Republic of Iraq
Ministry of Higher Education and Scientific Research
University of Babylon
College of Materials Engineering
Department of Polymer Engineering and Petrochemical Industries

Effect of some Parameters for Extrusion Process on the Recycled Polycarbonate Blends

A Thesis

Submitted to the Council of the College of Materials Engineering / University of Babylon in Partial Fulfillment of the Requirements for the Master Degree in Materials Engineering / Polymer

By

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(B.Sc. in Materials Engineering, 2016)

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2022 A.D 1444 A.H

صدق الله العظيم

سورة النور(الآية ٣٥)

Dedications

To my Mom and Dad;

The reason of what I become today. Thanks for your great support and conditions care through my life.

To my brothers;

Tawfeek

Mustafa

To my Aunt;

Amera

With Respect

Safa naseer

Acknowledgments

Firstly, all the thank and praise be to ***ALLAH*** for enabling me to achieve this study.

I would like to express my sincere thanks and deepest gratitude to my supervisor ***Prof. Dr. Ali Al-Zubiedy*** for his continued encouragement, knowledgeable advice, guidance and support throughout this study.

Additionally, I would like to thank ***Eng. Sara Kareem*** , ***Eng. Sura kamal*** and ***Eng. Noor baian*** for the help in carrying out the research. With the utmost gratitude, I would like to thank ***Eng. Adel Hussein Jabbar*** and ***Eng. Mustafa ali Hussein*** and my friends (***Haneen hamied***, ***Hajer mujahed*** and ***Zainab Hassan***) for their continuous support during the research period. Sincere Thanks to all staff of Department of Polymer Engineering and Petrochemical Industries / College of Materials Engineering / University of Babylon for their appreciable support.

safa 2022

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بابل
كلية هندسة المواد
قسم هندسة البوليمر والصناعات البتروكيمياوية

تأثير بعض العوامل على عملية البثق لخلائط البولي كاربونات المعاد تدويرها

رسالة

مقدمة الى كلية هندسة المواد/جامعة بابل وهي جزء من متطلبات نيل درجة الماجستير في هندسة المواد/البوليمر

من قبل الباحثة

صفا نصير توفيق

(بكالوريوس هندسة البوليمر ٢٠١٦)

بإشراف

أ. د. علي عبد الأمير الزبيدي

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Abstract:-

This work focuses on recycling compact disc (CDs), which are made of polycarbonate (PC), and converting them into useful products through the extrusion process. This study deals with the effect of speed, cutting size of CDs, and the percentage of addition of polymethyl methacrylate (PMMA) on the properties of the recycled polymeric material.

At the beginning of the work, the CDs were cleaned with sodium hydroxide, then dried and cut into three different sizes (1.18, 2.36, and 4.75) mm, after which they were mixed with a variety weight percentage of polymethyl methacrylate (10, 20, and 30) wt%.

The ideal temperature for extruding the material and the blend was determined after conducting several temperature tests. It was noticed that at a temperature of 195 °C, the blend does not melt and contains agglomerates. At 210°C, the blend completely melted, but at a temperature of 220°C, we noticed that the blend started to burn. Therefore, from the above, the suitable temperature for the blend in the extruder is 210 °C.

The temperature of the extruder was set at 210 °C, and the speed was changed between 25 and 50 rpm to choose the best speed.

Several tests were conducted, including density, tensile, hardness, and impact tests. A differential scanning calorimeter test (DSC) was also performed to find out the type of blend, in addition to an infrared Fourier transform spectrometer (FTIR) analysis to find out the type of bonding. The melt flow rate test was also carried out to find out the melt flow rate ,The morphological characteristics were studied by scanning electron microscopy (SEM).

The results showed that the cutting size, speeds, and percentage of PMMA addition have a direct effect on the mechanical, physical, and

morphological properties of the material. This effect can be seen in the increase of ultimate tensile strength and hardness with increasing speed to 50 rpm, 30 wt% polymethyl methacrylate, and cutting size (2.36 mm). In contrast, impact strength decreases with increasing polymethyl methacrylate in all blend ratios for all speeds and sizes. Moreover, the results show that when the speed is 50 rpm, it has good mechanical properties, and in addition to that, the melt flow rate increasing with the increasing speed and the percentage of addition of polymethyl methacrylate (PMMA), as the chains branching decreasing and the density and crystallinity increasing associated with the viscosity decreasing.

