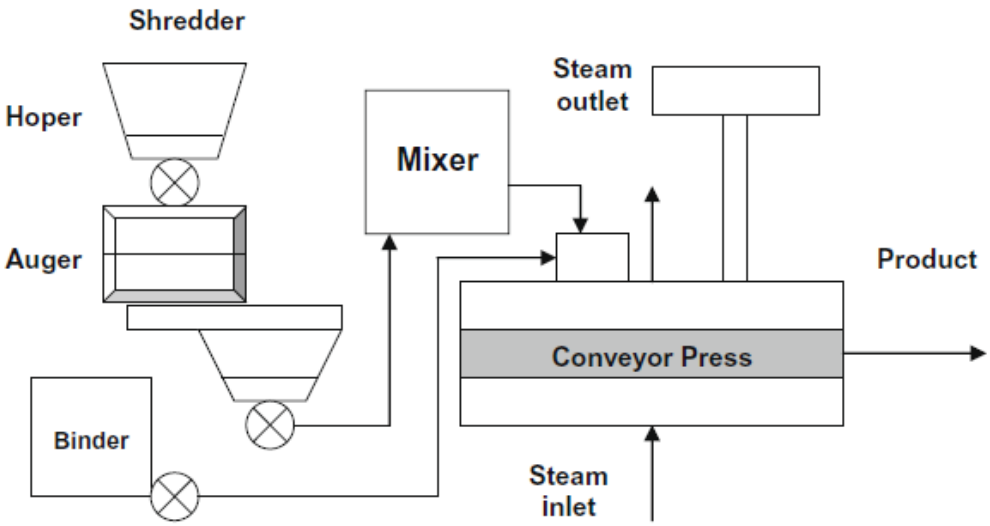


Figure 4 - Schematic of flexible foam re-bonding, adapted from Zia et al. (2007)

Other single-polymer PSW go through different ways of processing. Many foams (namely polyurethane, PU) are crushed to a powdered and grinded form to a particle size less than 0.2 mm using two-roll milling, cryogenic grinders or precision knife cutters. Another process used in mechanical recycling is re-bonding, in which recycled foam flakes originating from flexible slab stock foam production waste are usually blown from storage silos into a mixer that consists of a fixed drum with rotating blades or agitators, where the foam flakes are sprayed with an adhesive mixture (Zia et al., 2007).

Fig. 2 shows schematic illustration of the re-bonding process. One of the main advantages of this process is the capability to produce a clean product with new properties, i.e. higher density and lower hardness. In the case of PU, 10% binder is added to the 90% scrap. Waste is shredded and mixed with binder (dyes can also be added) and the mixture is then compressed. PU recycled granules are used as filler in polyester molding compounds and give added toughness to the material. This process yields a mixture of products such as carpet underlay and athletic mats from recovered pieces of flexible foams. The re-bond process incorporates both a surprising amount of flexibility and a wide variability in the mechanical properties of the final product. PVC represents an interesting case too, in terms of mechanical recycling. With the health concerns related to it, Recovinyl_ Co (UK) deals with post-consumer PVC to reproduce two grades via mechanical recycling. Due to its structure and composition, PVC can easily be mechanically recycled in order to obtain good quality recycling material.

Rigid PVC recycled material is generally used as an inner reinforcement layer in pipes, profiles production, garden furniture and rigid films manufacture. The flexible PVC waste is recycled into powder and is used as filler in the production of floor coverings of various kinds. Other applications of PVC waste are traffic cones, fences, flexible hoses and tubes, footwear, bags, clothing, etc.

A classic example of utilizing PSW is the recycling of PET. About, three-quarters of reclaimed PET in the UK and USA are used for manufacturing of fibers for carpets, apparel and bottles. Two approaches have been widely promoted, mechanical recycling and methanolysis (chemical recycling). Once the PET has been collected and sorted, it acts as a feedstock for reclamation processing lines. The process of reclamation involves washing the materials (mainly bottles) and conditioning the plastics to be processed as semi-virgin resin or master batch. In doing so, a clear grade of PET can be produced of high quality to compete with the virgin polymer. This technique is practiced is quite prominently in the EU and USA. In Tokyo (Japan), a council for PET bottle recycling has been established since 1993 to promote mechanical recycling of PET bottles in the municipalities of Tokyo (Council PET, 2005). PET bottles gathered from households are later sorted are then compressed and packed by municipalities for transportation to recycling plants operated by recycling industries. At the recycling plant, the waste is further selected and cleaned to remove impurities. The remaining PET bottles are then shredded, cleaned, foreign bodies and non-resins separated, and the left overs turned into flakes and pellets (granules made of flakes thermally processed by granulator) for recycling. The recycled materials are then sent to textile and sheet-making plants, where they are again molten to produce textile and sheet products by resin moulding techniques well established for PET and other plastics conversion (Council PET, 2005).

PET bottles obtained by household sorting are collected, compressed and packed by municipalities for transportation to recycling plants operated by recycling industries. At the recycling plant, the waste is selected to remove impurities and the remaining PET bottles are then shredded, cleaned, foreign bodies and non-resins separated, and the remainder turned into flakes and pellets (granules made of flakes thermally processed by granulator) for recycling. The recycled materials are then sent to textile and sheet-making plants, where they are again molten to produce textile and sheet products by resin moulding techniques well established for PET and other plastics conversion (Council PET, 2005). These techniques could be summarized as follows:

- Extrusion moulding: the resin or PSW flakes are molten and extruded through a mould by single or twin screws to form amoulded product. Products from this process include pipes, sheets, film and wire covering.
- Injection moulding: heated molten resin is injected into a mould to solidify and form the product desired. Products made this way range from washbowls, buckets and plastic models to larger products such as bumpers and pallets.
- Blow moulding: a parison (hollow plastic melt) obtained by extrusion or injection moulding is clamped in a mould, and inflated with air to make bottles for all kinds of uses, such as shampoo bottles. PET bottles are made by means of stretch blow moulding so as to make them less likely to rupture.
- Vacuum moulding: a heat-softened sheet is sandwiched in a mould, and the space between the sheet and mould sealed and evacuated to form products such as cups and trays.
- Inflation moulding: extrusion moulding where a molten resin is inflated into a cylinder to form a film. This method is used to make products such as shopping bags.

Another main company dealing with PSW is Nexcycle Plastics Inc. (NPI, Canada), which markets a number of recycled products made from scrap polyolefins (NPI, 2009). NPI deals with LDPE, LLDPE, MDPE, HDPE and PP. The scrap that is being dealt with is transformed mechanically to bales, rolls, regrinded PSW, and chunks. The company also deals with a variety of coloured scrap, including clear, white, black, mixed and printed PSW. Alternatively, many companies are also dealing with black and/or clear scrap for mechanical recycling processing lines, saving by that cost of sorting. This is the case of Metals and Recycling Co. (MRC, Kuwait); which covers almost exclusively the GCC, far and south-eastern Asian markets. The company processes various types of scrap plastic such as PP, PE, PVC, PPC, ABS, etc. The plant's output of PE and PP is mainly delivered as clean and uniform pellets (extruded 3 _ 3 mm granules), whereas other scrap materials are processed as flakes (MRC, 2009).

Acceptable quality of electricity supply to customers should show a perfect sinusoidal voltage waveform at all customer locations. The deviation of the voltage and current waveforms from sinusoidal is described as harmonic distortion. The harmonic component in an AC power system can be defined as the sinusoidal component of a periodic waveform with a frequency equal to an integer multiple of the system's fundamental frequency. Harmonics in voltage or current waveforms can then be conceived as perfectly sinusoidal components of frequencies multiple of the fundamental frequency (De La Rosa, 2006).

Harmonic distortion occurs as a result of nonlinear loads drawing non-sinusoidal current whenthey are even connected through a pure sine wave voltage source. Non-sinusoidal current contains harmonic current that interacts with the impedance of distribution lines and causes voltage harmonics. The connection of converter units also introduces additional total harmonicdistortions (THD) at the point of common coupling and in other buses. In grid-connected PV systems, the occurrence of harmonic distortions is dependent on the power converter technology used. Power electronics switching devices also inject high-frequency components rather than the desired current (Huda and Živanović, 2017).

The point of connection of PV systems into a power distribution network influences the harmonic distortion level introduced into the DN. Relative to low voltage connection points, PV systems connected at high voltage points in the network produces less harmonic distortion.In cases where there is an impedance mismatch between the grid and the inverter of the DG units at the points of common coupling, harmonic resonance also occurs (Pandi et al., 2013).

The inverter interface between the Solar PV and the grid works by converting DC to AC through the inverter, which is a semiconductor switching circuit, but the AC waves obtained from these devices may not be perfect sinusoidal waves. As a result, harmonics are introducedinto the power network. The total harmonic distortion permissible varies from country to country and regularly updated depending on the existing grid infrastructure and the hosting capacity. The specified values range from < 5% to < 8% and for inverter current up to the 50thharmonic (Jayasekara and Wolfs, 2010).

Effects of harmonic distortion

- Excesssive loading of consumers' electrical installation and power system elements byhigher-order frequencies of currents and voltages.
- Overheating of neutral conductors as a result of higher current harmonics whosefrequency is the multiplier of number.
- Increased 3rd harmonics in the neutral conductor can damage and even cause firebecause the neutral conductor is not usually overload protected.

- Increased transformer heating and saturation effects in the core of the conductor.
- Higher harmonic occurrence in the power grid can cause interferences ontelecommunication lines.
- Causes overloading and resonant condition on the capacitors bank (Stojkov et al.,2009).

2.3.4.1 mechanical recycling of polymers

Plastic waste can be recycled in different ways depending on types of polymers, product and packaging design, if the products consist of the single polymer or mixed polymers (Eco Products agency et al., 2009). Mechanical recycling is one of the most common methods for recycling of thermoplastic polymers such as PP, PE and PET .

This process implies collection, sorting, washing and grinding of the material. A schematic overview is presented in Figure 5. Collection and sorting are discussed separately below. Further, washing of products is a mandatory step for removal of food residues, pulp fibres or adhesives. There are various techniques to remove residues, e.g. via wet by water or dry cleaning of the surfaces through friction without using water. Afterwards, the size reduction from products to flakes via grinding is the last step in mechanical recycling. The compounding and pelletizing can be the optional reprocessing of the flakes into granulate due to easier work for converters

2.3.4.2 Types and steps of the technologies

An outline of the fundamental and primary phases involved in the process of mechanical recycling , where its starting from initial form of wate till it becomes a flakes (fig 5)

Figure 5 - scheme of the basic principal steps in a mechanical recycling process

As the first step in the value chain of mechanical recycling, collection systems play a crucial role in the conversion of waste raw materials into new plastic products. Collection schemes should be optimised, on the grounds that they determine the composition of the waste streams and accordingly the downstream procedures, like the pre-treatment, separation and recovery operations (kim Ragaert et al., 2019). These collection operations should be cost-effective and, approved and supported by waste owners in order to counteract landfilling. There are four main collection methods for plastic packaging waste: kerbside, drop-off, buy-back and deposit/refund programs :

- Kerbside collection is the most widely accessible collection method. For civilians, it is the most convenient procedure to participate in, what results in high recovery rates. Residents are requested to separate potential valuable recyclables (plastic, paper and cardboard, metals) from their household waste, commingled or not, into special receptacles or bags.
- In drop-off recycling, different containers for designated materials to be recycled, are placed at central community places. Such collection programs often suffer from low or unpredictable throughput.
- Buy-back centres, mostly run by private companies, purchase recyclables from consumers. These centres impose specifications to the recyclable waste materials, which makes the contamination level low.
- Deposit/refund programs imply the refunding of a deposit when plastic containers are returned to the appropriate redemption centre, or to the original seller.

In addition to the plastic trash generated by municipalities, it is necessary to establish and support collection systems specifically designed to obtain valuable raw materials from electrical and electronic equipment, end-of-life cars, and plastic agricultural films. Additionally, it will be crucial to synchronise the various preexisting collection systems. Organised sorting and collecting of plastic trash from companies is crucial, alongside the plastic waste collection for individuals. Efficient management of plastic industrial waste significantly enhances the rates at which potentially reusable and recyclable materials are taken up. Frequently, firms are granted incentives. 3.3 Sorting The arriving waste streams comprise heterogeneous mixtures of plastics with unknown compositions, which are highly likely to be polluted by organic fractions (e.g., food residues) and non-plastic inorganic fractions (such as metals, wood, paper, etc.) (Laurens Delva et al., 2019). In order to get high-quality goods by mechanical recycling, it will be necessary to clean, regrind, and sort the waste stream. A highly efficient sorting facility employs four distinct processes to segregate the incoming streams of plastic waste. Prior to anything else, it is important to eliminate non-plastic impurities such as metals, wood, paper, and other similar materials. The plastic percentage must be segregated into rigid and non-rigid components, such as foils. To achieve a high-quality recycled product, it is preferable to separate the plastic waste components into coloured and non-colored (transparent) parts. Finally, the various varieties of plastic must be sorted. Firstly, it is necessary to extract metals from the waste stream to prevent any potential harm to the recycling plant's gear. Ferrous metals, in particular, can be easily separated by employing the use of magnets. The extraction of non-ferrous metals, primarily aluminium but also zinc, copper, and lead, relies on the generation of eddy currents. An eddy current separator comprises a conveyor belt with a high-speed, autonomous magnetic rotor that can produce a powerful, quickly oscillating magnetic field (Scot). Karl Koermer, 2015. After the conducting particles move past the rotor, the magnetic field induces eddy currents, causing the non-ferrous particles to be pushed away. Wind sifters are commonly used to separate non-rigid polymers (such as foils and bags) from rigid plastics. (Delva et al., 2018)

These devices utilise a single ventilator to either blast or suck out non-rigid plastic trash, dependent on the changes in specific weight (surface to mass ratio). Wind sifters are capable of effectively segregating paper contaminants, (Kirschweng et al., 2017) such as labels, from the hard-plastic portion. Ballistic separators, comprising a vibrating screen, are also capable of effectively segregating flexible and inflexible plastics. The plastic trash streams contain a diverse range of colours. In addition to colour, plastic particles might differ in terms of their level of opacity. The utilisation of optical colour recognition sensors can significantly increase the worth of these recyclables by using color-based separation. Similarly, plastic particles that are either light in colour or have been separated can be easily dyed to match new design standards. Plastics of various sorts can occasionally be sorted by their respective colours. When one polymer becomes contaminated inside the matrix of another polymer material, it typically leads to a reduction in mechanical qualities and difficulties in reprocessing. An appropriate instance of a polymer pair that absolutely needs to be isolated is PET contaminated with PVC. (Farzi et al., 2019)

When PET is heated to its processing temperature, PVC will break down and produce hydrogen chloride gas, which is highly corrosive. In contrast, PET will not undergo melting under the PVC manufacturing conditions. Therefore, it is essential to utilise and enhance precise and economical sorting techniques. Automated separation methods can be classified into two distinct categories: direct and indirect sorting procedures. (Dogu et al.,2020)

2.3.5 Previous studies uning recycling technologies

Plastic aggregates used in many studies prepared from plastic waste obtained from different sources. As example plastic bottles were grinded in the laboratory by using a grinding machine and then sieved to get the suitable size fraction. (Frigione, 2010), (Saikia and Brito, 2014).

In their study, Al-Manaseer and Dalal (1997) examined how plastic particles impact the bulk density of concrete. In this investigation, a total of 12 concrete mixes were made, each with a different water-to-cement ratio (w/c) and including varied percentages (0%, 10%, 30%, and 50%) of plastic aggregates. Angular plastic aggregates derived from post-consumer materials, with a maximum size of 13 mm, were utilised. The researchers found that the bulk density of concrete decreased as the amount of plastic aggregates increased. The reduction in bulk density was directly proportional to the content of plastic aggregates. Specifically, the density of concrete decreased by 2.5%, 6%, and 13% for concrete containing 10%, 30%, and 50% plastic aggregates, respectively. The decrease in density was associated with the decreased unit weight of the polymers.

Marzouk et al. (2007) reported that the bulk density of cement mortar mixes was prepared by replac,ing 0–100% in volume of sand by two different sizes of PET aggregates. Their results showed that the reduction in the bulk density was small when the volume occupied by the aggregates was between 0 % to 30 % reduction; without taking into account the size. However, when this volume exceeded 50%, the composite bulk densities started to decrease until reaching a value 1000 kg/ m3. They also found that for the same volumetric percentage of substitution the bulk density decreased with decreasing particle size.

Ismail and Al-Hashmi, (2008) demonstrated the possibility of using various plastic wastes, containing approximately 80% polyethylene and 20% polystyrene, as fine aggregates, up to 4.75 mm in concrete. By increasing the quantity of the plastic waste content, the compressive tests showed the tendency for compressive strength values of plastic waste concrete to decrease below the reference concrete at each curing age. The concrete with 10% of plastic waste displayed the lowest compressive strength at 28 days curing age, about 30% lower than that of the reference concrete mixture. Also the study showed that 5%, 7%, and 8.7% lower densities of concrete mix containing 10%, 15%, and 20% plastic aggregates respectively.

Choi et al. (2005) studied the imapct of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the density of concrete. The mixed proportions of concrete were planned in such a way that the water/cement ratios were 45%, 49%, and 53%, and the replacement ratios of WPLA were 0%, 25%, 50%, and 75% by volume of fine aggregate. It was seen that the density of concrete mixtures decreased with the increase in WPLA content. In their study the influence of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the splitting tensile strength of concrete was observed. Mixture proportions of concrete were planned. The water/cement they concluded that: (i) splitting tensile strength of concrete mixtures decreased by 19%, 31%, and 54% with the increase in PET aggregates by 25%, 50%, and 75% respectively; and (ii) for a particular PET aggregate content, splitting tensile strength increased with the reduction in w/cm ratio. Also the study investigated the effect of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) (Nikbin et al., 2016) on the modulus of elasticity of concrete. According to the authors, modulus of elasticity of concrete mixtures decreased with the increase in PET aggregates.

Saikia and Brito, (2014) demonstrated the effects of size and shape of recycled polyethylene terephthalate (PET) aggregate on the fresh and hardened properties. Three types of PET aggregates, collected from a plastic recycling plant, two were shredded and separated fractions of similar types of PET bottles and one was a heat-treated product of the same PET bottles with sieve size from 0.5-11.2mm. 5%, 10% and 15% in volume of natural aggregate in the concrete mixes were replaced by an equal volume of three differently shaped and sized PET aggregates with deferent W/C ratios. The test results showed that density of fresh concretes decreased as the content of plastic aggregate increased. The differences in the size and shape of PET-aggregates affected the slump of fresh concrete mixes, which ultimately changed the mechanical behavior. The study also observed a reduction in the compressive strength of concrete due to the addition of PET-aggregates to replace natural aggregates. For 5% replacement the 28-day compressive is more than 75% of the compressive strength of reference concrete. For concrete with 10% and 15% plastic aggregate are respectively 71% and 59%. According to the authors, natural aggregates and PET-aggregate cannot interact with cement paste and therefore the interfacial transition zone in concrete containing PET-aggregate is weaker than that in the reference concrete, which lowers the resulting compressive strength.

(Shukla et al., 2019)

The study presented the abrasion behaviour of concrete specimens (depth of wear and weight loss) containing various types and contents of PET-aggregate, and the reference concrete. In this paper, 5%, 10% and 15% in volume of natural aggregate in the concrete mixes were replaced by an equal volume of three differently shaped and sized PETaggregates. According to the authors, the abrasion resistance of the concrete mixes with the various types of PET-aggregate is better than that of the normal concrete, also they found that the behaviour of the abrasion resistance of concrete arising from the incorporation of various types and contents of PET-aggregate suggests that this property depends on the compressive strength of concrete as well as on the properties of plastics. (Balte et al., 2017)

In the following paper, the 5 % ,10 % and 15 % volume of the natural aggregates present in the concrete mixes were replaced over by an equal volume of three different shaped and sized PET aggregates. To conclude, the authors found that the abrasion resistance of the concrete mixes with the different types of the PET aggregate is far much better than that of the normal concrete. They also inferred that the behavior of the abrasion resistance of the concrete coming from the incorporation of the different types and contents of the PET aggregates suggested that the property mainly depends upon the compressive strength of the concrete and the properties of the plastics.

Albano et al. (2009) conducted a study which included concrete with 10% of recycled PET exhibiting a compressive strength that meets the standard strength values for concrete with moderate strength between 21 and 30 MPa for a curing age of 28 days. They reported that the compressive strength at the age of 28 days is near the values for 60 days. Several factors were taken into consideration such as the type of failure, the formation of honeycombs, low workability, and particle size, which are responsible for lowering compressive strength of concrete containing PET aggregate than concrete containing natural aggregate. The reduction in compressive strength was more profound in concrete containing larger flaky PET aggregate than smaller one.

