PHYSICOMECHANICAL PROPERTIES OF CLAY REINFORCED PLASTIC WASTE CONCRETE AGGREGATES

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

MOHAMMAD ISMAIL ANUAR BIN MOHAMMAD SUFIAN

B051810068

970418-13-5365

FACULTY OF MANUFACTURING ENGINEERING

2022

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk: **PHYSICOMECHANICAL PROPERTIES OF CLAY REINFORCED PLASTIC WASTE CONCRETE AGGREGATES**

Sesi Pengajian: **2022/2023 Semester 1**

Saya **MOHAMMAD ISMAIL ANUAR BIN MOHAMMAD SUFIAN (970418-13-5365)**

mengaku membenarkan Laporan Projek Sarjana Muda (PSM) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

☐	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysiasebagaimana yang termaktub dalam AKTA RAHSIA RASMI
√	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/ badan di mana penyelidikan dijalankan)
☐	TIDAK TERHAD	

Disahkan oleh:

Alamat Tetap:

NO.33 HERITAGE GARDEN,
93050 KUCHING, SARAWAK.

Tarikh: 30/01/2023

Cop Rasmi:

PROF. MADYA DR. NORAIHAM BINTI MOHAMAD
Profesor Madya
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka

Tarikh: 29/01/2023

*Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled "Physicomechanical Properties of Clay reinforced Plastic Waste Concrete Aggregates" is the result of my own research except as cited in references.

Signature : ……………………………………
Author's Name : MOHAMMAD ISMAIL ANUAR BIN MOHAMMAD SUFIAN
Date : 30 January 2023

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

………………………………………………………… 29/01/2023

(Associate Professor Dr. Noraiham Binti Mohamad)

ABSTRAK

Penyusutan agregat semula jadi menjadi masalah global walaupun permintaan pembinaan struktur meningkat. Selain itu, pengumpulan sisa plastik merupakan cabaran besar yang dihadapi oleh manusia di seluruh dunia. Mengubah sisa plastik kepada agregat pembinaan nampaknya merupakan penyelesaian yang wajar untuk kedua-dua masalah. Walau bagaimanapun, interaksi buruk agregat plastik dengan simen organik mengurangkan kekuatan konkrit dan menjadi kebimbangan utama untuk ditangani. Isu ini boleh diselesaikan dengan menambahkan bahan semula jadi seperti tanah liat dalam rumusan agregat plastik. Dalam kajian ini, PP kitar semula yang menggabungkan 1 pph tanah liat kaolin telah dikompaun melalui sebatian cair berbantukan air menggunakan pengadun dalaman untuk menghasilkan agregat komposit plastik (PCA). PCA, PP yang dikompaun semula (PWA) dan pelet PP dara telah diacu mampatan yang dibentuk menggunakan mesin penekan panas pada suhu dan daya tekan 180°C dan 140kgf/cm^2 selama 30 minit. Bahan plastik ini telah diuji untuk sifat fizikal dan mekanikal mengikut piawaian ASTM D792, ASTM D1895, ASTM D2240 dan ASTM D638. Ciri-ciri tersebut disokong dengan analisis morfologi melalui pengimbasan mikroskop elektron (SEM), analisis komposisi melalui Fourier transform inframerah (FTIR), dan analisis struktur melalui difraktometri sinar-X (XRD). Kajian ini telah membuktikan bahawa PCA dengan 1 pph tanah liat kaolin telah meningkatkan sifat fizikal (ketumpatan) dan mekanikal (kekerasan, kekuatan tegangan, modulus tegangan). Kekuatan tegangan dan modulus PCA meningkat kepada 23.61MPa dan 224.39MPa dengan kenaikan 1.2 dan 8 % berbanding PWA. Nilainya tidak jauh berbeza daripada yang dikumpul oleh sampel PP dara. Keputusan ini membuktikan bahawa 1pph tanah liat kaolin diperkukuh PP matriks melalui proses berbantu air boleh meningkatkan sifat mekanikal dan fizikal komposit. Penemuan ini boleh menjadi alternatif untuk menyelesaikan kedua-dua isu penyusutan agregat semula jadi dan pencemaran plastik. Ia akan memanfaatkan kedua-dua pengeluar pembinaan dan plastik untuk mengguna pakai bahan hijau dan pengurusan sisa yang lebih hijau dalam industri.