Furthermore, the Differential Scanning Calorimeter (DSC) results revealed that the glass transition temperature of the reconstituted polycarbonate decreased after the two-speed extrusion process. As for the blend, the results showed the appearance of two regions of the glass transition temperature, which indicates that the blend is of the immiscible type.

The infrared Fourier Transform Spectrometer (FTIR) analysis revealed that the type of bonding between the blend's components is physical interaction, while the scanning electron microscope test revealed that the blend at 50 rpm at 210 °C has a smoother, less porous, and rougher surface than the blend at 25 rpm.

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List of Abbreviations

Character	Item
ASTM	American society for Testing and Material
ABS	Acrylonitrile butadiene styrene
CDs	Compact disc
^0C	Celsius
CO_2	Carbon Dioxide
DSC	Differential Scanning Calorimetry
EPA	Environmental Protection Agency
FTIR	Fourier Transform Infrared Spectroscopy Analysis
g	Gram
HIPS	high impact polystyrene
HDPE	High Density Polyethylene
I.S.	Impact Strength
KBr	Potassium bromide
LDPE	Low Density Polyethylene
MWP	Municipal Waste Polymer
MSW	Municipal Solid Waste
MPa	Mega Pascal
PC	Polycarbonate
PMMA	Polymethyl Methacrylate
PVC	Poly (vinyl chloride)
PP	Polypropylene
PET	Poly (ethylene terephthalate)

PS	Polystyrene
rPC	Recycled Polycarbonate
rpm	Revolution Per Minute
SEM	Scanning electron microscopy
T	Time
U.T.S	Ultimate Tensile Strength
WEEE	Waste Electric and Electronic Equipment
wt	Weight

List of Symbols

Symbols	Meaning	Units
NaOH	Sodium hydroxide	
NO2	Nitrogen Oxides	
SO2	Sulfur Dioxide	
T	Temperature	^0C
Tm	Melting Temperature	^0C
Tg	Glass Transition Temperature	^0C
I.S	Impact strength of the material	(kJ/m^2)
Uc	Impact energy	(kJ)
ρ	Density	g/cm^3
γ	Shear rate	s^{-1}
MFR	melt flow rate	g/10min
A	cross-sectional area of the sample	m^2

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الخلاصة:-

يركز هذا العمل على اعادة تدوير الاقراص المضغوطة, والتي تكون مصنوعة من بولي كاربونيت وتحويلها الى منتجات مفيدة من خلال عملية البثق. تتناول هذه الدراسة تأثير السرعة وحجم قطع الاقراص المضغوطة ونسبة اضافه البولي ميثيل ميثاكريلات على خواص المادة البوليميرية المعاد تدويرها.

في بداية العمل تم تنظيف الاقراص المضغوطة بواسطه هيدروكسيد الصوديوم وثم تجفيفها وتقطيعها الى ثلاث احجام مختلفة (١,١٨ ، ٢,٣٦ و ٤,٧٥)ملم بعد ذلك خلطها مع البولي ميثيل ميثاكريلات بنسب (١٠ ، ٢٠ و٣٠) بالوزن %.

حيث تم تحديد درجة الحرارة المثالية لبثق المادة والخليط من بعد اجراء عدة اختبارات لدرجة الحرارة فقد تم ملاحظة ان عند درجة حرارة ١٩٥ درجة مئوية ان الخليط لا ينصهر ويحتوي على تكتلات، اما عند ٢١٠ درجة مئوية انصهر الخليط بالكامل اما في درجة حرارة ال٢٢٠ درجة مئوية لاحظنا ان الخليط بدأ بالاحتراق. وبالتالي ،ومما سبق ،أن درجة الحرارة المناسبة للخلط في آلة البثق هي ٢١٠ درجة مئوية.

تم ضبط درجة حرارة ماكنة البثق عند ٢١٠ درجة مئوية وتغير السرعة عند ٢٥ و ٥٠ دورة في الدقيقة لاختيار افضل سرعة.

تم إجراء العديد من الاختبارات منها (الكثافة ، الشد ، الصلابة ، الصدمة).كما تم اجراء فحص المسعر الماسح التفاضلي لمعرفة نوع المزيج ، بالإضافة إلى فحص مطياف الاشعة تحت الحمراء لمعرفة نوع الترابط . وتم ايضا اجراء اختبار معدل تدفق الذوبان لمعرفة معدل جريان المنصهر، اما الخواص المورفولوجيا فقد درست بالمجهر الالكتروني الماسح.