Hannawi et al. (2010) investigated the effect of using non-biodegradable plastic aggregates made of polycarbonate (PC) and polyethylene terephthalate (PET) waste as partial replacement of natural aggregates in mortar. Different volume fractions of sands for 3%, 10%, 20% and 50% were replaced by the same volumes of plastic. The authors found a decrease in compressive strength when the content of plastic aggregates increases. The drop in compressive strength seems to be not correlated to the volume fraction of sand replaced by plastic aggregates. a decrease of 9.8%, 30.5%, 47.1% and 69% for mixtures with, respectively, 3%, 10%, 20% and 50% of PET-aggregates, and of 6.8%, 27.2%, 46.1% and 63.9% for mixtures containing, respectively,3%, 10%, 20% and 50% of PC aggregates is observed. (Charudatta et al., 2017)

The authors concluded that the drop in compressive strengths due to the addition of plastic aggregates can be attributed strongly to the weak bond between the matrix and plastic aggregates. The study presented the variations in the flexural strength of different mixtures as a function of the percentage of sand (in volume) replaced by the same volume of plastic 10 aggregate. By comparing to control mixture, no significant changes are observed for mixtures containing up to 10% of PET-aggregates and up to 20% of polycarbonate (PC) aggregates. The study also observed, a decrease of 9.5% and 17.9% for mixtures with, respectively, 20% and 50% of PET-aggregates is observed. For mixtures with 50% of PC aggregates, a decrease of 32.8% is measured. The authors discovered that the calculated flexural toughness factors increase significantly with increasing volume fraction of PET and PC aggregates. Thus, addition of PC and PET plastic aggregates in cement rich materials can give a good energy absorbing material which is very beneficial for several civil engineering applications like structures subjected to dynamic or impact.

Frigione (2010) demonstrated lower values of splitting tensile strength in concrete containing PET aggregate prepared using high w/c value than in a similar mix prepared at low w/c value. By replacing 5% by weight of fine aggregate (natural sand) with an equal weight of PET aggregates manufactured from the waste of un-washed PET bottles. Specimens with different cement content and water/cement ratio were manufactured.

Kou et al. (2009) explored the fresh and hardened properties of lightweight aggregate concretes that are prepared with the use of recycled plastic waste sourced from scraped PVC pipes to replace river sand as fine aggregates. Concrete mixes were tested, in which river sand was partially replaced by PVC plastic waste granules in percentages of 0%, 5%, 15%, 30% and 45% by volume. Splitting tensile strength 28-day values are 3.06, 2.89, 2.82, 2.58 and 1.83 MPa, respectively. Akçaözoglu et al. (2010) carried out a study of using shredded waste PET bottles as aggregate in lightweight concrete. The study was probed on two different group of mortar samples: one which was only with the PET aggregates and other which was with PET and sand aggregates. The authors based that the average values of the flexural strength were alike to that of the normal weight mortar.

Rahmani et al. (2013) investigated the effects of replacing 5%, 10% and 15% substitution of sand with PET processed particles. To determine the effect of the percentage of sand replacement with PET on concrete flexural strength, some beam specimens with dimensions of 50 × 10 × 10 cm3 were casted 11. By the authors, the flexural strength has an increasing correlation at first when the amount of PET particles increases, but it drops after a while. For example, the 5% replacement of sand volume with PET particles with w/c ratios of 0.42 and 0.54 shows 6.71% and 8.02% increase in flexural strength, respectively. However, 15% substitution of PET particles with w/c ratio of 0.42 and 0.54 yielded 14.7% and 6.25% reduction in the flexural strength, consecutively. The study also observed the effects of PET particles on tensile strength. By replacing 15% of sand volume with PET particles, the reduction observed in tensile strength were 15.9% and 18.06%, respectively.

2.3.6 Challenges and oppurtunites for improving plastic recycling

In western Europe, plastic waste generation is increasing at an approximately 3 per cent per annum, in rough agreement with the long-term economic growth, whereas the amount of mechanical recycling increased strongly at a rate of approximately 7 per cent per annum. In 2003, however, this still amounted to only 14.8 per cent of the waste plastic generated (from all sources). Combining together with feedstock recycling (1.7 per cent) and energy recovery (22.5 per cent), this amounted to a total recovery rate of approximately 39 per cent from the 21.1 million tonnes of plastic waste generated in 2003 (figure 6). This trend for both rates of mechanical recycling and energy recovery to increase is continuing, although so is the trend for increasing waste generation.

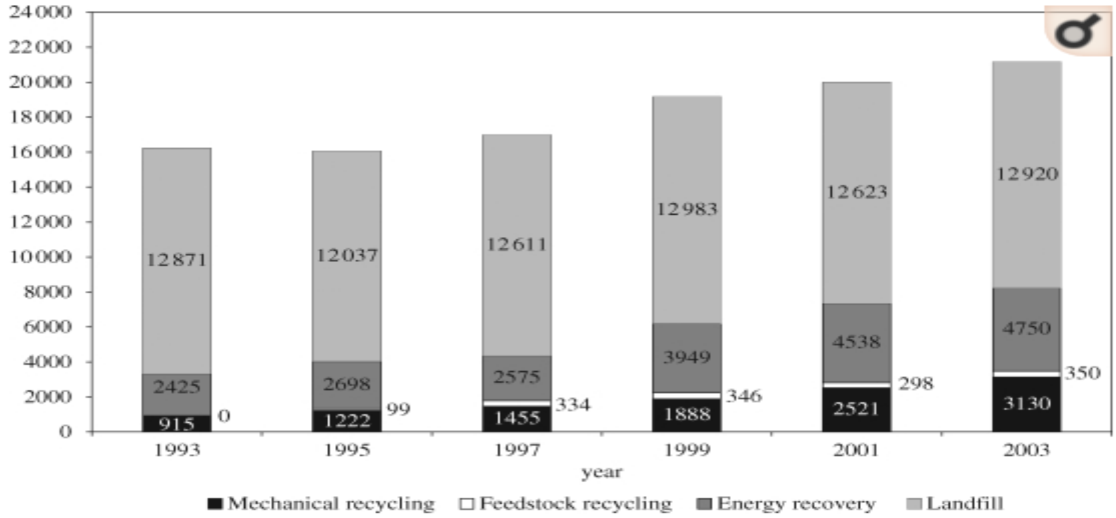


Figure 6 - Volumes of plastic waste disposed to landfill, and recovered by vari

The next main challenge is the effective recycling of mixed plastics waste in the plastics recycling sector. The main advantage is the ability to recycle a larger proportion of the plastic waste stream by expanding the post-consumer collection of plastic packaging to expand over a wider area for collecting a wider variety of materials and pack types. Product design for recycling has strong potential to assist in such recycling efforts. A study carried out in the UK found that the amount of packaging in a regular shopping basket that, even if collected, cannot be effectively recycled, ranged from 21 to 40% (Local Government Association (UK) 2007). Hence, more stronger implementation of policies to propagate the usage of environmental design principles by industry could have a bigger influence on the recycling performance, increasing the proportion of packaging that can economically be collected and diverted from landfill (Shaxson, 2009).

The same logical principle applies to durable consumer goods designed for disassembly, recycling and specifications for use of recycled resins are key actions to increase recycling. Most post-consumer collection schemes are exclusive for rigid packaging as flexible packaging tends to be problematic during the collection and sorting stages. Most current material recovery facilities have difficulty in handling the flexible plastic packaging because of the different handling features of the rigid packaging. The low weight-to-volume ratio of films and plastic bags also makes it less economically viable to invest in the necessary collection and sorting facilities. However, plastic films are currently recycled from sources including secondary packaging such as shrink-wrap of pallets and boxes and some agricultural films, so this is feasible under the right conditions. The correct approaches to increasing the recycling of films and flexible packaging could include separate collection, or investment in extra sorting and processing facilities at recovery facilities for handling mixed plastic wastes. In order to have successful recycling of mixed plastics, high-performance sorting of the input materials needs to be executed to ensure that plastic types are separated to high levels of purity; there is, however, a need for the further development of end markets for each polymer recycled stream. The quality and the effectiveness of post-consumer packaging recycling could be dramatically increased if the diversity of materials were to be rationalized to a subset of current usage. For example, if rigid plastic containers ranging from bottles, jars to trays were all PET, HDPE and PP, without clear PVC or PS, which are the main problem to sort from co-mingled recyclables, then all rigid plastic packaging could be collected and sorted to make recycled resins with minimal cross-contamination. The losses of rejected material and the value of the recycled resins would be enhanced. In addition, labels and adhesive materials should be selected to maximize recycling performance. Improvising the procedures for sorting/separation within recycling plants give a boost for further increasing the potential for both higher recycling volumes, and better eco efficiency by reducing the portions of the waste fractions, energy and water utility. The goals should be to maximize to increase both the volume and quality of recycled resins.

2.4 Polyethylene terephtalate

Because it is the primary material used for this study.PET is a thermoplastic, also defined as thermo-softening plastic, is a polymer that turns to a liquid when heated and freezes to a very glassy state when cooled sufficiently). One such example of a thermoplastic is polyethylene terephthalate also called as PET, PETE or the obsolete PETP is a thermoplastic polymer resin composing of terephthalic acid and ethylene glycol. PET being a strong, rigid and light material make it an ideal substance for applications in various fields such as the production of packing material for bottles, cortexes etc., film, constructions elements. It also finds applicability in synthetic fibers like beverage, food and liquid containers. It has also thermoforming functions and part of engineering resins in combinations with glass fiber. The term 'polyethylene terephthalate' is a misnomer; because this substance PET does not contain polyethylene. Thus, it's alternative name 'poly (ethylene terephthalate)' is often used in the literature for more accuracy and understanding. (Recycling-of-PET-plastic-waste, n.d.).

Based upon the processing and the thermal history, the polyethylene terephthalate can exist in two forms as amorphous (transparent) and a semi-crystalline polymer. The semi-crystalline material can appear physically as transparent having a particle size less than 500 nm or can be opage and white in shape; with particle size upto a few microns. This property depends on the crystal structure and the particle size. The monomers (bis-β-hydroxyterephthalate) can be generated by esterification reaction between the terephthalic acid and the ethylene glycol with water as a side product or by by transesterification reaction between ethylene glycol and dimethyl terephthalate with methanol as a byproduct . Polymerization takes place through a polycondensation reaction of the monomers (done immediately after esterification/transesterification) with water as the byproduct. (Begley et al., 2002)

The main production for PET is for the applicability of synthetic fibers (in excess of 60%) with bottle production accounting for around 30% of global demand. In terms of textile applications, PET is generally referred to as simply "polyester". The terminology "PET" is used generally used for packaging applications. The polyester industry makes up about 18% of world polymer production and is third largest industry after polyethylene (PE) and polypropylene (PP).

PET composes of polymerized units of the monomer ethylene terephthalate, with repeating C10H8O4 units. PET is recycled quite frequently and has the number "1" as its recycling symbol. The first PET was patented in 1941 by John Rex Whinfield, James Tennant Dickson and their employer the Calico Printers' Association of Manchester and the PET bottle was patented in 1973 by Nathaniel Wyeth. PET is also used as substrate in thin film and solar cell. .(bayer ,2002)

As, PET is an excellent barrier material, it is commonly used for producing plastic bottles; especially for the soft drinks. For some special bottles, the PET also sandwiches an additional plyviny alcohol for further reducing its oxygen permeability.

Bi-axially oriented PET film (often known by one of its trade names, "Mylar") can be aluminized by evaporating a thin film of metal onto it to reduce its permeability, and to make it reflective and opaque (MPET). The above mentioned properties hold applications in many domains like the flexible food packaging, thermal insulation for instance for the “space blankets “. As, it has a high mechanical strength; the PET film is also commonly used in tape applications for example for the carrier of the magnetic tape or backing for the pressure sensitive adhesive tapes.

The non-oriented PET sheet can undergo thermoforming and used to make packaging trays and blisters. If the crystallisable form of PET is used, it can be used to prepare frozen dinners as they have the capability to withstand the freezing and the oven baking temperatures. Filling these with glass particles or fibers makes them stiffer and durable

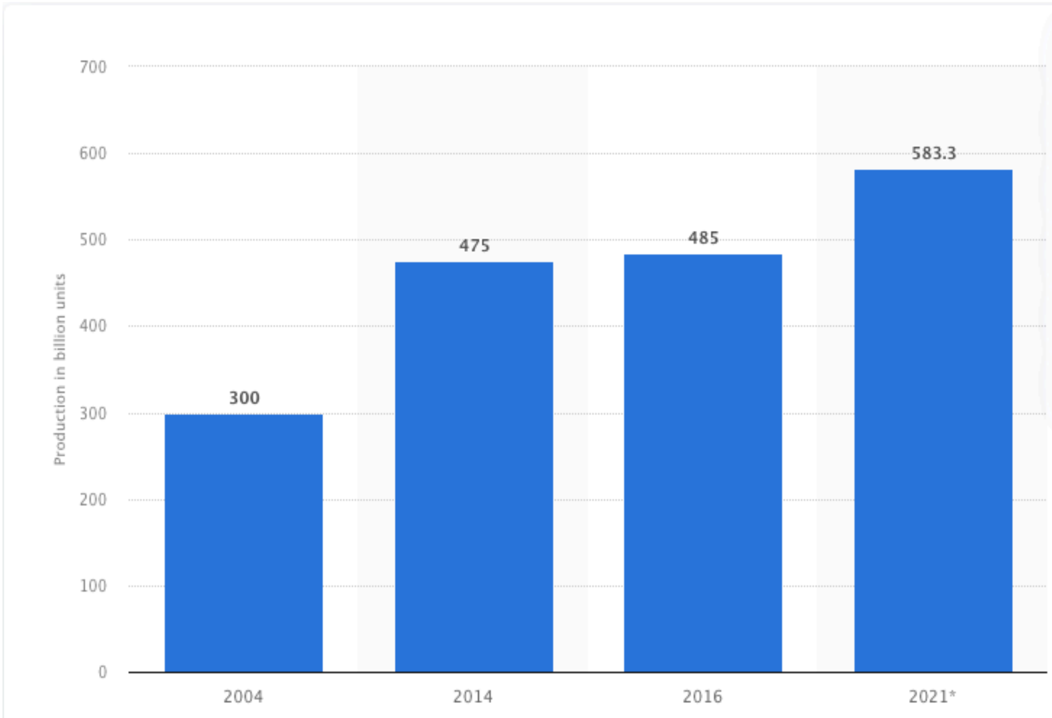


Figure 7 - Production of polyethylene terephthalate bottles worldwide from 2004 to 2021(in billions)

2.5 Recycling of mixed polymers

Polylactic acid (PLA) and its systems PLA are one of the most vital biodegradable polyesters derived from renewable sources i.e. starch and sugar. Till the last decade, the main applications of PLA were limited to biomedical and pharmaceutical applications such as implant devices, tissue scaffolds, and internal sutures due to its high cost and low molecular weight. Since, the existence of both hydroxyl and a carboxyl group in lactic acid allows it to be converted directly into polyesters via a polycondensation reaction; a considerable amount of interest has been paid to the academic research associated with PLA polymer and its copolymers [3e5]. Although PLA is a biodegradable material, which would significantly reduce environmental pollution associated with its waste, the knowledge behind this material recycling and changes in the properties of PLA upon its multiple processing is a very important subject of discussion.

Polyvinyl chloride (PVC) and its systems along with the low cost and high performance of PVC products combined together with its wide range of properties that can be obtained from different formulations has contributed to the widespread use of PVC in construction products. There has been a long time-lag between PVC consumption and the amassing of PVC waste arising from the long life of PVC products, which can be up to 50 years. It is quite clear that all produced PVC will eventually become waste in a few days' time. The European Association of Plastics Converters (EuPC) has estimated that the PVC waste for the periods between 2010 and 2020 will arise from the following sources. Many works have documented the recycling of PVC and its systems since the beginning of the last decade. (Hajekova et al, 2005).

Polyethylene's PE's are one of the most widely used plastics characterized by a density in the range 0.918e0.965 g/cm3 resulting in a range of toughness and flexibility. Their major application is in packaging film although their outstanding dielectric properties. Chemical recycling of PLA/PE and PLA/PBS blends

2.6 Filaments product for 3d printing

When it comes to consumer printers, there are two major technologies that drive the printing process: stereolithography (SLA) and fused deposition modeling (FDM, also known as fused filament fabrication, or FFF). Both methods deposit polymers in two significantly different ways: SLA uses a photosensitive resin which "cures" when exposed to light (usually ultraviolet), while FDM heats a filament made of thermoplastic resin up above its glass point and extrudes it onto a build surface. Although the end results are very similar, there are significant differences in the properties, handling, and use of resin versus filament.

In 3D printing, the filament is the material that is melted and extruded through a nozzle to create the printing layers that form a 3D object. Common materials used for 3D printing filaments include PLA (polylactic acid), ABS (acrylonitrile butadiene styrene), PETG (polyethylene terephthalate glycol), and many others. The choice of filament can affect the strength, durability, flexibility, and appearance of the final printed object. (Trhlikova et al., 2016)

3D printer filament is the substance utilised in 3D printing for the production of tangible items. A filament is a slender and elongated material that is inserted into a 3D printer, heated, and then systematically added layer by layer to construct the intended object. Various filaments are accessible for 3D printing, such as PLA, ABS, PETG, TPU, and others, each possessing distinct features and characteristics. The selection of filament can have a significant influence on the strength, flexibility, appearance, and other characteristics of the printed product.

Filament tends to be very easy to use. It's as safe to handle as the final product, and the only things you need to worry about are the heat from the extruder nozzle and the potential for fumes from the heated material. These are mitigated by making sure that adequate ventilation is in place based on what specific material you are using to print.(Wojtila et al., 2017)

Photosensitive resin is a bit more complex. Although filament is technically also a form of resin, it is the sensitivity to light that makes this work. It's a binding agent (such as the polymer you want to print in), mixed with monomers and photoinitiators. The monomers affect the viscosity of the photosensitive resin itself, while the photoinitiators cause the resin to cure in light. When the photosensitive resin is cured, the monomers and binding agents form longer molecules, chaining together and cross-linking. They react until light exposure is halted or all of the constituent chemicals have reacted to form the final hardened resin.

Resin has some additional safety concerns that filament does not. First, gloves and safety glasses are a must. Many times resins will mention "VOCs" in their specs. VOCs are volatile organic components, meaning they are potentially toxic organic compounds used as the monomers and photoinitiators. These compounds necessitate ventilation (more so than outgassing from filament) and that skin contact be avoided. Until a print has fully cured, these have to be considered while handling the print and printer.

The simple answer is that you use the one that your printer is designed for. A 3D printer is designed for a specific technology, and that dictates what material can be used in the printing process. If you're still weighing options for what to buy, consider the fact that resin based printers are limited in respect to the number of materials that can be used (while filament fed printers are moving in the direction of multiple extruders being the norm, each printing in a different material during the course of a print). It's also harder to produce your own materials with resin-based printer material, due to the chemistry involved. As discussed in previous articles, there are simple filament extruder systems available which make getting into this fairly easy, allowing you to potentially harvest material from a variety of sources. Besides making your own, filament generally tends to be less expensive. This has the potential to be a major savings. (Aris et al., 2020)

It's good to understand what you're working with before you start a project. Whether you use an FDM or SLA printer at home, know a little bit about the magic that goes into it so that prints can come out

2.7 Characteristics of filaments for 3d printing

Choosing the appropriate material for 3D printing can be challenging due to the wide range of options available. This paragraph presents the findings of a scientific research study that examined the latest materials used for filaments. The study focused on nylon, also known as Polyamide, which is also referred to as White strong & flexible, Durable plastic, or White plastic. The tensile strength of nylon as a 3D printing material is exceptional. You will not encounter any instances of the material breaking suddenly or becoming fragile. When printing thicker pieces with greater wall thickness and higher density infill, nylon 3D printer plastic demonstrates its ability to make durable parts that can withstand shock. Additionally,

It possesses exceptional resilience against impact. The further features include:

- Durable and pliable plastic material
- Minimum wall thickness of 1mm
- Natural white colour, but can be customized
- Approximately 10 layers per 1mm
- Manufactured from powder
- Alumide composition: Polyamide combined with Aluminum
- Capable of interlocking and movable elements, such as a chain

Figure 8 - printing Nylon filament(allrtha3d)

The second filaments material, we mention ABS: (Home printers)

- Strong plastic like legos are
- Made from spaghetti like filament
- Many color options
- About 3 layers per 1mm
- 1mm minimum wall thicknes

And now the last plastic filament, resin in Multiple options (Bopari et al., 2016)

- Also called White-, Black-, Transparent detail / White detail resin / High detail-, Transparent-, Paintable Resin
- Rigid and a bit delicate
- Liquid Photopolymer cured with UV light

- White, black & transparent most typical colors
- About 10 layers per 1mm
- 1mm minimum wall thickness

In our research we are focusing on just the plastic, but we can mention few other material filaments for 3d printers which almost expensive more than plastic filament, for example stainless steel: (Singh et al., 2016)

- Very strong material
- Made with multiple steps or from powder directly
- Coloring options like gold and bronze plating
- About 6 layers per 1mm
- 3mm minimum wall thickness

GOLD & SILVER:

- Strong materials
- Made from wax and then casted
- About 10 layers per 1mm
- 0.5mm minimum wall thickness

2.8 Mechanical test of materials and impact on final shape

Plastic materials must undergo mechanical testing in order to be evaluated for performance and behavior under various loading circumstances. The mechanical characteristics of plastics, such as their strength, stiffness, toughness, and impact resistance, are usefully revealed by these tests. The final shape and form of plastic components or products may change as a result of the findings of these testing. This expository paragraph examines the mechanical tests that are frequently applied to plastic materials and how they affect the final shape.