ABSTRACT

Natural aggregate depletion was becoming a global problem despite increased structural construction demands. Besides, accumulating plastic waste is a big challenge people face worldwide. Transforming waste plastics into construction aggregates appeared to be a sensible solution to both problems. However, the poor interaction of plastic aggregates with organic cement reduced concrete strength and became a major worry to be addressed. This issue could be solved by adding natural materials such as clay in the plastic aggregate formulation. In this study, recycled PP incorporating 1 pph of kaolin clay was compounded through a water-assisted melt compounding using an internal mixer to produce the plastic composite aggregates (PCA). The PCA, re-compounded recycled PP (PWA), and virgin PP pellets were compressions moulded using a hot press machine at a temperature and pressed force of 180°C and 140kgf/cm^2 for 30 minutes. The plastics were tested for physical and mechanical properties per standards ASTM D792, ASTM D1895, ASTM D2240 and ASTM D638. The properties were supported with morphological analysis through scanning electron microscopy (SEM), compositional analysis through Fourier transform infrared (FTIR), and structural analysis through X-ray diffractometry (XRD). This study had proven that PCA with 1 pph of kaolin clay had enhanced physical (density) and mechanical (hardness, tensile strength, tensile modulus) properties. PCA's tensile strength and modulus increased to 23.61MPa and 224.39MPa with an increment of 1.2 and 8 % compared to PWA. The values were not far different from those gathered by the PP virgin samples. This result proved that 1pph of kaolin clay reinforced PP matrix by the water-assisted process could enhance the composite's mechanical and physical properties. The findings could serve as an alternative to solve both issues of natural aggregate depletion and plastic pollution. It will benefit both construction and plastic manufacturers to adopt green materials and greener waste management in the industries.

DEDICATION

This report is dedicated to my dear parents and relatives, who helped me complete it without incident by providing spiritual and financial support. To my dear friends, thank you for always sticking with me through thick and thin and making me stronger. Also, I want to thank my supervisor, Associate Professor Dr. Noraiham Binti Mohamad, for constantly guiding me and providing me with vital knowledge that has helped me grow as a person. Thank you for what you have done. This work is dedicated to all of you.

ACKNOWLEDGEMENT

I want to thank Allah for allowing me to complete my studies successfully and without major setbacks. Not to mention my wonderful parents and family, who continue to inspire me to strive for success daily.

My respected supervisor, Associate Professor Dr. Noraiham Binti Mohamad, deserves special thanks for her outstanding mentorship, compassionate supervision, guidance, and direction and for exposing me to pertinent research experiences. Without her leadership and continuous support, this report would have been impossible.

I would also like to express my gratitude to Dr. Se Sian Meng and San Miguel Yamamura Plastics Film Sdn Bhd for their help and raw materials for my PSM 2. Together, I want to express my gratitude to FKP, FKP friends, professors, and technicians for the continuous support providing the facilities, help, and contributions during my studies. Without it, the journey would be challenging.

Lastly, thank you to UTeM for funding the research with the PJP/2020/FKP/PP/S01780 grant under the project title "Green Recycling Route for Plastic Manufacturer through Water-assisted Melt Compounding for Lightweight Plastic Waste Concrete Aggregates."