أظهرت النتائج أن حجم القطع والسرعات ونسبة إضافة البولي ميثيل ميثاكريلات لها تأثير مباشر على الخصائص الميكانيكية والفيزيائية والمورفولوجيا والريولوجية للمادة. يمكن ملاحظة هذا التأثير في زيادة قوة الشد القصوى والصلادة مع زيادة السرعة إلى٥٠ دورة في الدقيقة ، ٣٠ وزن ٪ من بولي ميثيل ميثاكريلات وحجم القطع (٢,٣٦) ملم. في المقابل ، تقل مقاومة الصدمة في جميع نسب الخلط مع زيادة نسبة البولي ميثيل ميثاكريلات لجميع السرعات والأحجام. علاوة على ذلك ، تظهر النتائج أنه عندما تكون السرعة ٥٠ دورة في الدقيقة ، فإنها تعطي خصائص ميكانيكية جيدة ، بالإضافة إلى أن معدل جريان المنصهر يزداد بزيادة السرعة ونسبة اضافة البولي ميثيل ميثاكريلات حيث تقل السلاسل المتفرعة وتزداد الكثافة والتبلور المرتبط بتناقص اللزوجة.

علاوة على ذلك ، كشفت نتائج المسعر الماسح التفاضلي أن درجة حرارة الانتقال الزجاجية للبولي كاربونيت المعاد تنخفض بعد عملية البثق بكلتا السرعتين. أما بالنسبة للخليط فقد أظهرت النتائج ظهور منطقتين من درجة حرارة الانتقال الزجاجي مما يدل على أن المزيج من النوع الغير ممتزج.

أظهرت نتائج مطيافية الاشعة تحت الحمراء عدم حدوث تفاعل كيميائي بين مكونات الخليط ، بينما أظهر المجهر الالكتروني الماسح أن المزيج بسرعة ٥٠ دورة في الدقيقة في درجة حرارة ٢١٠ درجة مئوية له سطح أكثر نعومة نسبيًا وأقل مسامية وخشونة من أسطح الخليط عند ٢٥ دورة في الدقيقة.

1. Introduction

A dramatic increase in polymer consumption (mainly plastics) has resulted from the incredible growth of the global population in recent years, coupled with the need for people to adopt improved living conditions[1]. Plastics (polymer) are synthetic polymers with high resistance to acids, bases, and chemicals. Plastics are resistant against microorganisms, and therefore are not biodegradable [2]. Polymer is classified into two types, thermoplastic and thermoset polymer. Thermoplastic is a type of polymer that is recyclable and further molded into another shape. The thermosetting polymer is a type of polymer that have the property of unchangeable molecular chains because molecular chains are strongly bonded with crosslinks [3]. Materials appear interwoven with our consumer society, where it would be hard to imagine living without plastics, which have found a myriad of uses in fields as diverse as household appliances, packaging, construction, medicine, electronics, and automotive and aerospace components. The unabated increase in the use of plastics has led to an increase in the quantity of plastics ending up in the waste stream [1].

The issue of remediation and recycling wastes in contemporary civilization is of a paramount importance economically, this is because the human leaves a huge amount of waste in various types behind him through his consumption and his daily life practices and these wastes are handled incorrectly around the world. This has led to the destruction of many components of the environment as well as the tremendous waste of available resources in the recycling and re-processing operations of different types of wastes, such as reuse it as raw materials again or reuse it in production of electric power through flammable types. In Iraq, especially after 2003 this problem takes serious trends, with increasing human consumption and with great economic openness, which led to a complex

problem through pollution of the environment, waste of resources and lack of vision and mechanisms to deal with the huge quantities of waste and inability of the private sector to contribute in solving this problem as it fits with the size of the daily flow of inhabitants of large and small cities, as well as inhabitants of the suburbs and countryside [4].

There are common methods for plastics recycling: mechanical recycling and chemical recycling [5]. Amongst the recycling methods, mechanical recycling is the most desirable approach because of its low cost and high reliability. In general, mechanical recycling keeps the molecular structure of the polymer molecule basically intact [1]. A mechanical recycling method which involves blending of the plastics is one of the solutions for recycling plastics [6].