(Sedlak et al., 2022)

One of the most fundamental mechanical tests performed on plastics is the tensile test. It entails applying a controlled tensile tension to a plastic specimen until it breaks. This test reveals details regarding the material's elastic modulus, elongation at break, and tensile strength. The outcome of tensile testing can affect the design and shape of plastic components since it establishes the maximum load and strain that a material can withstand before failing.(Dvorak et al., 2019)

Flexural testing, commonly referred to as bending testing, is used to assess the stiffness and strength of plastics when they are subjected to bending stresses. In this test, a plastic specimen is bent in three or four places, and the deflection and load response are measured. The ultimate shape of plastic components, particularly those subjected to bending or flexing loads, is influenced by the flexural modulus and flexural strength discovered during this test since they reveal the material's capacity to sustain bending pressures without permanent deformation or failure.(Joska et al., 2021)

To evaluate the impact strength and toughness of plastics, impact testing is done. The Izod or Charpy impact test, which involves striking a plastic specimen with a standard pendulum whether it is notched or not, is the most popular testing technique. Information regarding the specimen's resistance to rapid or dynamic stress can be gleaned from the energy it absorbed during fracture. The ability of a plastic material to withstand shocks and absorb energy without breaking or fracturing can have an impact on the ultimate shape and form of components, especially those exposed to impacts or shock loads.

To assess particular traits and behaviors of plastic materials, other mechanical tests, including as hardness, compression, and shear tests, may also be carried out. Each of these tests can affect the final shape and design of plastic components or products and offers useful insights into the mechanical properties of plastics.

The outcomes of mechanical testing serve as a guidance for engineers and designers in the selection of plastic materials suitable for certain applications as well as in the optimization of component shape and geometry to ensure sufficient strength, stiffness, toughness, and impact resistance. Making educated decisions and ensuring that the final shape of plastic items fulfills the required performance standards are made possible by testing to understand the mechanical properties of plastics. (Jansar et al., 2007)

In order to evaluate the mechanical properties of plastic materials and how they affect the final shape and form of components or products, mechanical testing is crucial. Strength, stiffness, toughness, and impact resistance are all factors that can be determined using tensile, flexural, impact, and other mechanical tests. These characteristics have an impact on the style and form of plastic parts, guaranteeing that they can endure a range of loading scenarios and satisfy the required performance standards. To get the best performance and shape in plastic items, engineers and designers can choose the right material and design components by conducting thorough mechanical tests

2.9 The hungarian use of recycled plastic

Similar to several other countries, Hungary recognises the significance of employing recycled plastic as a sustainable strategy for waste management and the preservation of resources. Recycled plastic is utilised in several industries and applications in Hungary. This paragraph highlights some of the common applications of recycled plastic in Hungary.

The manufacture of plastic packaging is a prominent use for recycled plastic in Hungary. Bottles, containers, and packaging films are made from recycled plastic, reducing the need for virgin plastic and lowering the environmental impact of plastic waste. By incorporating recycled resources back into the production cycle, this encourages a circular economy.(Andras et al., 2022)

Hungary uses recycled plastic in a variety of construction-related applications. Construction components like pipes, drainage systems, and insulation goods are made using recycled plastic. As long-lasting, affordable, and environmentally friendly substitutes for traditional building materials, these materials help conserve resources and cut down on wastIn addition, recycled plastic is used in the production of household goods and furniture. Hungary manufactures chairs, tables, and outdoor fixtures out of recycled plastic. These goods provide an environmentally sustainable option while preserving their high quality and attractiveness by utilizing recycled plastic. (Amadei et al., 2021)

In Hungary, the automobile sector is another business that uses recycled plastic. Automotive elements, including bumpers, body panels, and interior pieces, are made with recycled plastic. This approach supports the industry's initiatives for sustainability and resource preservation by reducing the usage of virgin plastic. Hungary also promotes the use of recycled plastic in the apparel and textile sectors. Clothing, footwear, and accessories are made from recycled plastic fibers like polyester. This lessens the environmental impact of the fashion industry and helps redirect plastic waste from landfills. Hungary has adopted a number of regulations and programs that support recycling and waste management in an effort to encourage the usage of recycled plastic. These include initiatives to separate waste, financial rewards, and education efforts to promote the use of recycled plastic by people, companies, and sectors.

Finally, Hungary uses recycled plastic in a variety of industries, such as packaging, building, furniture, automobile, and fashion. Hungary wants to lessen plastic waste, conserve resources, and advance a circular economy by using recycled plastic into a variety of applications. The nation's initiatives show a commitment to appropriate waste management and resource exploitation, and they are in line with global sustainability goals.

Thus, this research effectively proved that the recovered material had the potential to substitute for, and even surpass, coated wood chipboards in terms of performance. Additionally, the new process provides economic advantages as recovered polypropylene is more cost-effective compared to newly produced polypropylene. Following the conclusion of the project, compression moulding has been substituted by both injection moulding and extrusion. While extrusion items, such flooring profiles, continue to be made with new plastics due to their strict optical standards, the injection moulding process utilises approximately 60% recycled plastic. Werzalit's WPC department had generated six full-scale production lines and 16 new employment by September 2007. There is a growing production of WPC products, with a wide range of volumes and types. The plastic wood compound is sold as granulate to other companies that specialise in injection moulding. Bose, a renowned sound system supplier, is currently utilising the material to provide Audi with high-fidelity speakers. Innovative waste management (Geyer et al., 2017)

2.10 Summary of literature review

The analysis of published research has shown that there has been an increase in plastic recycling on a scale that has never been seen before. This is a consequence of the rise in the amount of waste materials as well as the development of technologies for 3D printing.

- It has been observed that recycling technology are continuing to advance. To satisfy the need for electricity posed by trash, novel and intricate approaches are currently making their way into the market.
- It was also clear to explain the rationale behind selecting the PET material for this research, especially in light of the fact that earlier studies relating to other materials had bee conducted.
- The mechanical composition of the plastic recycling machine includes a crusher and an extruder.

Nevertheless, this study does not provide a thorough examination of the relationship between the two factors, as its main emphasis is on the subsequent processes following recycling.

- The evaluation determined that studies have been undertaken on the mechanical properties of filament produced from recycled materials and its comparison with virgin material.
- The optimal material can be achieved by the combination of concrete and plastic. In this research, the plastic used will be obtained from the recycling machine as recycled material.

From the review of the relevant literature, it is possible to draw the conclusion that recycling can be done in a variety of ways and for a variety of purposes, and that this varies depending on the recycling legislation in this nation, the consumption patterns of the local population, the cost of filament, and the percentage of pollution that is caused by plastic. As a result, a knowledge gap about the materials used in 3D filament printing has been identified.

Consequently, this enabled the present study to successfully accomplish its stated objectives, namely, to address the existing knowledge deficit by providing answers

III. MATERIALS AND METHODS

This chapter presents the materials, procedures, and processes used in the research, including the scientific methods involved in the experimental measurements and the description of the test systems to obtain the set research objectives.

3.1 Small scale recycling technologies

The purpose of this project is to investigate and develop an autonomous recycling station that operates without human intervention. The station will be designed to automatically process plastic waste, with the operator only required to load the plastic into the system and collect the resulting filament at the output.

For this we know that we need to create a link between the shredder and extruder for the transfer of the plastic from the first to the second machine (through a conveyor belt for example). But, this project at end of study, we limit ourselves to only extrusion and grinding operations and the transfer will be manual.

This solution is made up mainly by a rotor on which attaches staggered straight blades relative to the other by an angle of 45 °. The axis (1) is enclosed within a cylindrical structure (2) in order to secure the blades (3).

in a perpendicular position. In the lateral sides of the key set two additional anvil-blades (4) to blades to ensure efficient grinding of the plastic. (See fig 9)

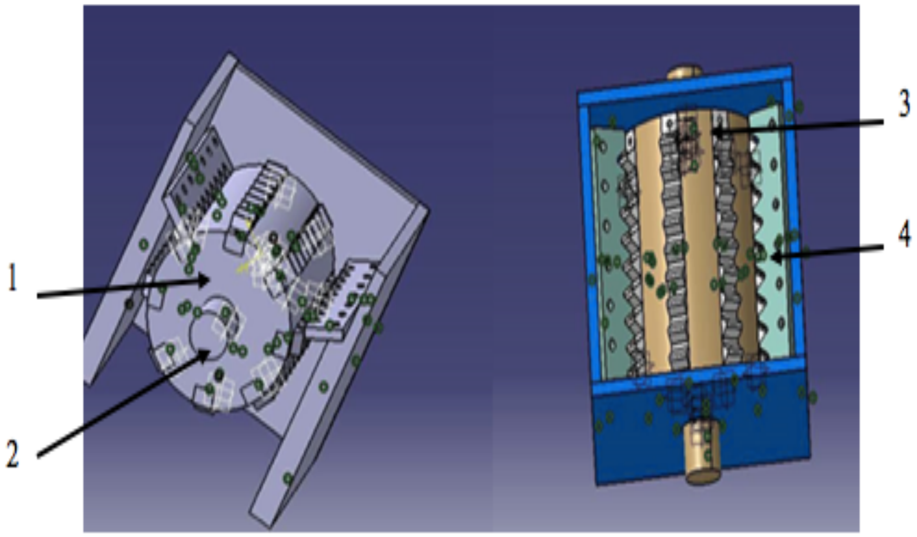


Figure 9 - overview of the crusher (first solution)

This second solution consists of a crusher with two rows of circular blades (1). Thus, this crusher consists of two rotating shafts in the opposite direction. Also, it is composed by an anvil-blade (2), as shown in the figure 9., that always bring back plastic parts in the active area of grinding. In the lower part of the crusher there a sieve (3) to make sure that we get very small grains.

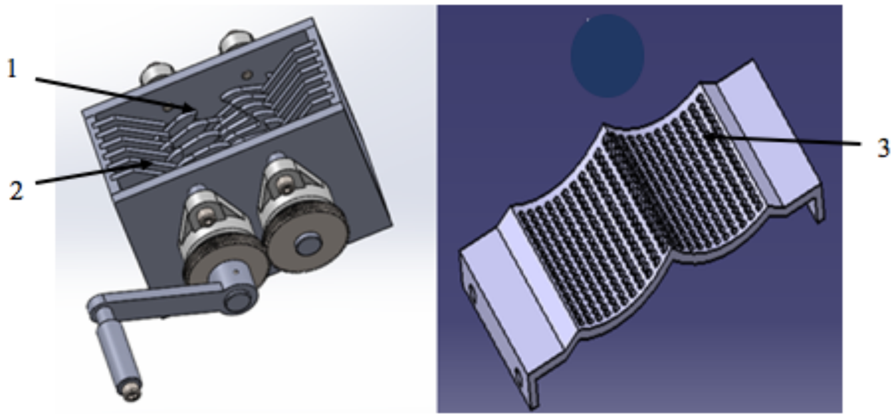


Figure 10 - overview of the crusher (second solution)

This first solution for extruder is screw extrusion uniform and with an engine attached to an angular gear in order to save space and reduce the size of this prototype, and to order the motor speed according to our need.

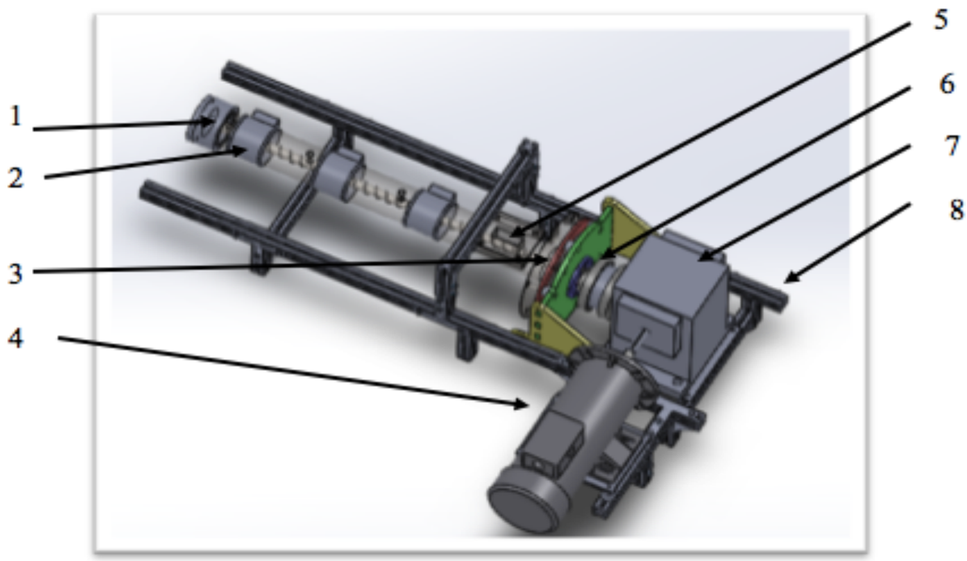


Figure 11 - overview of the extruder (first solution)

1: Nozzle	2: Heater band
3: Thermal insulation	4: engine
5: Grain entry hole	6: Rigid coupling
7: Angular gear	8: Stand

This solution is much simpler that it contains only the elements necessary for the functioning. It differs to the first solution by the hopper.

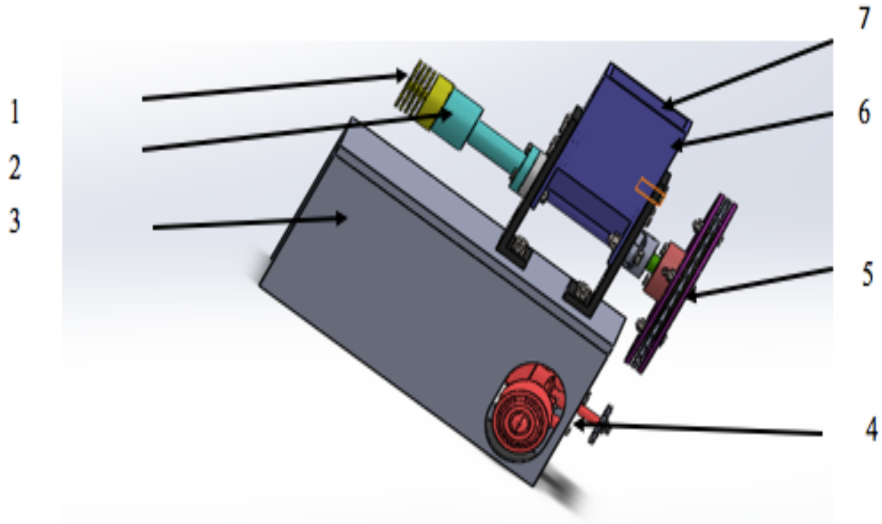


Figure 12 - overview of the extruder (second solution)

1: Nozzle	2: Heater band
3: Stand of extruder	4: engine
5: Gearwheel	6: Stand of the hopper
7: Hopper	

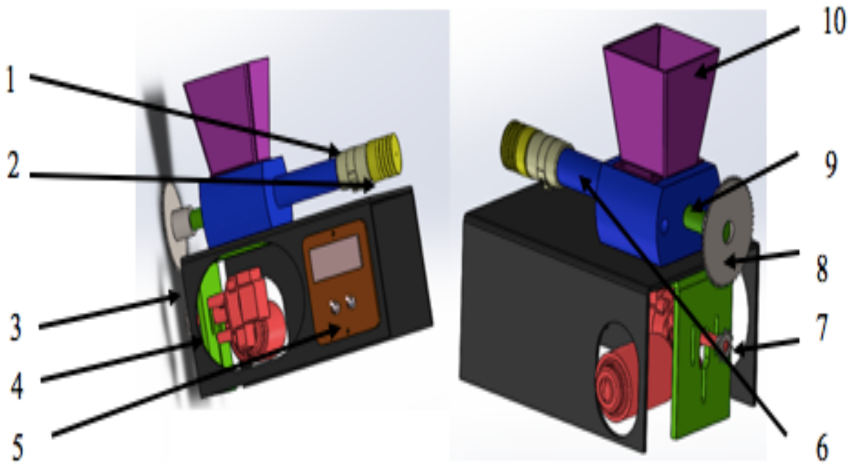


Figure 13 - overview of the extruder (third solution)

1: Heating package	2: Nozzle
3: Stand of extruder	4: engine
5: Control panel	6: Extrusion chamber
7: Small pinion	8: Large pinion
9: Extrusion screw	10: Hopper

To choose between two solutions or more, we will use one approached to determine the most appropriate system using a system of weighting of search criteria following:

- Complexity: This criterion depends on the technical solutions chosen in order to ensure the functioning of the system.
- Feasibility: It is the possibility of the realization of view material and cost.
- Availability: It is crucial to design a mechanism capable of being realized in our country (availability of parts and metals in the local market).
- Durability : This test characterizes the ability of the system to maintain its profitability

Evaluation of solutions in this step, by assigning a score of 1 to 5 for each criteria of a solution and subsequently compare solutions and choose one among them.

	Solution 1	**Solution 2**
Feasibility	1	4
Complexity	3	2
Availability	4	4
Durability	1	3
Total	9	13

Table 2 - Evaluation of solutions for Crusher

	Solution 1	**Solution 2**	**Solution 3**
Feasibility	2	3	4
Complexity	4	1	3
Availability	1	2	4
Durability	3	1	3
Total	**10**	**7**	**14**

Table 3 - Evaluation of solutions for extruder

After making this assessment, we will conclude the second solution for the crusher and the third solution for extruder.

3.2 Materials and methods used to prepare filament from recycled and virgin PET

In order to obtain the recycled material that we utilised in this investigation, which was recycled polyethylene terephtalate, we ground up waste plastic bottles.

There are several phases involved in the process of preparing PET plastic waste aggregate, including the following:

- Collecting the PET bottles wastes.
- Removing the cover and trade label.
- Washing and drying the bottles.
- Shredding and grinding the PET bottles to the specified particle size

The grinding process was carried out in the FKF ZRT. (see in Fig. 2):

Figure 14 - PET plastic recycling steps

The plastic PET bottles were grinded in order to prepare the accumulated waste of PET plastic. Three principal stages mark the grinding of PET plastic accumulation. The first involves collecting the plastic waste, the second consists of drying the bottles, and the third involves grinding and shredding the bottles to a particular particle size. FKF Zrt, a Budapest-based plastic recycling company carried out the process of grinding. The distinct kinds of selective waste recycled by the company are illustrated in Table 4 below. The monthly sorting of incoming waste serves as the basis for the statistics.

2018		January		February		March	
		Kg	m/m%	Kg	m/m%	Kg	m/m%
PET	Clean	30,4	12,2	27,0	10,6	30,2	11,9
	Blue	38,5	15,4	30,4	11,9	32,6	12,8
	Coloured	10,9	4,4	16,0	6,3	18,9	7,4
Foil	Dyed	6,3	2,5	8,6	3,4	5,6	2,2
	Natural	4,1	1,6	7,3	2,9	5,0	2,0
Flacon		36,5	14,6	25,4	10,0	22,4	8,8
Hungarocell		0,3	0,1	1,0	0,4	1,4	0,6
Metal	Tinned metal	6,0	2,4	6,2	2,4	3,0	1,2
	Aluminium	6,1	2,4	6,4	2,5	3,3	1,3
Other Waste		111,1	44,4	126,3	49,6	131,8	51,8
Altogether		250,2	100,0	254,6	100,0	254,2	100,0
Recyclable		138,8	55,5	127,3	50,0	121,0	47,6
Non-Recyclable		111,4	44,5	127,3	50,0	133,2	52,4

Table 4 - Ratio and types of collected selective waste during the first semester2018

The main production for PET is for the applicability of synthetic fibres (in excess of 60%) with bottle production accounting for around 30% of global demand. In terms of textile applications, PET is generally referred to as simply "polyester". The terminology “PET" is used generally for packaging applications. The polyester industry makes up about 18% of world polymer production and is third largest industry after polyethylene (PE) and polypropylene (PP). (Rahmani et al., 2013).