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LISTS OF ABBREVIATIONS

ABS	-	Acrylonitrile Butadiene Styrene
ASTM	-	American society for testing and materials
BS	-	British Standard
CA	-	Coarse Aggregate
DSC	-	Differential canning calorimetry
E	-	Young's modulus
Fc	-	Compressive Strength
Ft	-	Tensile Strength
FTIR	-	Fourier Transform Infrared Spectroscopy
HDPE	-	High-density Polyethylene
K	-	Thermal Conductivity
LDPE	-	Low-density Polyethylene
PA	-	Plastic Aggregate
PC	-	Polycarbonate
PCA	-	Plastic Composite Aggregate
PET	-	Polyethylene Terephthalate
PFA	-	Plastic Fine Aggregates
PP	-	Polypropylene
PS	-	Polystyrene
PSA	-	Particle Size Analyzer
PWA	-	Plastic Waste Aggregate
PU	-	Polyurethane
SEM	-	Scanning Electron Microscopy
UTM	-	Universal Testing Machine
Wt%	-	Weight Percentage
XRD	-	X-Ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Research Background

First and foremost, concrete is one of the world's oldest and most widely used construction materials, owing to its low cost, wide availability, long durability, and ability to withstand adverse weather conditions. Concrete output was ten times that of steel in terms of tonnage worldwide (Tantawi et al.). Concrete was the world's most commonly used building material and the second most generally utilised material after water (Bhardwaj and Kumar, 2017). Rather than being composed of a single substance, concrete was made up of a variety of basic materials. These essential resources include water, sand, cement, gravel, or shattered stones. Coarse aggregates, such as gravel or broken stones, and fine aggregates, such as sand, were examples of coarse and fine aggregates. The cement coats and binds the fine and coarse particles when combined. The hydration process occurs shortly after the components are combined, generating strength and culminating in rock-solid concrete (Ismail et al., 2013).

On the other hand, environmental concerns were becoming one of the most important roadblocks to producing natural concrete aggregates. Natural concrete aggregate, which accounts for three-quarters of the concrete's composition, was a legitimate concern. Malaysia produced 77.7 million tonnes of natural aggregate in 2007 (Ismail et al., 2013). Because the growing demand for concrete aggregates demands the massive used of natural stone materials, continued aggregate use would deplete the resources over time (Rahman et al., 2009).

Global plastic consumption, on the other hand, has skyrocketed, and plastic things have become an inseparable part of our everyday life (Gu & Ozbakkaloglu, 2016). Among the many types of recycling management systems, repurposing plastic waste in the construction sector was recognised as a beneficial solution for the disposal of plastic waste. Recycled plastics may be utilised without losing quality throughout the service cycle, and they can even be used in place of virgin construction materials. Plastic aggregates (PA) were frequently utilised to substitute natural aggregates in concrete, and numerous research investigated the properties of concrete made with plastic components (Almeshal et al., 2020).

This research project evaluated the physicomechanical properties of clay-reinforced plastic composite aggregates (PCA), specifically from waste or recycled polypropylene composites. Compared to a pure polymer matrix, polymer-clay composites often had better mechanical, barrier, and flame-retardant characteristics (Rousseaux et al., 2010). There was not as much research on the physicomechanical properties of combining polypropylene composite with clay. The physicomechanical properties of the compared concrete aggregates were the density, specific gravity, hardness, and tensile properties. Finally, by substituting recycled polypropylene composites for naturally produced resources, the latter was preserved by minimising its use in concrete production. This will allow for better manufacturing of greener concrete for the environment and a greater acceptance of green material development and use in the modern period.

Plastic waste, on the other hand, was becoming a global problem. Plastics used in everyday life deteriorate over time and cannot be totally recycled. Massive volumes of plastic garbage necessitate enormous storage areas (Sharma & Bansal, 2016). Globally, more than 400 million tonnes of plastic are produced each year, according to the United Nations Environment Programme (UNEP). Until 2015, over 6300 Mt of plastic garbage had been created, with roughly 9% being recycled, 12% being burnt, and 79% being deposited in landfills or the environment. If present development and garbage disposal trends continue, over 12 billion tonnes of plastic waste will be in landfills or the natural environment by 2050 (Geyer et al., 2017). Reprocessing waste plastic material in making concrete was an environmentally viable alternative to plastic waste disposal because of its ecological and economic benefits. In addition, this helped reduce the quantity of plastic trash incinerated or the amount of plastic waste material.