On the other hand, the continuous and rapid evolution in the field of computing, and in particular in the field of storage devices, has led to the obsolescence of optical discs (CDs and DVDs) in favor of mass storage devices. In addition, in Spain, approximately 100,000 CDs become obsolete each month and end up in landfills or incinerators because the data they contain simply ceases to be useful [7]. Compact disc (CDs) is made up of a polycarbonate disc body (95% by volume) with dye and reflective layers on their surfaces. The dye layer contains organic dyes such as cyanine and metalize to store data; the reflective layer is made up metals, largely aluminum, to reflect the laser, as shown Figure. (1.1), all of these materials, if buried in landfills, not only become "lost" resources but may cause significant environmental impacts because they take a long time to break down [8].

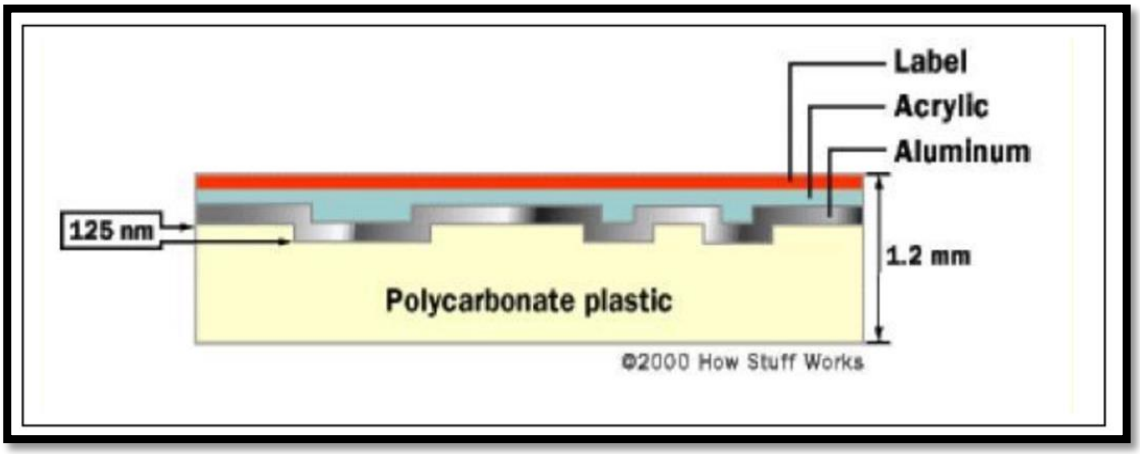


Figure. (1. 1): Cross-sectional view of a compact disc [9].

Polycarbonate (PC) is one of the important engineering plastics with a wide variety of applications due to the excellent mechanical properties, high impact strength, heat resistance and high modulus of elasticity, as well as due to its excellent balance of toughness, clarity, high thermal resistance and transparency [10, 11]. The recycling of this plastic material after the end of first life cycle has attracted attention recently [12, 13].

Some physical and mechanical properties of PC can be severely reduced by recycling. Pérez at al. reported that after ten times of recycling the tensile strength reduced by 30% [14].

Poly-methyl methacrylate (PMMA) exhibits excellent mechanical properties and good performance at various processing conditions. It is an amorphous polymer having high optical properties, good chemical resistance and high tensile strength [15]. However, the use of PMMA presents some practical disadvantages, e.g. brittleness, low elongation at break and high water absorption. To circumvent these drawbacks, many efforts have been made through copolymerization and polymer blending. Among a number of PMMA blends studied for miscibility, the mixture of PMMA and polycarbonate (PC) is one of the most investigated polymeric systems. This may be attributed to the excellent properties of PC, including outstanding ductility and low water absorption.

Extrusion process is a method that depends on continuous annealing of polymeric materials in the annealing system of the extrusion machine and pushing it forward and then extruding through a channel called the die. The extrusion process plays a prominent role in the formation of thermoplastics, thermosets, and rubber. Extrusion, as opposed to injection molding, is a continuous process, and can be adapted to produce a wide range of finished or semi-finished products, including tubes, sheets, films and wire packaging [16, 17, 18].

There are several important variables for the extrusion process, including (temperature, speed, and time) and others according to the physical properties of the material, especially its fluidity and flow, and each variable is determined by laboratory tests.

Polymer shredding is the method of decreasing the waste polymer to small pieces for further handling. Therefore, it is not possible to over-emphasize the improvement of shredding machines for plastic waste management [19].

The Polymer blends are the mixture of two or more polymers that can either mix completely on a molecular scale or form two-phase structure. Polymer blends exhibit a new combination of properties of component and depend strongly on the morphology of the blended materials. By blending polymers, new materials can be developed that combine physical and mechanical properties of their component, depending on the composition and level of compatibility.