PET is recycled quite frequently and has the number "1" as its recycling symbol. The first PET was patented in 1941 by John Rex Winfield, James Tennant Dickson and their employer the Calico Printers' Association of Manchester and the PET bottle was patented in 1973 by Nathaniel Wyeth. PET is also used as substrate in thin film and solar cell.(Bornak, 2013).

For the purpose of the experiment, materials made of polyethylene terephtalate that were both coloured and clean were selected

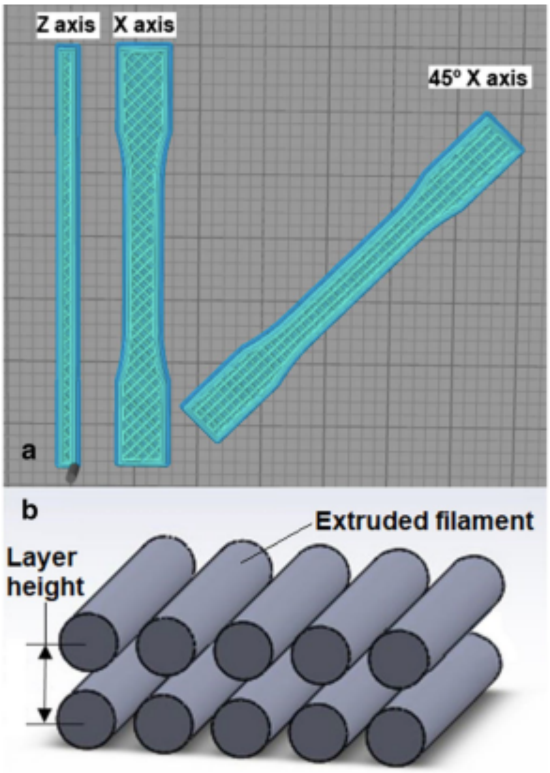


Figure 15 - Geometrical drawing of specimens for tensile test

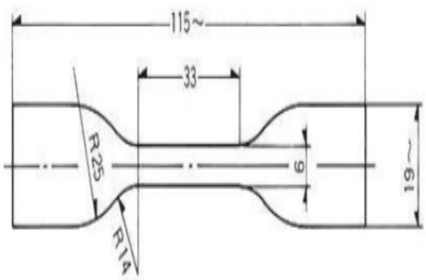


Figure 16 - Geometrical drawing of specimens for tensile test

My participation in The Department of Mechanical Engineering at Szent Istvan University carried out the mechanical strength testing of 3D printed parts. Prior to the extrusion process, the sample was dried and thermal properties of the material are indicated in Table5.

Material:	Polyethylene Terephthalate
Melting point [°C]:	225
Drying time [hours]:	4-5
Drying temperature [°C]:	160

Table 5 - thermal properites for PET

According to the above-mentioned test method the sample was designed by the Catia software with the actual shape and dimensions and has been exported to an STL format, so that it can be read and interpreted by the printing parameterization software. All of the 40 specimens were printed using Makerbot 3D printing (Fig 17). The same raw material used for the printed specimens was used for this. And same for recyled material. In this way the results obtained can be comparable. These specimens were manufactured in the condition which are defined in previous table .

Figure 17 - Sketch large 3d printers, Makerbot (Free Dee.hu)

After obtaining the samples from the 3D printing Free Dee printing solutions. Prior to the drying and shredding of the material using an extrusion machine as shown in Figure 18, the PET was also dried for extrusion, in order to adequately prepare the sample. Extrusion then occurred once thoroughly dry. The method of extrusion is comparable for the majority of the most prevalent types of plastic, and figure 15 illustrates a sampling of the machines that are used for extrusion

Figure 18 - sample of extrusion machine during the preparation of specimens

The speed of the fan and temperature remained constant, while the shredding of the material occurred using three distinct diameters. Once three tests were completed, the measurement was ready. The features of the daily test are presented in table 6

TEST	Diameter of shredded material(mm)	Temperature range[°C](standard)	Filament fan speed (%) and extruder revolution per minute (rpm))
1	2,85	240-245	80%-5 rpm
2	2	240-245	80%-5 rpm
3	1,75	240-245	80%-5 rpm

Table 6 - setting and parameters using during the test(standards or PET material)

The specimens that will be tested on the research of this dissertation will follow the parameters from standard test ASTM methods. ASTM are standards to follow on the experimental research to determine mechanical properties of materials. Given material restrictions, for each type of material, there were made three specimens for each printing temperature. There were printed the same number of specimens for each filament for the three mechanical tests such a tensile, deviation and eleasticty.

This gives a total of five specimens per filament for each mechanical test

Regarding the guidelines of the ASTM D638-02a, the tensile specimen was made accordingly the Type I of the suggested samples. This standard recommends these dimensions for the majority of tensile tests specimens' production (ASTM International, 2003). However, there were made some small modifications to promote more precise results. Since the tensile testing machine reveals to have some inconsistencies reading lower strength values, it is recommended to produce a sample with large dimensions of the area subjected to traction, promoting higher values of the strength. It is important to mention that the central rectangular section is thinner than the extremities to avoid a fracture near the grips. Consequentially, ($A0 = W \cdot T$) is the area subjected to the traction. It is also noteworthy to refer that in order to avoid a stress concentration on the transition between the grips section and the section subjected to traction, it was made a radius R for that effect (Fernandes, 2016).

3.1 Testing materials and comparison in mechanical properties

The test commences with measuring the filaments in intervals of 1 m as well as the diameter of the recycled PET. This allows an examination of the filament quality control. Subsequently, the thermal properties are examined after identifying the melting points and the cross-section and surface of the materials are tested. The tensile testing for the raw materials is part of the second test.

In line with the Iso 527–1:2012 standard of the American Society of Testing Materials

(ASTM), the tensile specimens were created (as illustrated in Figure 19).

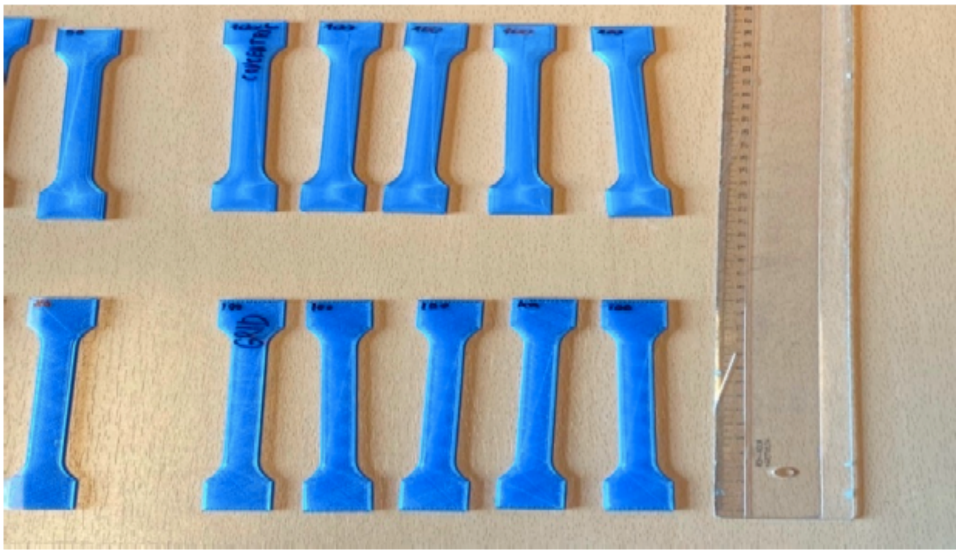


Figure 19 - testing materials standard for the specimens

The virgin materilal PET (not recycled one) filament with a diameter of 1.75 mm enabled the manufacturing of the original test samples. A digital micrometer with 0.01 mm accuracy was used to assess the length and width of the shear specimens after the specimens were generated at 210 celcus degree, with a nozzle of 0.4 mm. At a head travel speed of 5 mm per min, the Testometrinc Zwick/Roel

Z100 was used to carry out the tensile testing, as seen in Figure 20 , after the tensile test, a sample of final shape of virgin PET specimens is shown in Figure 19 .

Tensile properties including tensile yield strength and tensile modulus of elasticity were cited in Table 7.

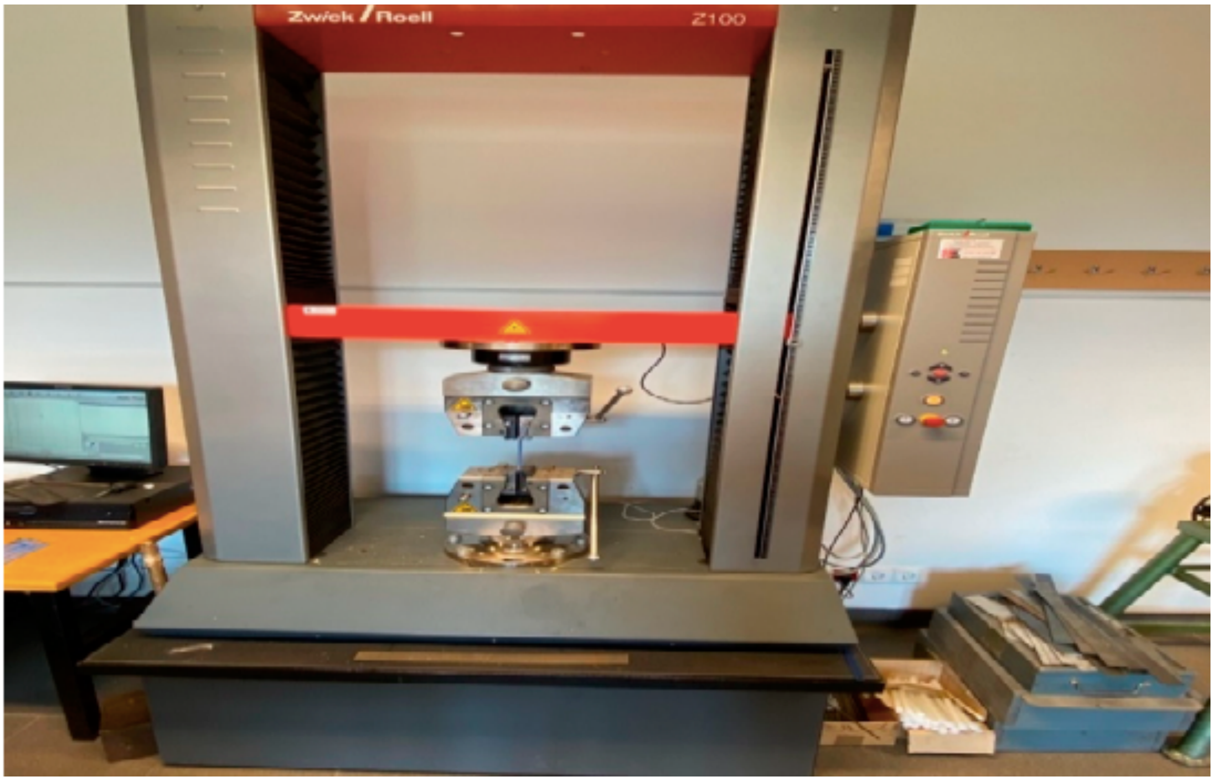


Figure 20 - Testing tensile specimens, Testometric.

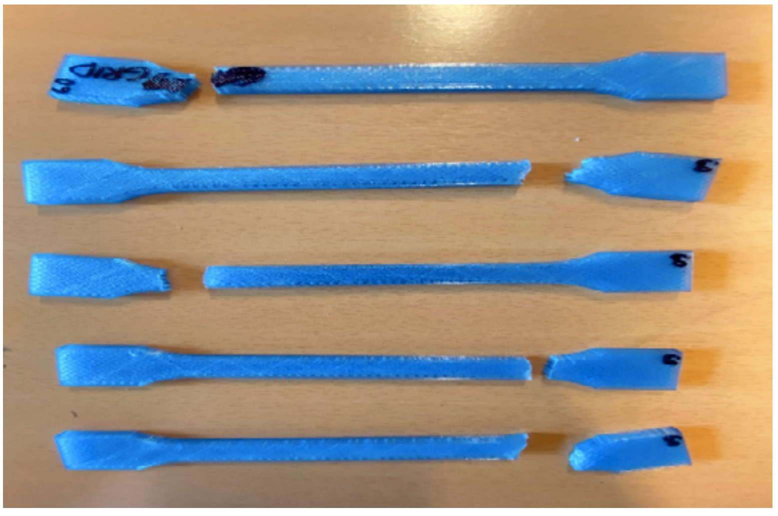


Figure 21 - Sample of specimens after the tensile test (virgin PET)

This tensile test aims to provide mechanical properties regarding the resistance of the material to tensile loads and the elasticity or stiffness of the material. Thus, it will be used the collected data to state three important mechanical properties: Young Modulus, regarding the elastic/stiff property; Tensile

Strength, regarding the maximum supported tensile stress; Yield Strength, regarding the maximum stress supported until the material passes through elastic to plastic deformation (Beer & Jonhnson, 1981; Budynas & Nisbett, 2015; William D. Callister & Rethwisch, 2012). These concepts will be explained with more detail in the next paragraphs.

	Virgin	recycled
Number of specimens	20	20
Average tensile yield strength (MPa)	34.871	29.742
Standard deviation	1.593	2.778
Average tensile modulus of elasticity (MPa)	3670	3346
Standard deviation	224	413

Table 7 - Mechanical properties of virgin ans recycled speciments

Regarding the equipment used to perform this test, the testing machine used was an INSTRON 5566. This machine was setup with a load of 10 kN and a speed of testing of 2mm/min. It also necessary to introduce on the software the values of Thickness (T) and With (W), allowing the machine to determine and collect instant data related to the Strength (F) and displacement (Δl). The initial area (A0) can be obtained by multiplying T by W. In this traction test there are some precautions to take into consideration. To start this procedure, it is necessary to introduce some data on the software, such as the number of samples that will be tested (36) and the speed of testing. It is really important to guarantee that the axis of the specimen is aligned with the direction of the application of the load. Thereafter, it is possible to start the tensile test. However, it is extremely important to reset to zero the value of the measured strength before starting every traction of a specimen. When starting the test, the machine reads a small negative load value, which has no implications in the results. However, if in the next test the load value is not reset, the machine will accumulate this value. If this procedure continues sample after sample, the starting read load will increase to values that will interfere with the reliability of the results. Resetting this load value to zero will prevent the machine from reading mistaken values. In this tensile test it is possible to determine the stress, σ, and nominal extension, ε, through equations [1] and [2]: $\sigma = F\ A0$ $\varepsilon = \Delta \mathrm{l}\ L$ With the properties' values, it is possible to draw the Stress-Strain curve for the tested specimen. In the Stress-Strain graph represented in figure 22 there are highlighted two important stages and some properties that can be determined. The linear zone represents the elastic deformation stage of the material, where, theoretical, the material has the capacity of returning to its initial geometry if the stress is removed. The second phase, when the graph is not linear, is the plastic deformation stage where the material starts to collapse. Basically, the atoms start to break their bonds and re-forming with neighbours. It this situation the material does not returns to its original form, when the stress is removed. With this information it is possible to determine two important properties: Yield Strength and Tensile Strength, relative to the mechanical resistance (Beer & Jonhnson, 1981; Budynas & Nisbett, 2015; William D. Callister & Rethwisch, 2012). The Yield Strength (σy) corresponds to the stress value where the material passes from elastic deformation to plastic deformation. This is represented as point P and given that it is too difficult to precisely measure it, point P can be determined by drawing straight line 43 parallel to the elastic stage with a 0.2% strain offset. The Yield Strength corresponds to the intersection point of this 0.2% offset line with the graph. The Tensile Strength (TS) is the maximum stress sustained by the material, before the occurrence of a fracture and is represented in figure 22 by point M. Another important property is the Elastic Modulus or Young Modulus. It is relative to the toughness property, which is an information on the material's resistance to fracture, that is to say, the capacity to absorb energy and plastically deform before fracturing. It can be obtained by determining the slope of the linear stage, the Elastic deformation. In this analysis, the Elastic Modulus was determined by using linear regression. It was considered the maximum possible number of points to ensure that the determination coefficient (R 2) was greater than 0.99. Maximizing the value of R 2allows to determine a more coherent value of the slope of the line parallel to linear zone, and so a more precise value of the Elastic Modulus (Beer & Jonhnson, 1981; Budynas & Nisbett, 2015; Fernandes, 2016; William D. Callister & Rethwisch, 2012)

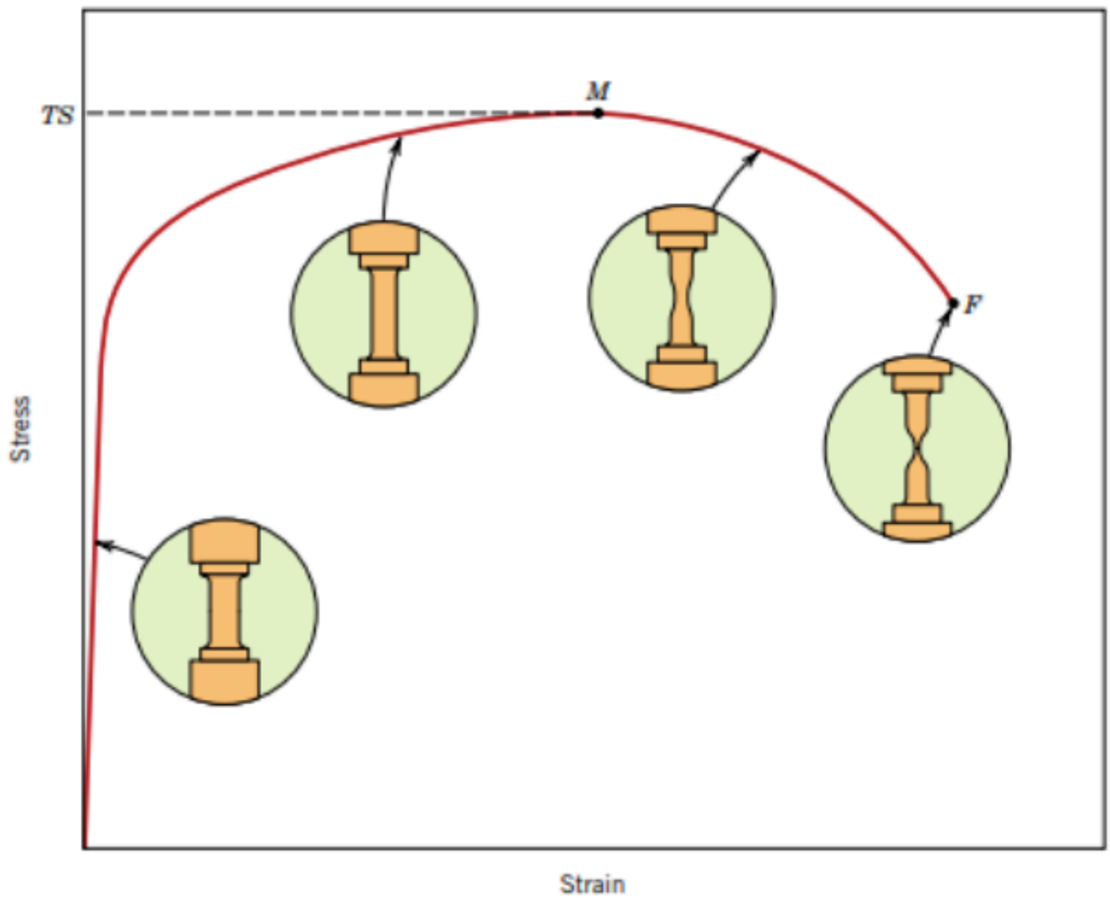


Figure 22 - Stress Strain Diagram Roture Point M representation (William D. Callister & Rethwisch, 2012)

3.4 Polyethylene terephtalate: homogeneous materials after using recycled method

The growing worldwide apprehensions about environmental sustainability have stimulated the investigation of innovative approaches to curtail waste production and foster material recycling. The disposal of waste plastic poses a significant challenge to waste management systems and is a major contributor to environmental pollution. Recent research has centered on the utilization of waste plastic in the production of concrete as a novel strategy for promoting sustainable construction. The purpose of this paragraph is to present a comprehensive summary of the advantages and drawbacks that may arise from the integration of waste plastic into concrete blends to ensure that recycled plastic doesn’t affect the quality of material while mixing plastic in concrete as an exampleThe focus is on the potential of this approach to improve the mechanical characteristics and longevity of concrete, while also addressing the negative environmental consequences of plastic waste.

Concrete is a construction material that is extensively utilized worldwide, and it has a significant environmental impact due to its consumption of natural resources and the high carbon emissions that are linked to its production. The integration of discarded plastic materials into concrete has surfaced as a potentially effective resolution to tackle the problems associated with plastic waste disposal, while also improving the functionality of concrete constructions. The utilization of waste plastic, such as PET bottles, PP bags, and PS foam, in concrete has been found to have advantageous effects on its mechanical, thermal, and durability properties due to the distinctive attributes of these materials.