1.2 Problem Statement

Concrete production worldwide was estimated to be around 20–25 billion tonnes per year (Randl et al., 2014). The increased demand for concrete aggregates necessitates the significant used of natural stone resources, which disrupts the natural equilibrium of the ecosystem. As a result, conflict over soil usage will emerge, necessitating more land for development and, at the same time, an increase in demand for building minerals necessary for construction activity.

As a result of the tremendous economic and demographic growth, many business and residential districts around the quarries were being developed and expanded (Institution of Engineers Malaysia, 2007). Furthermore, many academics have stressed critical topics related to environmental damage mitigation, such as monitoring and reducing the impacts and consequences of quarry and mining emissions (Ashraf et al., 2011). In the future, the landmasses utilised for mining or quarrying for aggregate production will no longer be available. The expanding population and the urbanisation and industrialization processes will constrain them. As a result, aggregate usage issues must be addressed before a substantial shortage occurs.

Composite materials are among the most technically complex materials available today. It has been discovered that using recycled polypropylene reinforced by clay improves the properties of composites. By incorporating high-strength fibres into a polymer matrix, mechanical properties such as ultimate tensile strength, flexural modulus, and temperature resistance can be significantly improved. However, a study by Saikia et al. (2012) discovered that using plastic as an aggregate reduced compressive strength. It was thought to be caused by a lack of surface contact between plastic waste aggregate and organic cement ingredients. As a result, adding clay particles improved surface compatibility between plastic waste aggregate and cement during processing, enhancing mechanical properties. Both the particle size and the cohesive paste of kaolin clay can contribute to increased strength.

Kaolin clay increases the spaces between sand particles and suspends the aggregates inside the paste when used to form a paste. The paste was evenly shaped and strongly consistent (Shen et al., 2012). It removed the dependency on surface modifiers to enhance the surface characteristics of the plastic aggregates. The natural clay particles were a more suitable substitute and lessened these dangers. Still, the study on the potential of recycled polymer reinforced by clay as a potential aggregate in concrete is scarce. Besides the compatibility between hydrophilic clay particles and hydrophobic PP particles would impose an issue. Therefore, this study determined the potential of recycled PP reinforced by clay prepared by a water-assisted process from the aspect of physical and mechanical properties.

It was compared with recycled PP and virgin PP. The findings would be a platform for sustainable concrete aggregates, reduce considerable health risks, and serve as the wise choice to solve the depletion of natural aggregates and plastic pollution in landfills.

1.3 Objectives

The following were the objectives that had achieved throughout the whole research study:

1. To compare the physical and mechanical properties of virgin polypropylene (PP), recycled polypropylene and PP composites.
2. To evaluate the morphological, compositional, and structural characteristics of the virgin polypropylene (PP), recycled polypropylene and PP composites.

1.4 Scopes of the Research

1. PWA and PCA with 1wt% Kaolin clay compounds were prepared using an internal mixer through a melt compounding method. The virgin PP pellets were used as received. The virgin PP, PWA, and PCA compounds were pressed by a hot press at 180°C.
2. The physical properties of all plastics, virgin PP, PWA and PCA were tested. The density, according to ASTM D1895, by using an electronic densimeter. While the mechanical properties were also tested, which included hardness following ASTM D2240 by using Durometer Shore D Hardness Tester, and tensile properties were according to ASTM D638 by using Universal Test Machine (UTM).
3. The samples of virgin PP, PWA and PCA were analysed through morphological analysis using SEM, compositional analysis using FTIR, and structural analysis using XRD.