Polymers may be compatible (miscible) or incompatible (immiscible) when blended. A miscible polymer blend means single-phase system [20]. Miscibility or compatibility is an important criterion for obtaining a synergistic effect from the blend with appropriate composition [21, 22]. Most polymers are immiscible or incompatible. The reasons for

incompatibility are high interfacial tension and consequently poor interface adhesion [23].

2. Aims of this Work :

I. Study the effect of extrusion machine parameters (speed and temperatures) on the properties of recycled polycarbonate.

II. Reduce waste and environmental pollution caused by these non-degradable wastes to maintain a healthy and clean environment.

2. Introduction:

The usability of polymer-based products is growing every day in the modern world, which causes an increase in polymer waste production and a crisis in waste disposal [24]. Where the production of polymers has increased substantially over the last 60 years from around 0.5 million tons in 1950 to over 260 million tons today [25]. Polymers are largely utilized and therefore contribute to an ever increasing of solid waste volume. Polymer is made of polymer chemicals and they are non-biodegradable. This means that polymer will not decompose when it is placed in the earth [26].

At present, the polymer wastes are disposed of primarily by landfill and incineration. The incineration and landfill deposition of municipal waste polymers (MWP) may cause environmental problems and is becoming more expensive. Due to increasing volume of MWP and decreasing landfill capacity for disposal, landfill becomes more challenging [27]. The disposal of polymer waste in an open environment leads to various environmental problems due to their low biodegradability and presence in large quantities which are disturbing the ecological balance of nature and is the major cause of health hazards to living beings [28, 29, 30].

2. 1. Municipal Solid Waste (MSW):

Non-hazardous waste is often referred to as municipal solid waste (MSW). The United States Environmental Protection Agency (EPA) characterizes MSW as “waste consisting of everyday items, used and then thrown away, such as product packaging, bottles, food scraps and newspapers which comes from homes, schools, hospitals and businesses. MSW is classified into three broad categories according to where it is generated: household waste, commercial waste, and institutional waste [31, 32]. Figure (2.1.a) shows global polymer waste contributes to about 10-13% of the entire MSW [33], and Figure. (2.1.b) shows the general composition of the plastic fraction itself [34]. The

main constituents of the plastic-fraction of the Waste Electric and Electronic Equipment (WEEE) are ABS, high impact polystyrene (HIPS), polycarbonate (PC), PC/ ABS and polypropylene (PP) [34].

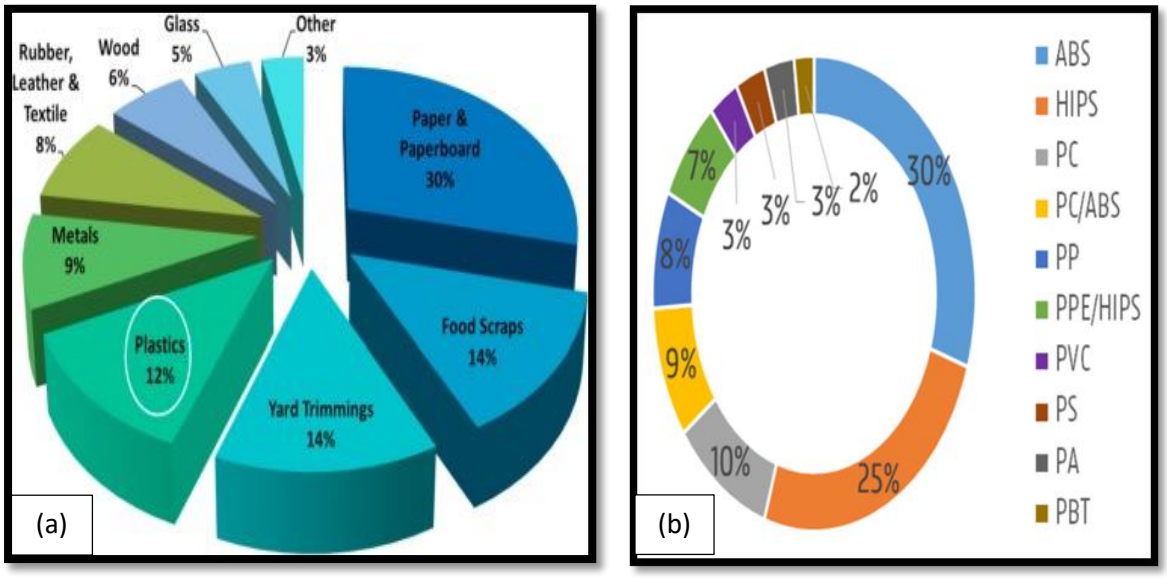


Figure. (2. 1): (a) Sources of MSW; (b) Polymer Waste Composition [33, 34].