Incorporating waste plastic into concrete mixtures presents various noteworthy benefits. Initially, plastic particles function as a substance that fills a space, leading to a reduction in the amount of cement needed and consequently mitigating the ecological ramifications linked to cement manufacturing. Moreover, the intrinsic polymer properties of discarded plastic enhance the workability and flowability of concrete, thereby augmenting its ease of placement and diminishing the requirement for excessive water. Consequently, this leads to an improvement in the strength and durability of concrete structures. In addition, it has been observed that waste plastic particles possess pozzolanic characteristics. These particles react with calcium hydroxide in the presence of cement, leading to the formation of supplementary cementitious compounds. This process ultimately results in the improvement of the long-term strength and durability of concrete.

Although there are several advantages associated with the integration of waste plastic into concrete, there exist certain obstacles that must be addressed. The need to obtain a consistent and high-quality plastic aggregate requires appropriate sorting, cleaning, and processing of plastic waste due to its heterogeneous nature. The heterogeneity of plastic particle dimensions, morphology, and chemical constituents may exert an influence on the manipulability and mechanical characteristics of the resultant concrete blends. In addition, there are apprehensions regarding the possibility of hazardous substances being released from waste plastic into the surroundings and the extended resilience of plastic-altered concrete, which necessitate comprehensive scrutiny and evaluation to guarantee the safety and endurance of these substances.

This part aims to study the possibility of using waste plastic bottles (PET-polyethylene terephthalate) and tanks (LDPE-low polyethylene density) in concrete without any other transformation than grinding, in order to minimize the cost of the final material. The influence of the proportion of waste used on physical and mechanical characteristics of the new material will be studied.

In order to minimise plastic waste and align with the goals and principles that should shape the future world, focusing on eradicating poverty, protecting the environment, and promoting suistanable development

The unprocessed sand (figure 23) was sifted to obtain three distinct types of sand:

- SandI, with grain diameters ranging from 0.5
- Sand II, with grain diameters less than 0.5 –
- Sand III, comprising the complete sand sample.

The specimens were fabricated using three distinct varieties of sand.

Figure 23 - Sand used during the test

The results from the above system are given in both tabulated and graphical forms. Daily, monthly, yearly and total plant production are the main output parameters from the system in addition to carbon dioxide (Co2) saving and system data.

Figure 24 - LDPE Plastic

Small and large PET bottles are used in this study. PET bottles with different sizes and colors are minced to achieve extremely small diameters and particles that can pass sieve.

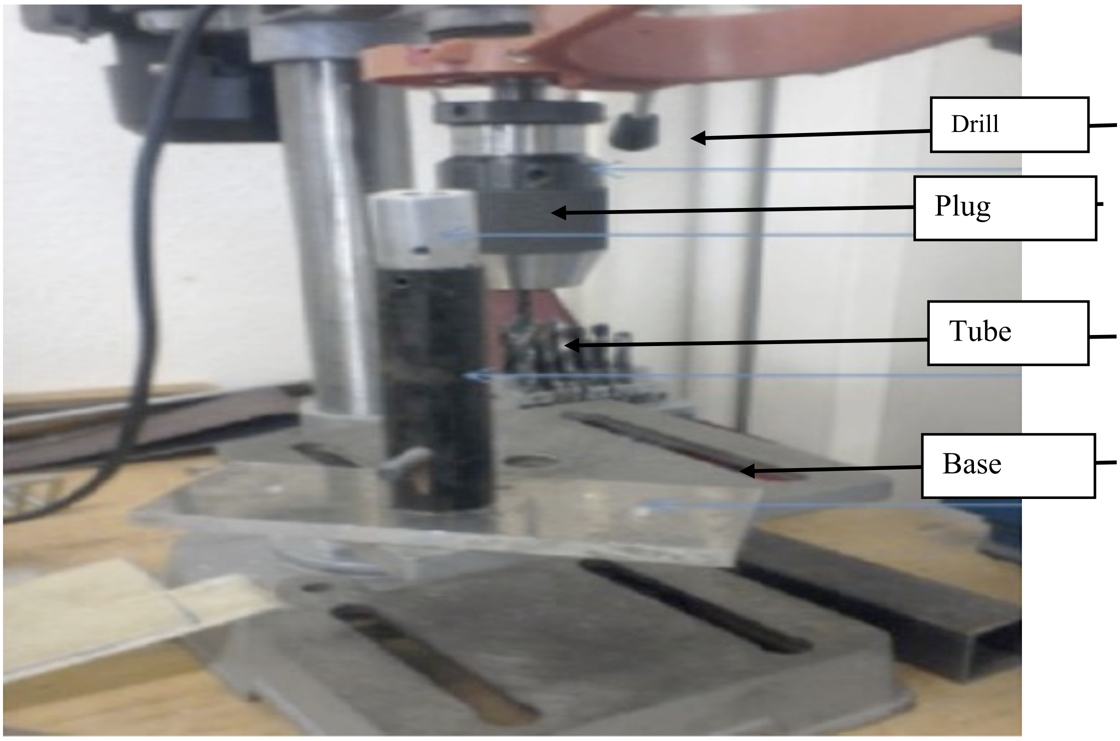


Figure 25 - Thermoplastic mixer (RM 2000C)

The plastic sand mixture is inserted into a tube (as shown in Figure 25) and heated to a temperature of 170 °C. The content consists of plastic sand and a drill. The plastic constitutes 25% of the whole combination by mass. Once the plastic has completely melted and the sand has been thoroughly blended with the plastic, we proceed to place the mixture into a mould. The mould is thereafter placed beneath a thermopress (Figure 22). A heat cannon (depicted in Figure 26). The tube is heated using a hot air gun until the temperature inside reaches 170 °C. This process takes around 20 minutes

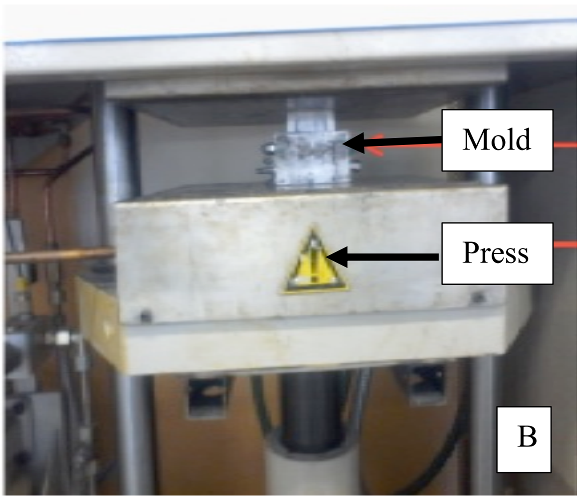


Figure 26 - Hot air gun injection (A) and injection molding machine (B)

The integration of waste plastic into concrete has emerged as a feasible approach to promote sustainable construction practices. Integrating plastic trash into concrete mixtures offers a hopeful method to alleviate the adverse effects of plastic waste on landfills. This novel technology has the capacity to produce numerous advantages, such as higher mechanical qualities, increased durability, and less environmental effect. Further research and development are necessary to properly address the challenges associated with the processing of plastic waste, ensuring quality, and maintaining the long-term effectiveness of plastic-modified concrete. By implementing this innovative approach, the construction industry has the capacity to significantly contribute to the circular economy and promote environmental sustainability initiatives.

IV. RESULTS

The results obtained from the experimentation and the discussions highlighting the new scientific findings. These include the new filaments characteristics

4.1 Results and discussion on the Small scale recycling technologies

In the following chapter, i will go over the specifics of the solution that was selected in the previous chapter. The method will start with the description system and the scheme of kinematics. Next, we will specify the technical aspects while utilizing the CAD SOLIDWORKS 2015 program as we detail the design of the many blocks that make up the system, and then we will assemble everything. Following this step, we will proceed to carry out calculations and dimensioning of the Crusher. Following that, we will validate the structure by conducting a static analysis, and this chapter will come to a close with a conclusion.

4.1.1 Measurements and design of the Crusher

Crushers are mechanical apparatuses that are employed to fragment larger substances into smaller particles, rendering them amenable for subsequent processing. The evaluation and configuration of crushers are pivotal factors that have a direct impact on the efficacy and proficiency of crushing procedures. The attainment of precision in the size reduction process is contingent upon the attainment of accuracy in measurement. Additionally, the optimization of the crusher's performance, energy efficiency, and overall productivity is facilitated by the careful consideration of design elements.

During the design phase, we gave each individual component its own distinct design, taking into mind its practicability and the likelihood that it will be able to be manufactured. The components that make up the crusher are as follows: twelve blades, twelve anvil-blades, a right axis, a left axis, a cover, a sieve, fourteen casing spacers, four nuts, two pins, and a crank. After you've finished designing all of the individual components, we'll move on to the Assembly step.

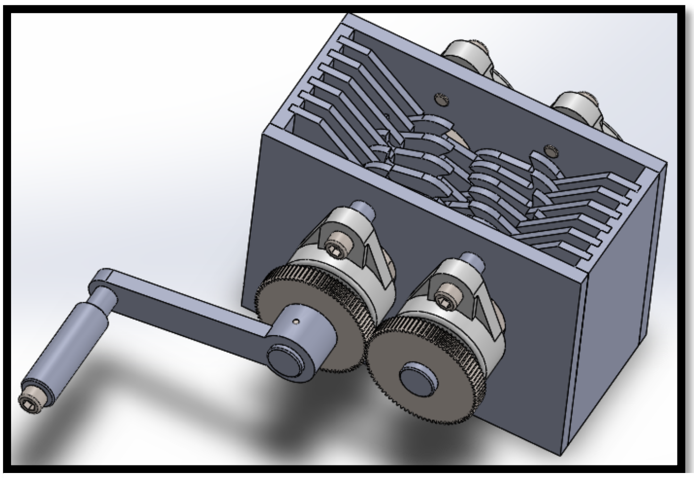


Figure 27 - Overview of the complete design of the crusher

4.1.1.1 Bending of the axis

We measured the load that was being applied to the axle by the blades, spacers, and nuts, and then we used the RDM 6 software to distribute that load as a uniform load. You can see this illustrated in the picture below. The following definitions describe the distribution of the load value q:

$$q = \frac{load}{Length} = \frac{mass \times g}{L} = \frac{3{,}42 \times 10}{190} = 0{,}18 \text{ N/mm} \qquad (3)$$

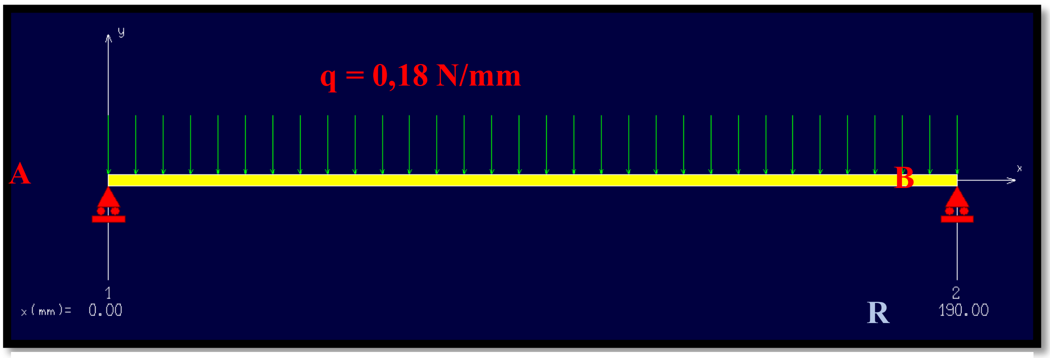


Figure 28 - distribution on the load

Applying the two equations of equilibrium yields:

$$\sum \vec{F}ext = 0 \quad \rightarrow Ra + Rb - q \times L = 0 \qquad (4)$$

$$\rightarrow Ra = q \times L - Rb$$

$$\sum M/A = 0 \quad \rightarrow - q \times L \times \frac{L}{2} + Rb \times L = 0 \qquad (5)$$

$$\rightarrow Rb = q \times \frac{L}{2} = 0{,}18 \times \frac{150}{2}$$

$$\rightarrow Rb = 17{,}1 \text{ N}$$

$$\rightarrow Ra = 17{,}1$$

Now, we will generate the arrow and bending moment by RDM 6 at the moment.

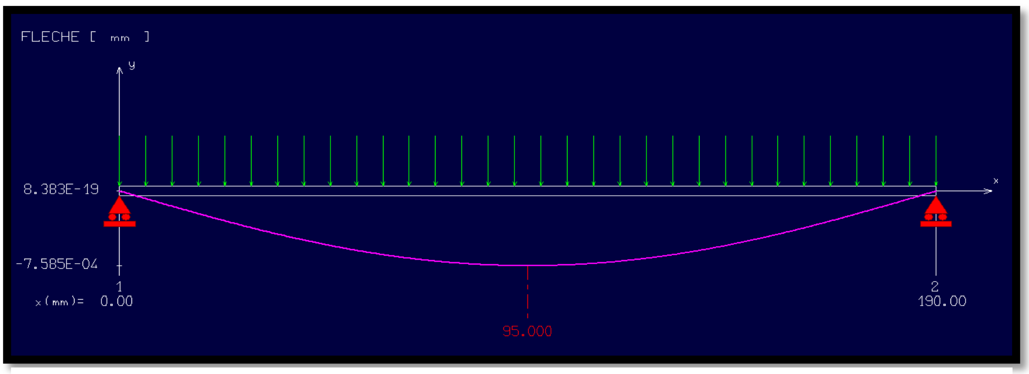


Figure 29 - overview of deflection

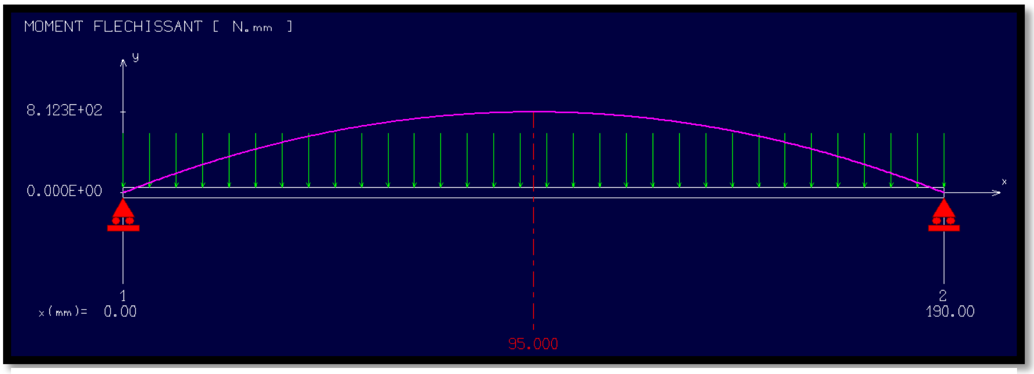


Figure 30 - bending moment of axis

Using RDM 6,   Mf,max = 812 Nm

To determine the eligible minimum diameter of the shaft, check the following:

$$\frac{M_{f,max}}{Iz} \times \frac{d}{2} \leq \sigma_{all} \qquad (\sigma_{all} = \frac{\sigma_y}{s}) \qquad (6)$$

With:

- d: diameter of shaft axis.
- s: Factor of safety (choosing s=3) [Annex 5].
- Iz : inertia moment of axis (Iz = $\frac{\pi . d^4}{64}$).
- σ_{all} : allowable stress

Our material is unalloyed steel (X 160 Cr Mo V 12) with chromium and molybdenum and commonly used for making screws.

Yield strength is of 800 N/mm² for small (< 100 mm) dimensions and 700 N/mm² for the higher dimensions.our case length was 190 mm .

So:

$$\sigma_y = 700 \text{ MPa.[annex 4]}$$

Then,

$$d \geq \sqrt[3]{\frac{32.M_{f,max}}{\pi \, \sigma_{all}}} = \sqrt[3]{\frac{32 \times 812}{\pi \times 233{,}3}}$$

$$\rightarrow \quad d \geq 4{,}59 \text{ mm}$$

4.1.1.2 Torsion of the axis

In this part, it is focusing on the torsion of the shaft.

It must: $\tau \leq \sigma_{all}$ (7)

Knowing that: $\tau = \frac{T}{J_{Gx}} \times \frac{d}{2}$ and $\mathbf{J} = \frac{\pi . d^4}{32}$

And $\sigma_{all} = \frac{0{,}5 \times \sigma_y}{s} = \frac{0{,}5 \times 700}{3} = 116{,}\ 33$ MPa

Therefore $d \geq \sqrt[3]{\frac{16 \times T}{\pi \times \sigma_{all}}} = \sqrt[3]{\frac{16 \times\ 25{,}2.10^3}{\pi \times 116{,}33}} = 13$ mm

With:

- T: The required torque to be applied by the operator on the crank for crushing the
- plastic. [11]
- τ : Shear stress.
- J : Polar moment of inertia .
- σ_{all}: Allowable normal stress.
- σ_y : Yield strength. [Annex 4]
- s : Safety factor. [Annex 5]

Following the completion of the calculations, we made use of the finite element calculation tool within SolidWorks Simulation 2015. We have applied loads to the axis in the form of the torque that is driving the axis as well as the load that is coming from the blades. Additionally, we have not overlooked the fact that gravity must be taken into account due to the masses of the blades, rings, spacers, and nuts.

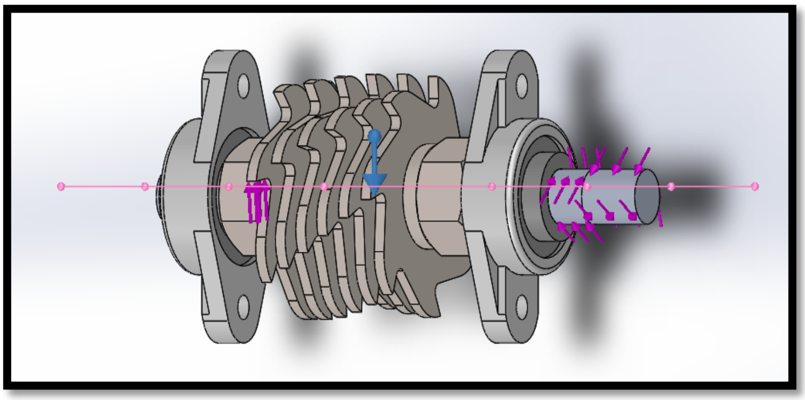


Figure 31 - Loads imposed on the axis

Analysis of the constraints based on the geometry of the shaft gave a maximum stress of Von Mises of the order of 15.5 MPa.

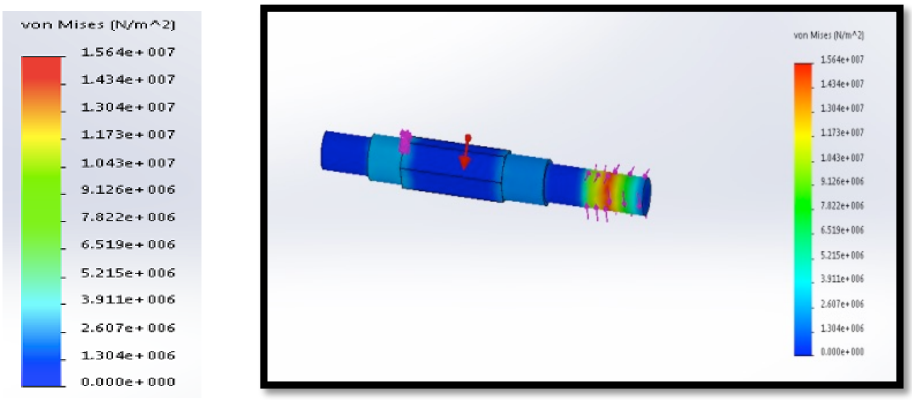


Figure 32 - Analysis of the constraints for the axis of the crusher

$$15{,}6\ \text{MPa} \leq \frac{\sigma_e}{s} = \frac{410}{3} = 136{,}6\ \text{MPa}$$

With: s is the safety factor → Validate

The analysis of movement gave us a maximum displacement of 9 µm:

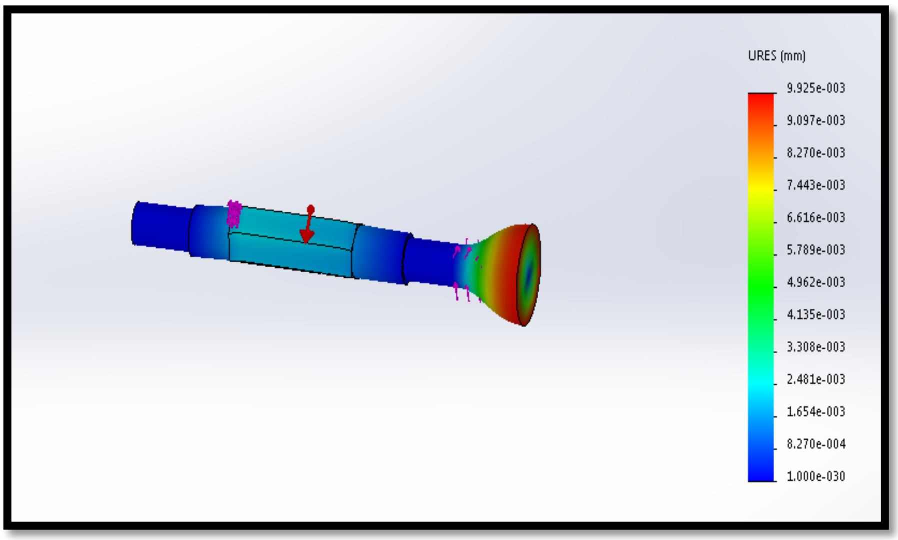


Figure 33 - Analysis of displacement for the axis of the crusher

The axes of our grinder can operate safely. So, we can continue to count on the final material: steel Z 160 VC 12

4.1.2 Measurements and design of the Extruder

Extruders play a crucial role in diverse manufacturing industries by facilitating the effective manipulation and formation of materials. The assessment and configuration of extruders are crucial factors in attaining the most favorable extrusion efficacy. Precise quantification of essential variables and meticulous evaluation of design elements are imperative in guaranteeing uniformity in product excellence, elevated efficiency, and economically viable functioning.