1.5 Rationale of Research and Sustainability Element

The rationale of this research was to encourage the use of waste or recycled polypropylene because of its high waste output in landfills, which poses a threat to the environment. This strategy decreases trash production in the environment and benefits humans since the aggregates created may be used to manufacture construction concrete. Because plastics were so much lighter than conventional concrete, the manufacturing and usage of plastics as concrete aggregates utilised much less energy than traditional concrete. The findings of this research will serve as a reference tool in future research on the production of clay-reinforced recycled polypropylene composites as concrete aggregates for low-risk construction purposes.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Chapter 2 focused on extracting and filtering essential and relevant evidence from the previous publications as a guideline, principle and reference to guarantee that the contents meet the chapter's goal. All of the information gathered was divided into four categories. Firstly, the plastic waste was explained, encompassing its types and how the plastic waste was being recycled. Secondly was the conventional concrete, followed by types of concrete, the general component of concrete and its grade, and types of aggregate in concrete. The third subchapter was on plastic waste aggregates reinforced concrete, followed by plastic composites aggregates, clay reinforced plastic composites, and the processing method of plastic aggregates. Finally, the last subchapter covers the established findings on the physicomechanical of plastic waste aggregates. It is divided into two which is physical properties and mechanical properties. The physical properties include density, and specific gravity, while mechanical properties include hardness, and tensile strength.

2.1 Plastic Waste

The world was on the edge of a garbage calamity, and our collective decisions over the next several years will determine the fate of our planet. Plastic output had surpassed that of practically every other commodity since the 1950s (Almeshal et al., 2020). Plastic used had resulted in vast volumes of waste and increased emissions. According to the United Nations Environmental Program 2019, the globe accumulated a lot of plastic rubbish between 1950 and 2015, with more than 200 million tonnes of plastic waste.

Recycling, landfilling, and incineration are the three primary techniques of dealing with post-consumer plastic, according to the waste order hypothesis (Gertsakis & Lewis, 2003). The ecosystem was harmed by large amounts of polymeric waste and poor biodegradability. Because all forms of plastic used in everyday life decay over time and cannot be fully recycled, massive amounts of plastic waste demand massive storage facilities(Sharma & Bansal, 2016). Reprocessing waste was important in a variety of aspects. It aids in recycling, lowers energy production, reduced pollution in the environment, and helped conserve crucial and limited environmental resources (Ismail & AL-Hashmi, 2008).

Malaysia was tracking global trends in overall plastic rubbish output and single-use plastic consumption, which had been on the rise since the 1970s, as shown in Figure 2.1. Furthermore, plastic garbage accounted for 19% of total waste created in Malaysia in 2007 (Chen et al., 2021). Plastic recycling was a viable method to manage plastic waste for environmental preservation and sustainable development (Kamaruddin et al., 2017). Figure 2.2 shows the extensively increasing of plastic waste from 1950 to 2015 in a million metric tons that was getting critical year by year. The utilisation of plastic trash in civil construction had been intensively investigated in recent decades(Gu & Ozbakkaloglu, 2016). Plastic trash had been employed as fine or coarse aggregate in concrete and mortar in most situations (Babafemi et al., 2018). Polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polycarbonate, metalized plastic waste (MPW), and polystyrene had all been explored as plastic waste materials (PS). Plastic trash was suited for usage and recycling in the building sector due to its great features like as durability, lightweight, strength, hardness, and good heat insulation.

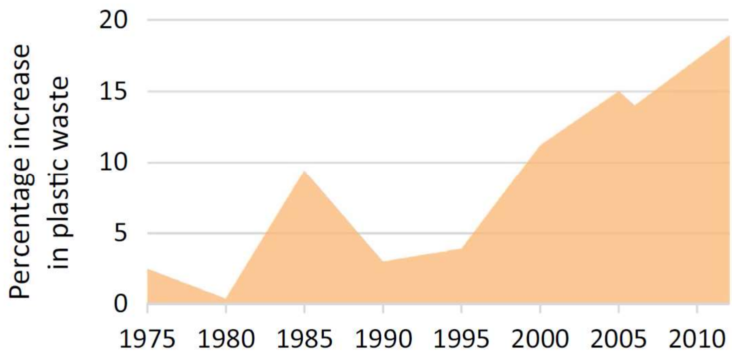

Figure 2. 1: Percentage increase of the generation of plastic wastes in Malaysia from 1975 to 2010 (Chen et al., 2021).