When the operator is finished loading the extruder with recovered plastic that has been crushed by the shredder, they do so by feeding grain plastic into the hopper. The grain is pushed further into the extrusion chamber by the extrusion screw as it turns and as it passes through its feeding area. At this point, the plastic will start to acquire a paunch. The plastic mixture eventually becomes homogenous as it moves into the area of compression, at which point it begins to heat up. Finally, when the plastic mixture reaches the area where the pumping is taking place, it becomes soft as a result of the band heaters, and it is pumped to the outside through the nozzle in order to make the appropriate filament.

Following the design phase of the various components, we will now move on to the Assembly phase.

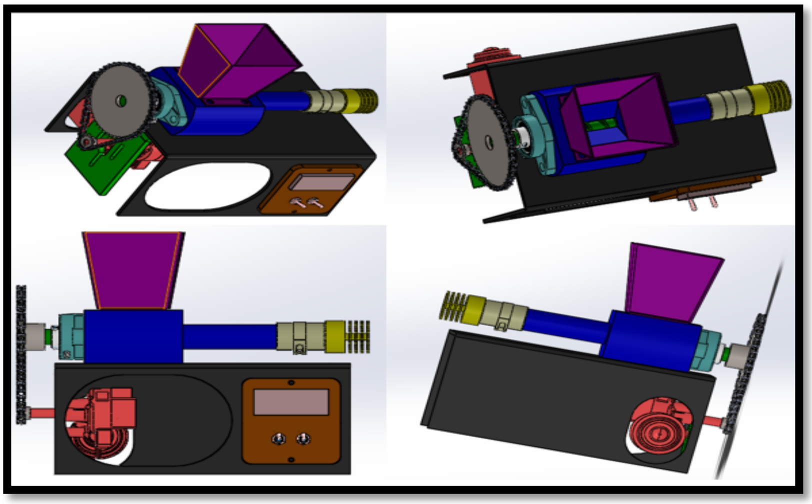


Figure 34 - Overview of the design of the extruder

However, prior to that, the theoretical computation and sizing of the parts were established

4.1.2.1 Sizing the screw extruder

To size the screws, we did use to reference "engineering Techniques. The case presented below, is a typical uniform screw. [9]

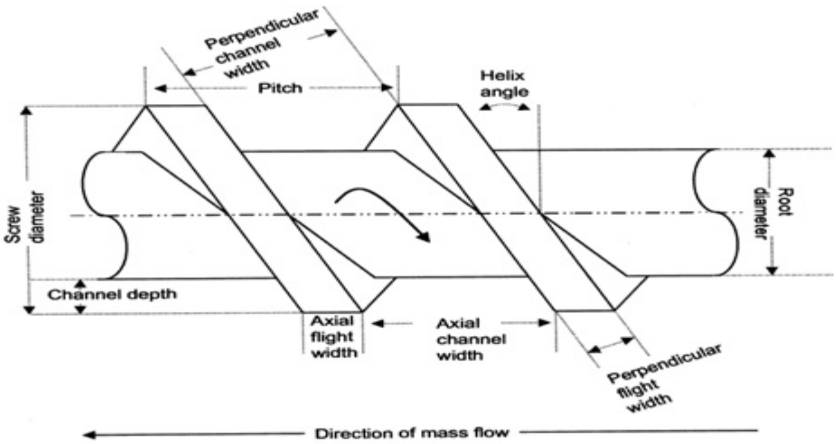


Figure 35 - Parameter of extruder screw

With:

- Screw outside diameter: D = 20mm.
- Root diameter : d = 12mm.
- Pitch of screw: B = D = 20mm.
- Axial flight width: e = 3mm.

The first two parameters are used to calculate the channel depth:

$$H = \frac{D - d}{2} = \frac{20 - 12}{2} = 4 \text{ mm} \qquad (15)$$

Determine, now, the θ screw helix angle:

$$\text{Tan } \theta = \frac{B}{\pi \times D} = \frac{20}{\pi \times 20} = 0{,}318 \qquad (16)$$

$$\rightarrow \theta = 17{,}6°$$

The channel width is defined by:

$$W = B \times \cos\theta - e = 16{,}06 \text{ mm} \qquad (17)$$

The helical length defined by:

$$Z = \frac{B}{\sin\theta} = 66{,}14 \text{ mm} \quad (18)$$

To ensure operation without risk of breakage, the screw must withstand the maximum torque that can be provided by the engine. This value is obtained at power and maximum speed [10] .

$$T_{max} = \frac{P_{max}}{\frac{2.\pi}{60} \times N_{max,scr}} = \frac{P_{max}}{\frac{2.\pi}{60} \times N_{max,mot}} \times i_{tot} \quad (22)$$

With :
- T_{max} (N.m) : Maximum torque that can be transmitted by the motor to the screw.
- P_{max} (W) : Maximal power of motor.
- $N_{max,scr}$ (tr/min) : Maximal speed of revolution for the screw.
- $N_{max,mot}$ (tr/min) : Maximal speed of revolution for the motor.
- i_{ot} : Reduction ratio between screw and motor.

The shear stress (in N/mm^2) of a section subjected to torsion is calculated as follows:

$$\tau_t = \frac{T_{max}}{W_p} \quad (23)$$

With $\quad Wp = \frac{\pi\, d^3}{16}$: Polar moment of inertia (mm^3)

Finally, we find that: $\quad \tau_t = \frac{T_{max} \times 10^3 \times 16}{\pi \times d^3}$

The shear stress must be less than the allowed shear stress:

$$\tau_{all} = 0,65 \times \sigma_s \quad (24)$$

With :
- σ_s : Tensile yield strength.
- τ_t : Shear stress.
- τ_{all} : Maximal allowed stress.

The steel combined with chromium and molybdenum is commonly used for the manufacture of screws. Its tensile yield strength is 800 N/mm^2 for small (< 100 mm) dimensions and 700 N/mm^2 for the higher dimensions.

→ The maximal allowed stress is: τ_{all}= 0, 65 × 700 = 455 N/mm

$$\tau_t \leq \tau_{all}$$

→ the extruder screw resist

4.2 Development of 3D printing raw materials (polyethylene terephtalate)

The advancement of additive manufacturing technology has been significantly influenced by the development of raw materials used in 3D printing, which has played a crucial role in expanding its capabilities and applications. Polymer-based materials, namely polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), and polyamide (PA), have been widely employed in the field of 3D printing owing to their exceptional printability, economical viability, and diverse physical characteristics. Scholars have directed their attention towards the creation of sophisticated polymer composites that exhibit improved mechanical strength, thermal stability, and electrical conductivity, tailored for particular uses in the aerospace, automotive, and medical sectors.

Evaluating the mechanical properties of the samples created from the virgin PET filament is the aim of this thesis. The original printed 3D samples are recycled to produce the specimens made by the PET filament which, in turn, are compared with the results of the study. The pliancy of PET when recycled was the determining factor leading to its selection in this paper

4.2.1 Tensile properties for virgin and recycled Polyethylene Terephtalate

Extensometers for polyethylene material were not needed as the extension/strain ratio was sufficient to estimate strain [15]. The PET tensile specimens' strain/extension ratio was 0.243 after plotting the strain from extensometers against the crosshead extension. The strain from the crosshead extension, which form part of the modulus calculations, were estimated via the aforementioned method.

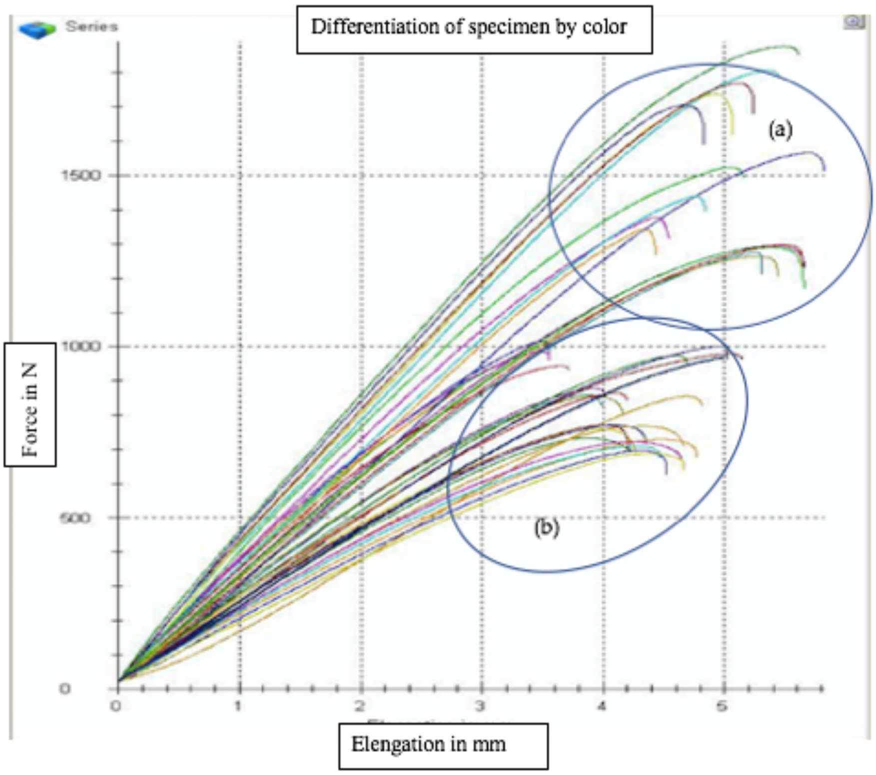


Figure 36 - Tensile Elongation of a recycled (a) and virgin (b) 3D printed PET.

As was indicated earlier, using stress-strain diagrams, one may also identify the qualities that are wanted, such as the Young Modulus, Yield Strength, and Tensile Strength. The next study will give, for each material, the Stress-Strain curves as well as the tables indicating the mechanical properties that were analyzed based on the three trials that were performed at each printing temperature. These properties were determined by analyzing the results of the trials. Beginning with the PET samples, the Stress-Strain curve that corresponds to the example average of value s gathered is displayed in figure 37. This is done for each printing temperature.

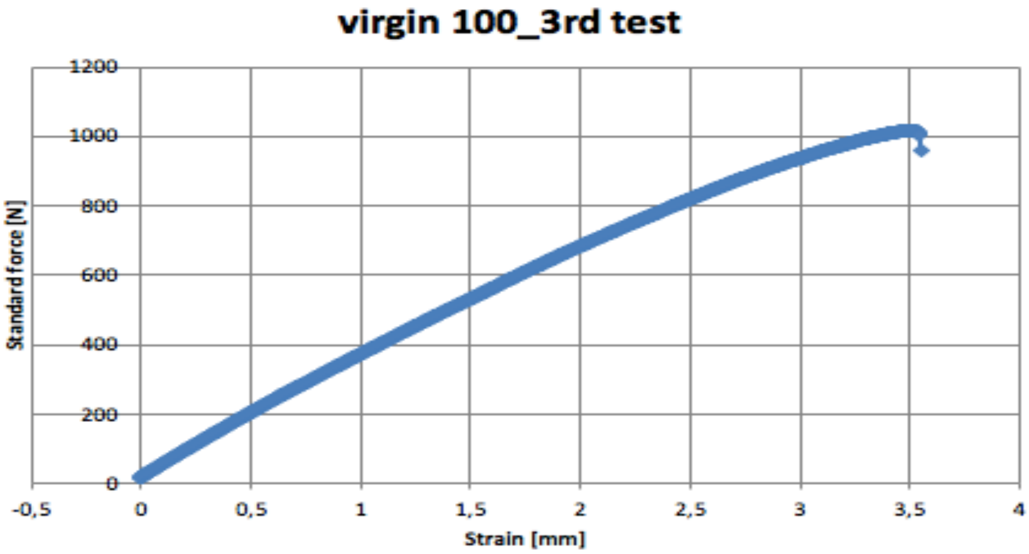


Figure 37 - Strain from third test for 100% virgin material

4.2.2 Tensile strength and elongation break of virigin and recycled material

The optimal printing temperatures for 3D printing can vary significantly depending on the type of printer, the printing technology, and the material being used. Here’s how you can identify the appropriate printing temperatures for different scenarios in 3D printing:

In spite of the different temperatures used for printing, the strain-stress curves of the PET samples were found to be very similar. This could result in comparable values for the three qualities that are being studied. It is essential to emphasize the fact that all of the PET specimens broke fairly shortly after reaching their maximum values for tensile strength. The tensile test results for PET determined its mechanical properties, and those results are provided in tables 8, 9, 10, and 11, respectively, for each %.

Virgin PET	Test numbers	Average tensile strength (MPa)
100%	5	25,26
80%	5	21,34
60%	5	23,92
40%	5	18,10

Table 8 - Tensile strength of Virgin PET Filament

Recycled PET	Test numbers	Average tensile strength (MPa)
100%	5	43,15
80%	5	34,214
60%	5	37,80
40%	5	24,33

Table 9 - Tensile strength of Recycled PET Filament

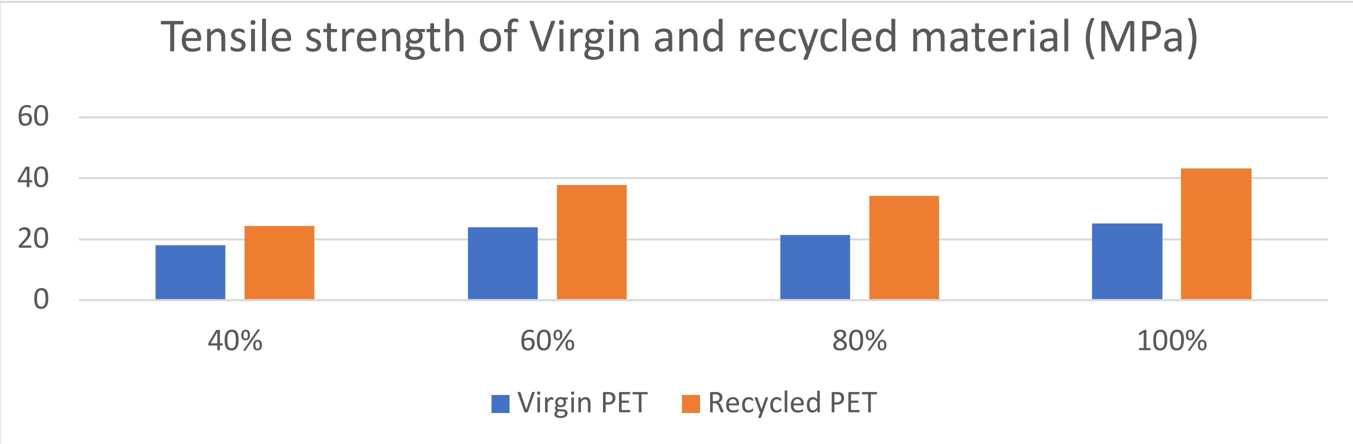


Figure 38 - Tensile strength of a recycled and virgin 3D printed PET.

The values of Yield Strength and Tensile Strength of the PET specimens present values that are equivalent to one another at each printing temperature, as can be observed in the curves presented in figure 36. It was established that the specimens printed at 250 degrees Celsius had a bigger value for the Young Modulus, whereas the other printing temperatures had values that were equivalent to one another in terms of their Young Modulus values. On the one hand, the printing temperature of 240 degrees Celsius presented the larger values of both the tensile strength and the yield strength. The printing temperature of 250 degrees Celsius, on the other hand, indicated a greater value for the Young Modulus. When printed at any one of the four separate temperatures,

it is also possible to verify that the variance coefficient has low values for all of the characteristics. This can be done in a number of ways. Tables 12 and 13 provide average values for the mechanical features of PET, considering the data that was received from each of the samples and focusing on the overall qualities of PET rather than the printing temperature as an impact factor. These tables take into consideration the data that was gathered from all of the samples.

The acronym ABS can be translated in a number of different ways, depending on its mechanical properties: Young Modulus is calculated to be 792.51 MPa, Yield Strength is calculated to be 18.63 MPa, and Tensile Strength is calculated to be 21.21 MPa. Figure 37 depicts the Stress-Strain curve for PET samples, which corresponds to the average values for each printing temperature. These values were determined by taking into account the PET samples.

It is fascinating to take note of the fact that the stress-strain curves that were displayed for each of the printing temperatures are, in fact, rather comparable to one another. In both the elastic and the plastic deformation zones of the diagram, the behavior of these curves is the same. The printing temperature, on the other hand, which is set at 220 degrees Celsius, has a specific feature that is most likely responsible for influencing these temperature values. It was established that just one specimen out of the three samples that were tested during printing at this temperature cracked. One of the samples exhibited this behavior as well. Due to the limited sample size, only three specimens printed at 220 degrees Celsius were investigated and tested. It is possible that this fracture may not represent an atypical case. In order to conduct an accurate investigation into this occurrence, it will be necessary to examine additional samples. The values of the specimens' mechanical qualities that were obtained through PET are reported in tables 10 and 11, respectively, and they vary depending on the temperature at which the printing takes place.

The elongation at break of a material is a measurement used to determine how much it can be stretched before it breaks under tension. It is an indication of the ductility and flexibility of the material. In this academic paragraph, the effects of elongation at break on material behavior and its applicability in a variety of industries and applications are discussed, along with their respective applicability. The elongation at break is a factor that determines the tensile properties of polymers, metals, and composites. It determines how much a material can deform before it breaks. The term "elongation at break" refers to the amount that a specimen has grown in length up until the point where it has broken during a tensile test. The elongation upon break is a measure of the deformation resistance of the material. Greater values of elongation at break suggest greater deformation resistance and toughness due to the fact that the material can be stretched before it fractures. Materials with a low elongation at break tend to be brittle and easily fracture when subjected to stress. The mechanical parameters of PET that were determined from its elongation at each % are listed in tables 10 and 11

Virgin PET	Test numbers	Average elongation at break (%)
100%	5	2,39
80%	5	2,61
60%	5	2,812
40%	5	3,12

Table 10 - Tensile strength and elongation break of Virgin PET Filament

Recycled PET	Test numbers	Average elongation at break (%)
100%	5	1,336
80%	5	1,45
60%	5	1,64
40%	5	1,98

Table 11 - Tensile strength and elongation break of Recycled PET Filament

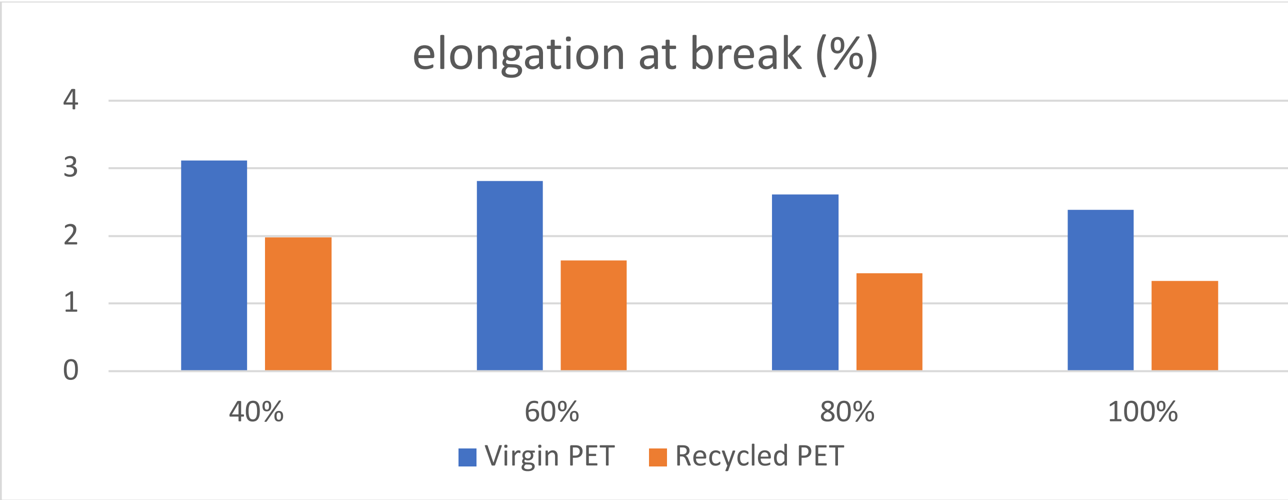


Figure 39 - Elongation at a break of a recycled and virgin 3D printed PET.

In this experiment, neither the load nor the elongation records were preserved, nor were any independent extensometers utilized. An intermediate shear specimen's level of hardness was measured using a shore D digital durometer. This was done so that the levels of hardness displayed by the specimen could be determined. In order to account for the potential for the needle to slide into one of the numerous minute surface divots, the hardness was measured a total of four times, and the maximum value was recorded after each measurement.

4.2.3 Shear strength properties

Plastics' shear strength depends on molecular structure, chemical makeup, production circumstances, additives, and reinforcements. Polycarbonate and acrylics have better shear strengths than semi-crystalline polymers like polyethylene and polypropylene. Fillers, fibers, and reinforcements also affect plastic composite shear strength. Understanding plastic shear strength is essential for developing buildings and components that can endure shear loads without deforming or failing. These qualities help engineers choose plastic materials that can withstand shear stresses and maintain structural integrity. It helps choose manufacturing and design procedures to enhance plastic component performance and reliability. Shear strength qualities are essential for part safety and functionality in plastic-intensive industries like automotive, aerospace, and consumer electronics. Plastic fasteners, clips, and brackets must have shear strength to retain structural integrity and secure components in automotive applications. Protecting sensitive electronic components and assuring dependability under shear stress requires understanding plastic encapsulating materials' shear strength properties.

In conclusion, plastics' shear strength qualities determine their resistance to shear pressures and deformation without failure. Shear tests measure these qualities, which aid material selection, design, and engineering. Plastic components and structures in numerous sectors can be reliable and sturdy by understanding plastic shear strength.

The results of the tests were compiled by examining virgin as well as recycled test specimens for the same attributes, such as the tensile strength, shear strength, and hardness of the material. A total of forty samples of virgin and recycled material were each subjected to the testing procedure in order to get information regarding the yield strength and the tensile modulus of elasticity. Table 2 is an all-inclusive summary of the situation. An offset value of 0.11 mm was initially established before carrying out the investigation into the yield point. In order to calculate the tensile modulus, tensile specimens had to be subjected to a relationship that had been established in advance between the crosshead extension and the strain. This made it possible to determine the modulus of the function. Examining the extension to strain ratio while making use of the reference as a point of departure allows one to calculate the strain without having to make use of an extensometer that is calibrated for the same type of material

	Virgin	Recycled
Number of specimens	20	20
Average shear yield strength(MPa)	28,448	29,253
Standard deviation	0.69	2.00

Table 12 - Shear Strength of Virgin Versus Recycled Polyethylene Terephtalate 3D Printed Specimens

4.2.4 . Hardness properties for virgin and recycled Polyethylene Terephthalate

	Virgin	Recycled
Number of specimens	20	20
Average hardness (shore D)	73,10	68,71
Standard deviation	0.725	2

Table 13 - The hardness of Virgin Versus Recycled Polyethylene Terephtalate 3D Printed Specimens

The natural world strongly backs up these findings. Nevertheless, there were some distinctions to be made between the original and the recycled version. On the other hand, the average mechanical qualities of the recycled specimens were approximately 3 to 9 percentage points lower than those of the virgin specimens. In addition, it is important to point out that there was an increase in the standard deviation, which demonstrates that there was a rise in the amount of variation in the results obtained from the recycled material.

A more sustainable approach of chemical recycling is in high demand, particularly one that requires less energy and can be easily computed for mixing waste plastics. There should be a limited requirement for sorting, and there should be minimal need to push the technique towards the use of non-recyclable polymers. Following an analysis of the relevant literature, it was determined that the only method for recycling plastic solid waste now in existence is the mechanical recycling process. The primary step in the process involves washing away any organic residue, which is then followed by shredding, melting, and re-molding of the polymer in order to create a material that is compatible with virgin plastic and may be blended with it to make a material that is acceptable for production. The contemporary methods that are being employed beyond the classic mechanical recycling incorporate the use of pyrolysis for the selective synthesis of gases, fuels, or waxes via the use of catalysts. This process is referred to as chemical recycling. It goes beyond the traditional mechanical recycling. Despite the fact that it has significant energy cost needs, it does not see widespread use. Incineration, also known as the capture of energy in the form of heat through the burning of the materials, is an additional approach that can be considered. Due to the fact that the components are burned during this process, it does not contribute to many recapitalizations of the recovery and reuse of the components, but it does make the treatment of mixed trash more convenient because it eliminates the need to separate out the waste. In addition to the fact that it is not an energy-efficient process like recycling, they have a laboratory that is well-equipped for evaluating waste plastic that has been recycled.

The majority of the laboratory experiments for this study project were carried out in conjunction with the FKF Zrt, as was clearly demonstrated. The company has a strong working relationship with the faculty of mechanical engineering, and they also have a lab that is well-equipped for testing recycled plastic waste. Previous tests have shown that conductive antistatic ABS has many benefits, including excellent mechanical strength, impact resistance with dimensional stability, high flow creep resistance, and excellent heat and low-temperature resistance. The company also works closely with the faculty of mechanical engineering. It was determined that the PET filament was superior. The most significant issue that arises during the process of rPET extrusion is the blockage of the flow of material. Towards the middle of the process of extrusion, the extrudate will eventually stop coming out of the die, which will cause the HDPE filament to first get thinner and then break. The extrusion of unblemished HDPE did not proceed without encountering any difficulties.

Because of the combined effects of a number of different elements, the qualities such as tensile strength and hardness were found to have decreased. This could be due to a deterioration in the qualities of the recycled filament itself, or it could be due to issues that have arisen as a result of the 3D printing process, such as interruptions in the extrusion process or a restriction in the amount of inter-layer adhesion that can be achieved. Because the properties of individual filaments could not be investigated, certain aspects of the system were left out of the study. There were several problems related with using recycled filament, such as the nozzles becoming clogged. Additionally, there were problems with the printing process, which can lead to flaws in the specimens. The fact that the filament re-extrusion was performed without the use of a filter was the primary problem associated with the process; as a result, the filament may have been contaminated with a few minute contaminants.

It was not very logical that the recycled material's average shear strength was around 6.8% higher than that of the virgin material. This was the most important finding. The specimens should have different levels of expansion, and one possible explanation for this is that there was a change in the poison's ratio, which resulted in the specimen being compressed and expanded against the sides of the shear jig. In addition to this, there may have been some microscopic changes in the interlocking of the extruded recycled PET as a result of it being laid down. Working with recycled filament can result in an increase in the amount of ultrafine particle emissions, which would be a potential negative

4.3 Homogenous composite: recycling technologie

Mixing plastic waste in concrete to obtain a homogeneous composite has gained attention as a potential solution for both waste management and improving the properties of concrete.

Plastic waste is crushed or shredded and mixed into concrete during batching. Plastic particles partially replace concrete aggregates or fillers. PET, HDPE, and recycled plastic can be used.

Waste plastic may improve concrete. First, it keeps plastic garbage out of landfills and incinerators. Second, it improves composite mechanical characteristics. Plastic particles reinforce concrete's tensile and flexural strength. Flexibility improves the composite's cracking and impact resistance.

4.3.1 Non recycling method

One nonrecycling option for mixing waste plastic and concrete is to use it as fuel in the cement kiln. Co-incineration or co-processing is this procedure. It does not directly recycle plastic trash into the concrete mixture, but it addresses waste management issues by using the waste material.

This nonrecycling process shreds or granulates waste plastic to increase combustion. Plastic waste, coal, petroleum coke, and natural gas are added to the cement kiln. Plastic waste is completely burned in the kiln, generating electricity and heat.

Depending on the approach taken, several distinct types of samples were collected.

The initial procedure, We end up with a mixture that is not homogenous samples

Figure 40 - Nonhomogeneous samples

It is therefore impossible to extract samples with this method. In this method the absence of mixing justifies the condition of the samples. There is a segregation of plastic and sand.

Due to particle size, density, and behavior during mixing and curing, waste plastic and sand can separate when blended into concrete non-recycling methods such co-processing in cement kilns. This academic paragraph discusses segregation difficulties and mitigation. Segregation causes a mixture's components to settle unevenly. Waste plastic and sand can segregate in concrete due to their different sizes and densities. Plastic particles may separate from sand particles and concentrate in the concrete mixture during mixing.

Several methods can reduce plastic-sand segregation in waste plastic-concrete mixtures: Proper Mixing Technique: Proper mixing ensures a more uniform dispersion of plastic particles and sand in the concrete mixture. Longer mixing times, intermittent mixing cycles, and mechanical agitation improve dispersion and reduce segregation.

Gradation Control: Controlling plastic and sand particle sizes helps reduce segregation. Ensuring that plastic and sand particle sizes are suitable and within an acceptable range can promote interlocking and reduce separation.

Chemical admixtures like viscosity-modifying agents or superplasticizers can increase the workability and cohesiveness of the waste plastic-concrete combination. These admixtures improve plastic-sand compatibility, minimizing segregation.

Proper curing and compaction promote homogeneous hydration and consolidation of the waste plastic-concrete mixture. This reduces cavities and irregularities that could separate plastic and sand.Quality Control: Thorough quality control during mixing, putting, and curing helps identify and fix segregation concerns. Monitoring the mixture's workability, uniformity, and homogeneity ensures the final product fulfills criteria.

Even with these safeguards, segregation may occur. Thus, it is crucial to evaluate the waste plastic, sand, mixing, and curing conditions to enhance segregation reduction.

In conclusion, non-recycling waste plastic put into concrete may cause plastic and sand segregation. Proper mixing, particle gradation, admixtures, curing, compaction, and quality monitoring can reduce segregation. To avoid segregation and create a more uniform waste plastic-concrete combination, it's important to evaluate the components and process parameters.

4.3.2 Materials after recycling

Recycling plastic trash into concrete creates a homogeneous sample with plastic evenly dispersed. Recycling plastic waste into concrete involves converting it into a form that can be mixed with the other concrete ingredients. This academic paragraph discusses recycling technology and uniformity.

Second method We obtain very homogeneous samples (Figure 41).

Figure 41 - Homogeneous samples

Recycling processes make plastic waste in concrete homogeneous. First, these technologies turn waste plastic into granules, flakes, or fibers that can be mixed into concrete. Depending on the form and recycling technology, plastic trash is shred, ground, or melted.

Second, recycling processes improve plastic particle size, shape, and distribution in concrete. Processing parameters can be adjusted to make recycled plastic compatible with other concrete mix components.

Mixing plastic trash in concrete can be done using several recycling methods. Common ways are:

Mechanical Blending: This method mixes recycled plastic particles with cement, aggregates, and water. Tumble blending, high-shear mixing, and paddle mixing can distribute plastic particles throughout the concrete matrix.

Extrusion: Melting plastic debris and pressing it through a die creates a continuous profile or filament. For easy inclusion into concrete, the plastic product can be processed or cut to length.

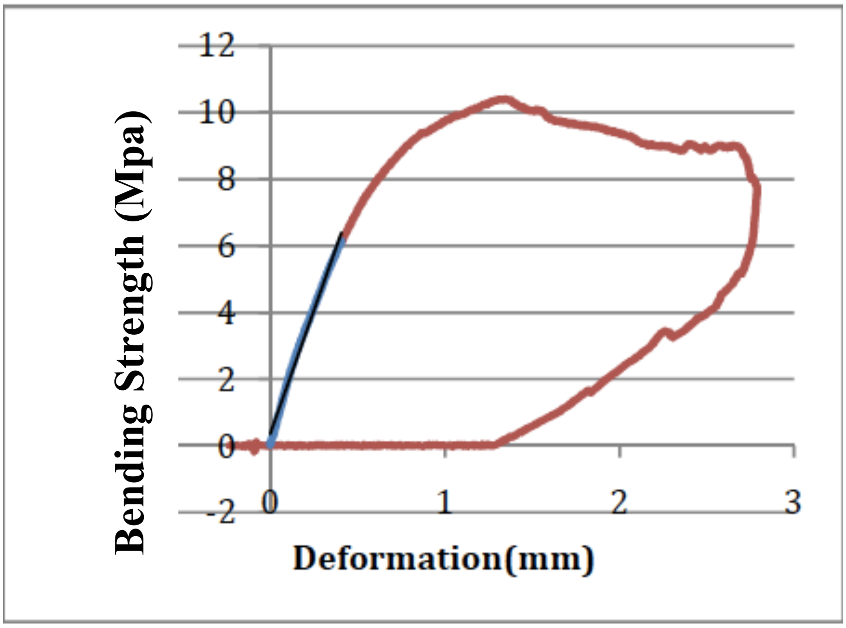
Melt-Mixing: Plastic trash is melted and mixed with other concrete ingredients while molten. The molten liquid solidifies as a composite material after cooling.

Fiber Reinforcement: This approach strengthens concrete by adding recycled plastic fibers. Reinforcing and homogenizing the composite, the fibers are evenly distributed.

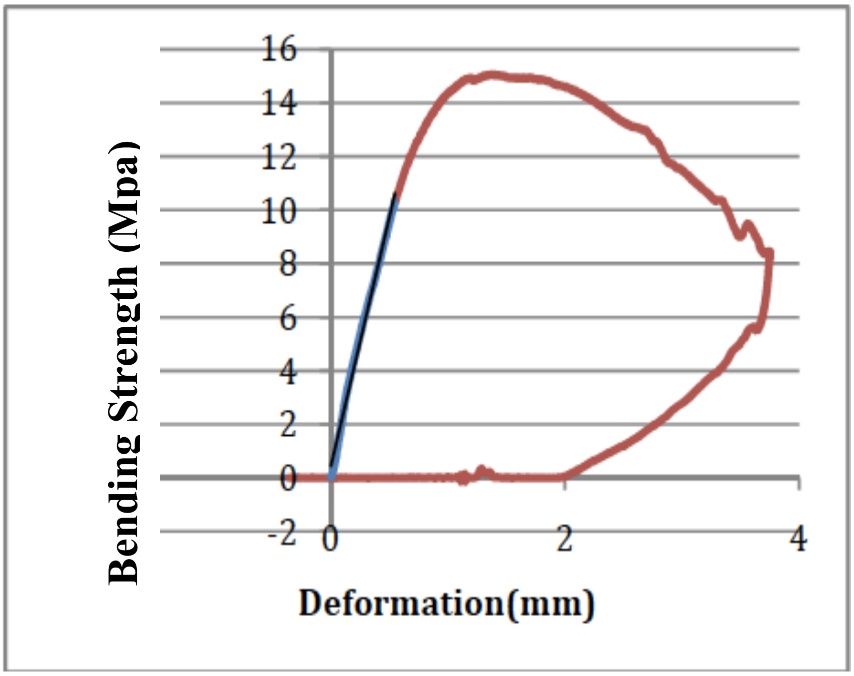
These recycling processes make plastic waste in concrete homogenous. Controlled processing and blending of plastic particles or fibers ensures equal dispersion within the concrete matrix, improving composite material performance and characteristics.

Finally, recycling technologies help combine plastic trash with concrete into a uniform sample. These technologies make plastic waste constant and offer improved control over the size, shape, and distribution of plastic particles or fibers in concrete. Mechanical blending, extrusion, melt-mixing, and fiber reinforcing are used. These recycling technologies provide a more homogenous plastic waste-concrete composite, improving performance and sustainability.

- Mixing resulted in a good mixture.
- The grain size of the sand can be seen on the smooth surface of the samples.
- This method was therefore adopted for the development of samples on which we performed
- bending.

A	

B



C

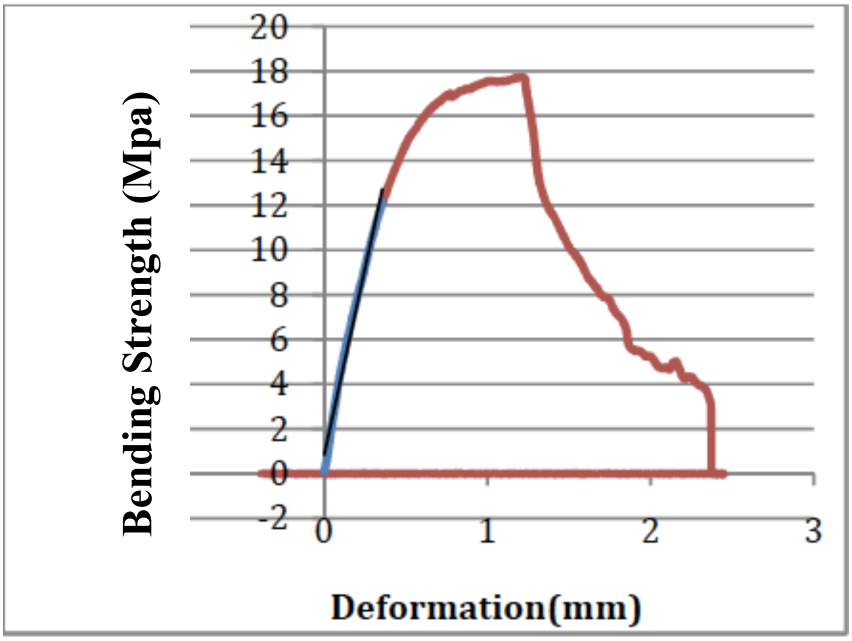


Figure 42 - 3-point flexural strength curve: A (sand with 0.5 <d <1); B (whole sand); C (sand with d <0.5)

After conducting an analysis on these curves, we have discovered that the resistances change in accordance with the particle size. The grain size must be narrow for the flexural strength to rise, and the higher the grain size, the thinner the grain must be.

We obtain values of 10 MPa, 15 MPa, and 18 MPa, respectively, for sand with 0.5 d 1, entire sand, and sand with d 0.5 (where D is the grain diameter of the sand).

This shift in flexural strength can be explained by the fact that coarse grains in a mixture encourage contact between grains, which then results in the creation of portions of the material that are fragile.

These figures exceed the requirements of the NBN EN 1339 standard (BNOR, 2004), which calls for a stronger flexural strength of at least 3.5. After that, the use of this material in construction could be advised. It even has a flexural strength that is larger than the compressive strength that was found by the PRSDO-CER project (CIFAL 2011) on a material that was composed of sand and plastic.

Through careful examination of these curves, we have determined that the resistances change in accordance with Figure 42 displays the outcomes of testing conducted on the flexural strengths of recycled PET sand. The addition of PET led to a decrease in the compressive and flexural strengths; the pattern was very similar to that of the compressive strength. At a replacement ratio of 10%, flexural strength reduced by 2.4%, however at a replacement ratio of 40% or 50%, it decreased by 58% or 84.2% respectively at 28 days. During the process of removing the specimens from the mold, one of the PET. 50 samples fractured, which is an indication of the significant drop at this substitution level. 5.92 MPa was the stress level while the replacement ratio was at 30%.

V. New scientific results

5.1 Modeling recycling machine

In this section, i examine the many sorts of plastics and identify the pollution that is brought on by the former. This project also gave me the opportunity to plan and scale the construction of a recycling station for the conversion of plastic into filaments for use in three-dimensional printers. This station will contribute to the fight against pollution, which is important to us.

The station includes two machines: one for grinding the plastic, and the other for extruding the appropriate filaments. These machines work together to complete the station's functions. Both of these machines were the subject of a theoretical academic investigation, which we also carried out using SOLIDWORKS 2015 as our design software. The theoretical analysis covers everything from the essential mechanical calculations to the design and evaluation of the structure through the application of various techniques.

5.2 Development of 3d raw materials from solid waste

Comparative tests were carried out on the mechanical properties of virgin PET and 3D printed recycled PET to demonstrate that one option for PET recycling is recycling into 3D printing. The comparison found that there is no noticeable difference between the properties of the two types of PET. It was found that the p-value did not exceed 0.003. Achieving a value of 0.003 is the primary result of the study as it proves the validity of the hypothesis made, solid PET waste is suitable for use as raw material for 3D printing.