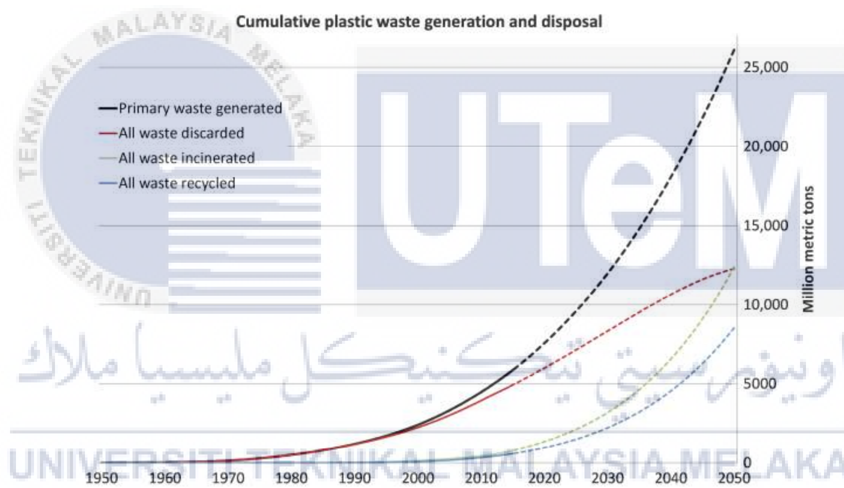

Figure 2. 2: Cumulative plastic waste generation and disposal (in a million metric tons). Solid lines show historical data from 1950 to 2015; dashed lines show projections (Geyer et al., 2017)

2.1.1 Types of Plastic Waste

Plastic was everywhere, including wrappers, containers, bottles, automobiles, shoes, baby wipes, and tea bags. Its diverse applications extend from household to manufacturing industries, especially using plastic bags and packaging materials. It was reasonable to state that avoiding plastic trash was difficult. Thermosetting polymers and thermoplastics were the two most common plastic types. Thermosetting, also known as thermosets, was the process of heating polymers until their chemical properties change, resulting in a threedimensional link that may be used to manufacture polyurethane (PU), phenol-formaldehyde, epoxy resins, vinyl ester resins, and silicone. These polymers, however, cannot be remelted and reformed after they had been heated and manufactured.

Thermoplastics were a class of polymers that can be created, melted, and solidified again. These characteristics, which give thermoplastics their name, were reversible. Thermoplastics melt when exposed to adequate heat and then solidify when allowed to cool. Polystyrene (PS), polyethylene terephthalate (PET), polyethylene (PE), polycarbonate (PC), fluoropolymers, polyarylsulfone, and polyvinyl chloride (PVC) were examples of thermoplastics (PlasticEurope, 2019). The most often used plastic aggregates in concrete were polyvinyl chloride (PVC), polyethylene terephthalate (PET), polystyrene (PS), and low-density polyethylene (LDPE), as indicated in Table 2.1. Understanding the many sorts of plastic garbage might be beneficial. The types of plastics and their recyclability potential were shown in the Table 2.1 (Almeshal et al., 2020).

Table 2. 1: Recycled and virgin application, description, and recyclability of the plastic polymer (Almeshal et al., 2020)

Polymer	Explanation	Recycled polymer application	Virgin polymer application	Recyclability
PET: Polyethylene Terephthalate	Transparent, strong, usable as a filament	Bottles of detergent, bottles of soft drinks, fleece coats	Mineral water and bottles for soft drinks	PET was completely recyclable
HDPE: High Density Polyethylene	Plastic, typically white or coloured	Bottles of detergent, bags of compost, boxes, mobile rubbish bins	Frozen food packs, crinkly grocery bags, bottles of milk, and cream	Accepted at most recycling centres
LDPE: Low Density Polyethylene	Flexible plastic, delicate	Business and seeds packaging, films for construction, and packs	Garbage containers, ice cream tub lids, and dark polymer sheets	LDPE can be recycled
PP: Polypropylene	Multiple applications,	Recycling enclosures	Potato snack sacks, beverage tubing,	Most versatile and most