5.3 Mechanical properties of virgin and recycled polyethylene terephthalate

I have found that the mechanical properties of virgin polyethylene terephthalate (PET) and recycled PET can vary depending on a number of factors, including the conditions under which the PET is processed, the presence of contaminants or additives, and the degree of degradation that occurs during the recycling process. This scientific result summarises the routinely evaluated mechanical properties of virgin PET and recycled PET.

As a result of these tests, it was found that the average shear strength of the recycled material was approximately 6.8% higher than that of the virgin material. The specimens should have expanded to different extents, and one possible explanation for this is that the Poisson's ratio changed, causing the specimen to compress and expand relative to the sides of the shear tool. In addition, microscopic changes in the interlocking of the extruded recycled PET may have occurred as a result of the deposition. Working with recycled fibres may result in an increase in the emission of ultrafine particles, which could be a potential negative.

5.4 FLexural strength on the composite of Waste PET in concrete

Another possibility for PET recycling is the production of PET-concrete composite. To determine the criteria for its applicability, I investigated the flexural strength of the composite for different mixing ratios. The content and distribution of waste PET, the concrete matrix and the waste PET-concrete bonding affect the flexural strength of the waste PET-concrete composite. By analysing standard bending tests, I found that both compressive and flexural strengths decreased with the addition of PET; the pattern was quite similar to that of compressive strength. The flexural strength decreased by 2.4% at 28 days when the replacement ratio was 10%; however, when the replacement ratio was 40% or 50%, it decreased by 58% and 84.2%, respectively, in accordance with the replacement ratio.

5.5 Homogenous composite – recycling technologies

By examining the curves obtained in the bending tests, I discovered that the resistances vary with particle size. Flexural strength increases in direct proportion to the particle size of the thin layers of material.

For PET sand with a particle diameter of 0.5 mm or less, for all sand and for sand with a particle diameter of less than 0.5 mm, values of 10 MPa, 15 MPa and 18 MPa are obtained.

This shift in the flexural strength can be explained by the coarse grains in the mixture promoting contact between the grains, which then leads to the formation of brittle particles in the material.

These values are higher than the requirements of the NBN EN 1339 standard (BNOR, 2004), which specifies a flexural strength of 3,5 or higher or equivalent. Subsequently, the use of this material in the construction industry is recommended. It has a flexural strength even higher than the compressive strength achieved by the PRSDO-CER project (CIFAL 2011) on a material composed of sand and plastic.

5.6 CONCLUSION AND SUGGESTIONS

Crushers break big materials into smaller pieces for processing. Crusher evaluation and setup directly affect crushing efficiency. Size reduction precision depends on measurement accuracy. Design factors optimize crusher performance, energy efficiency, and productivity.

We designed each component with practicality and manufacturing in mind. The crusher has twelve blades, twelve anvil-blades, two axes, a cover, a sieve, fourteen casing spacers, four nuts, two pins, and a crank. After you design all the components, we'll assemble them.

Extruders help manufactures manipulate and shape materials. Extrusion efficiency depends on extruder evaluation and configuration. Quantifying key factors and carefully assessing design features ensures product quality, efficiency, and profitability.

After loading the extruder with shredder-crushed plastic, the operator feeds grain plastic into the hopper. The extrusion screw spins and feeds the grain into the extrusion chamber. The plastic will start to sag. As it enters compression, the plastic mixture homogenizes and heats up. Finally, the band heaters soften the plastic mixture, which is blasted out through the nozzle to produce the filament.

3D printing raw materials have helped progress additive manufacturing technologies. Due to their printability, cost, and versatility, polymer-based materials like polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), and polyamide (PA) are commonly used in 3D printing. Scholars have developed polymer composites with better mechanical strength, thermal stability, and electrical conductivity for aerospace, automotive, and medical applications.

This thesis evaluates virgin PET filament sample mechanical properties. The PET filament specimens are compared to the study results after recycling the 3D printed samples. This paper chose PET because of its recycled pliancy.

Stress-strain graphs can help highlight desired properties like Young Modulus, Yield Strength, and Tensile Strength. The following study will present Stress-Strain curves and mechanical property tables for each material based on three trials at each printing temperature. Trial results revealed these qualities. Figure 37 shows the Stress-Strain curve for the PET sample average value s. For each printing temperature.

Figure 36 shows that at each printing temperature, PET specimen Yield Strength and Tensile Strength are equal. The specimens printed at 250 degrees Celsius exhibited a higher Young Modulus than those printed at other temperatures, which were similar. The printing temperature of 240 degrees Celsius has higher tensile and yield strengths. However, printing at 250 degrees Celsius increased the Young Modulus. The variation coefficient is minimal for all features when printed at any of the four temperatures. Several methods are available. Tables 12 and 13 show average PET mechanical feature values based on sample data, not printing temperature. These tables include all sample data.

Based on its mechanical properties, ABS can be translated as Young Modulus (792.51 MPa), Yield Strength (18.63 MPa), or Tensile Strength (21.21 MPa). Figure 29 shows the average PET sample stress-strain curve for each printing temperature. PET samples determined these results.

Elongation at break measures how much a material can be stretched before breaking under tension. It shows ductility and suppleness. This academic paragraph discusses the impact of elongation at break on material behavior and its applicability in many industries and applications. Polymers, metals, and composites have tensile characteristics based on elongation at break. It determines material deformation before breaking. "Elongation at break" is the length a specimen has grown before breaking in a tensile test. Elongation at break indicates material deformation resistance. Since the material can be extended before breaking, higher elongation at break values indicate stronger deformation resistance and toughness. Low-elongation materials are fragile and rapidly break under force.

Several approaches reduce plastic-sand segregation in waste plastic-concrete mixtures: Proper Mixing: Mixing evenly distributes plastic particles and sand in concrete. Longer mixing durations, intermittent cycles, and mechanical agitation promote dispersion and reduce segregation.

Gradation control reduces segregation. Suitable plastic and sand particle sizes can increase interlocking and reduce separation.

Viscosity-modifying chemicals and superplasticizers can make waste plastic-concrete more workable and cohesive. These additives reduce plastic-sand segregation.

Curing and compaction ensure homogeneous hydration and consolidation of the waste plastic-concrete mixture. Reduces holes and imperfections that could separate plastic and sand. Quality Control: Quality control during mixing, placing, and curing detects and fixes segregation issues. The product meets standards by monitoring the mixture's workability, uniformity, and homogeneity.

Segregation may occur despite these measures. To reduce segregation, waste plastic, sand, mixing, and curing conditions must be assessed.

In conclusion, nonrecyclable waste plastic in concrete may create plastic-sand segregation. Mixing, particle gradation, admixtures, curing, compaction, and quality monitoring prevent segregation. Evaluating components and process parameters prevents segregation and creates a more homogeneous waste plastic-concrete mix.

Finally, recycling systems mix plastic waste and concrete into a homogenous sample. These methods manage concrete particle size, shape, and distribution and make plastic waste constant. Mechanical blending, extrusion, melt-mixing, and fiber reinforcing are used. These recycling technologies make plastic waste-concrete composites more homogeneous, boosting performance and sustainability.

5.7 SUMMARY

A small-scale plastic recycling technique and PET filament for 3D printing provide a sustainable and innovative way to turn plastic waste into useful resources. This academic paragraph discusses crucial factors of developing such a technology and its filament product.

Collecting and sorting plastic waste is the first stage in building a small-scale PET recycling method. PET waste from families, industry, and businesses must be collected efficiently. Sorting PET from other plastics, whether manually and automatically, ensures a clean and consistent feedstock for recycling.

After sorting, PET waste is processed. Shredding or granulating plastic helps in processing. PET waste is cleaned and washed to remove debris, labels, and residue.

The next critical step is turning cleaned and processed PET into 3D-printable filament. A unique extrusion mechanism melts PET flakes or granules from recycling. This extrusion process melts PET and forces it through a die to generate a continuous filament with a particular diameter and shape.

Additives or modifiers can be added during extrusion to improve filament strength, flexibility, or heat resistance. Depending on the required filament properties, these additives may include strengthening agents, colorants, or flame retardants.

To ensure recycled PET filament uniformity and reliability, quality control is conducted throughout development. Mechanical qualities, dimensional correctness, and 3D printing compatibility may be tested. Optimize filament performance by changing process parameters or composition.

3D printing with PET filament is sustainable. Recycled plastic trash reduces the environmental impact of filament manufacture. PET filament works with many 3D printers and may be used to make many products and prototypes.

In conclusion, developing a small-scale PET plastic recycling technology and a 3D printing filament product requires collecting and sorting PET waste, processing and cleaning the plastic, and extruding the recycled PET into filament. Additives and quality control enable high-quality 3D printing filament. This novel technology improves plastic waste management and opens new additive manufacturing applications for recycled PET

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A2: Publications related to the dissertation

Refereed papers in foreign languages:

1. Oussai, A., & Zoltan, B. (2017). synergy. Design and sizing of a plastic recycling station into filament for 3D printer (pp. 1-6). V. Synergy International Conference, Engineering, Agriculture and Green Industry Innovation, Gödöllő, Hungary

2. Oussai, A., Zoltan, B., & Laszlo, K. (2018). ISCAME_paper181003. In Development of a small-scale plastic recycling technology and a special filament product for 3D printing (pp. 1–6). Debrecen: International Journal of Engineering and Management science

3. Oussai, A., Zoltan, B., Szalkai,I & Laszlo, K.(2019) Development of 3D printing raw materials from

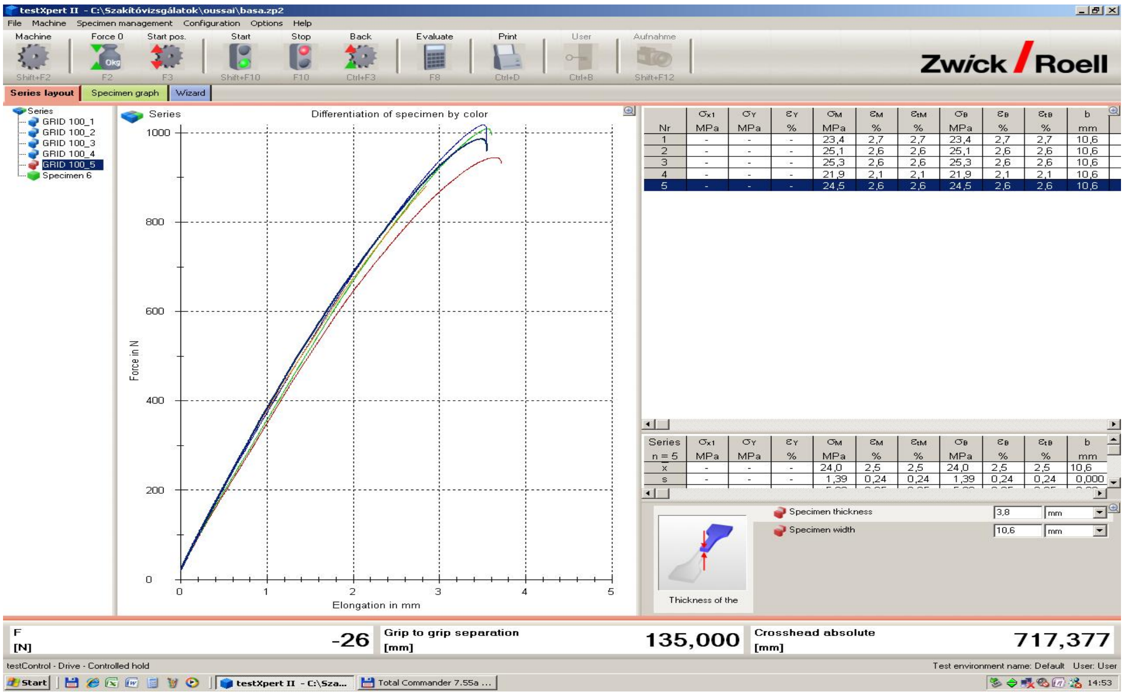
plastic waste.Szent Istvan University scientific journal of mechanical engineering.

4. Oussai, A., Zoltan, B., Szalkai,I & Laszlo, K.(2019) Development of 3D printing raw materials from plastic waste. ERAZ 2019. (Publication in Jounral and Monograph).September 2019
5. Oussai, A., Zoltan, B., & Laszlo, K. (2021). Development of 3D pritning raw materials from plastic waste . A case study on Recycled Polyethylene Terephtalate, Applied science, Basel ,Switzerland 11(16).7338 https://doi.org/10.3390/app11167338
6. Oussai, A., Zoltan, B., & Laszlo, K. (2022). Laboratory tests of plastic recycling for 3D printing utlisation, Journal of Applied Mechanical Engineering. Volume 11 issue 7. DOI: 10.35248/2168-9873.22.11.425
7. Oussai, A., Zoltan, B., & Laszlo, K. (2022). A small-Scale Recycling technology: Proposal pf Plastic waste recycling technic. Volume 11 issue 1 pp-36-41.e-ISSN: 2320-0874 p_ISSN : 2320-0936
8. Oussai, A., Zoltan, B., Szalkai,I & Laszlo, K.(2019) Development of 3D printing raw materials from plastic waste. Budapest 5 th International Scientific Conference_ERAZ 2019. (published in the conference proceeding)

International conference proceeding

1. Oussai , A , Zolran , B , Laszlo ,k (20219)International Conference on Engineering & Technology (ICET-19)
2. Floria Usa Paper Id: ICACKD35784 Paper Title: " Development of 3D printing raw materials from plastic waste”
3. Oussai, A., Zoltan, B., Szalkai,I & Laszlo, K.(2019) Development of 3D printing raw materials from plastic waste. Budapest 5 th International Scientific Conference_ERAZ 2019. (published in the conference
4. proceeding)
5. Oussai, A., Zoltan, B., & Laszlo, K. (2018). ISCAME_paper181003. In Development of a small-scale plastic recycling technology and a special filament product for 3D printing (pp. 1–6). Debrecen: Published in International Journal of Engineering and Management science.
6. Oussai, A., & Zoltan, B. (2017). synergy. Design and sizing of a plastic recycling station into filament for 3D printer (pp. 1-6). Godollo: Synergy international conference. (published in the conference proceeding).

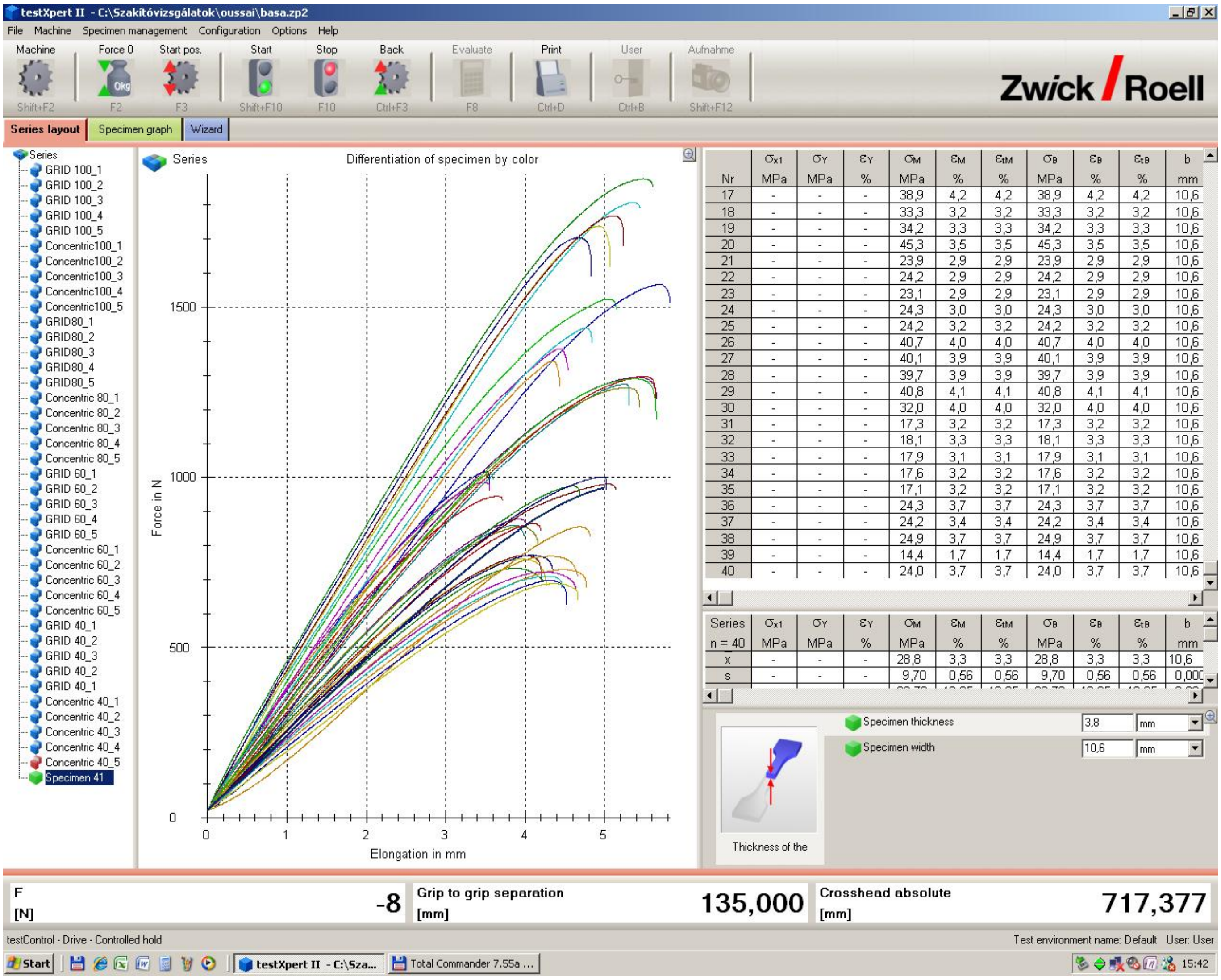
A3: Zwick Roell software during shear strength test



A4: Plastic recycling statictics from Hungarian recycling FKF Hungary dunig first quarter

2018		January		February		March	
		Kg	m/m%	Kg	m/m%	Kg	m/m%
PET	Clean	30.4	12.2	27.0	10.6	30.2	11.9
	Blue	38.5	15.4	30.4	11.9	32.6	12.8
	Coloured	10.9	4.4	16.0	6.3	18.9	7.4
Foil	Dyed	6.3	2.5	8.6	3.4	5.6	2.2
	Natural	4.1	1.6	7.3	2.9	5.0	2.0
Flacon		36.5	14.6	25.4	10.0	22.4	8.8
Hungarocell		0.3	0.1	1.0	0.4	1.4	0.6
Metal	Tinned metal	6.0	2.4	6.2	2.4	3.0	1.2
	Aluminium	6.1	2.4	6.4	2.5	3.3	1.3
Other Waste		111.1	44.4	126.3	49.6	131.8	51.8
Altogether		250.2	100.0	254.6	100.0	254.2	100.0
Recyclable		138.8	55.5	127.3	50.0	121.0	47.6
Non-Recyclable		111.4	44.5	127.3	50.0	133.2	52.4

A5: Tensile stress curves of total specimens (Zwick Roell Software)



A6: Thermal properties of Polyethylene Terephtalate

Material	Polyethylene Terephthalate
Melting point [°C].	225
Drying time [hours]	4-5
Drying temperature [°C]	160

A7: Mechanical properties of Polyethylene Terephtalate specimens during test

mm	N
0	19,36654
0	19,22396
0	19,27959
-1,6E-05	19,04177
0,000179	18,99428
0,002197	19,66665
0,004646	20,33266
0,006744	20,89516
0,009258	21,37026
0,01149	21,73452
0,013809	21,90883
0,01633	22,13076
0,019088	22,47109
0,022171	22,81142
0,024315	23,16787
0,026504	23,45302
0,028785	23,65126
0,031173	23,86513
0,033783	24,11074
0,036415	24,3246
0,039077	24,52285
0,041847	24,75234
0,044868	25,01357
0,04792	25,37001
0,051012	25,72637
0,054216	26,08282
0,057581	26,47051
0,060899	26,81915
0,064226	27,0335
0,067667	27,31036

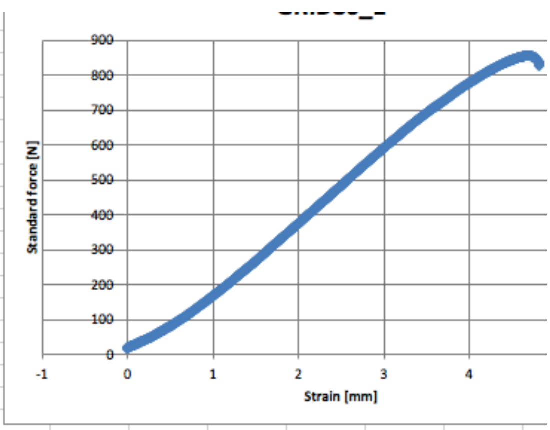


Chart Area

5.8 ACKNOWLEDGEMENTS

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Oussai Alaeddine
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