The increased uses of polymers products as packaging applications in recent years have increased the quantity of polymers in the solid waste stream to a great extent. The quantum of solid waste is ever increasing due to the increase in population, development activities, changes in lifestyle, and socio-economic conditions [35]. Amongst the management methods for municipal Solid Waste:

I. source reduction,
II. reuse,
III. recycling,
IV. landfill,
V. waste-to energy conversion [36].

Figure. (2. 2) shows a flowchart of this waste management system [32], and Figure. (2. 3) shows waste management hierarchy [37], where describes the preferred course of action for managing waste. Different versions of the

hierarchy are adopted, but they all follow a step-wise process for waste where prevention, minimization, and reuse (& recycling) of waste products are prioritized [38].

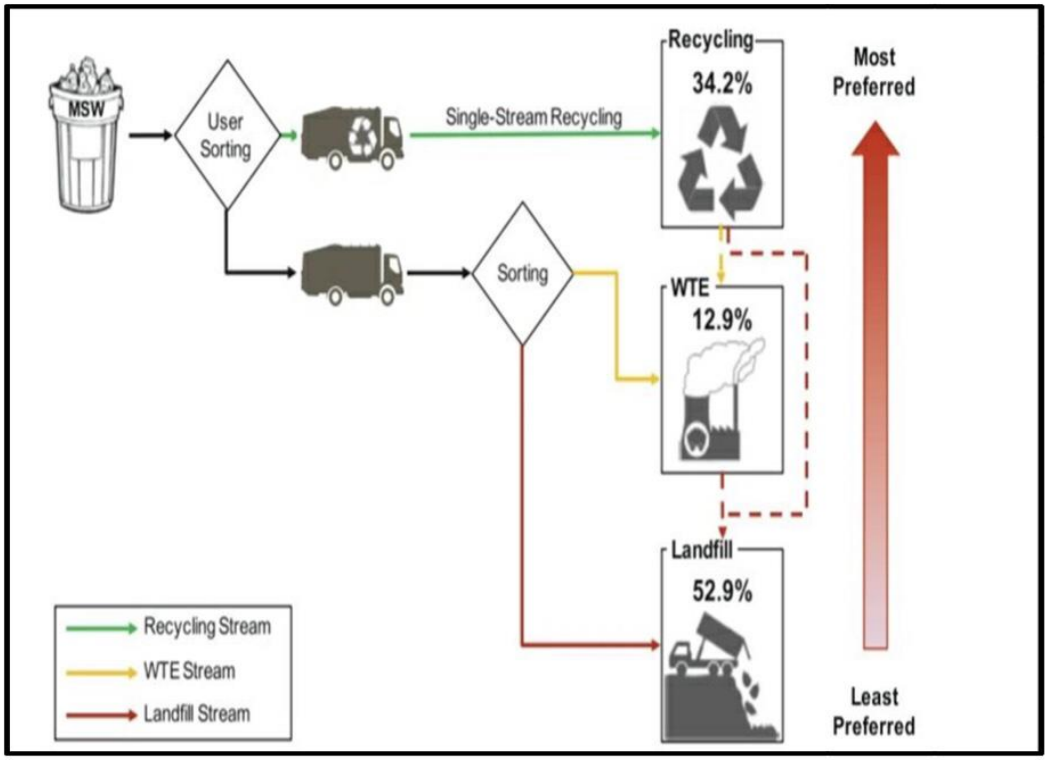


Figure. (2. 2): Flowchart of the Waste Management Stream in the USA\ 2013 [32].

Figure. (2. 3): Waste Management Hierarchy [37].

2. 2. Recycling of Polymers

Polymer can be degraded in the environment by four mechanisms: photo-degradation, thermo-oxidative degradation, hydrolytic degradation, and biodegradation by microorganisms. The natural degradation of polymer begins with photo-degradation due to the UV light from the sun which provides the activation energy required to initiate the incorporation of oxygen atoms into the polymer, leading to thermo-oxidative degradation. In this step, the polymer becomes brittle and fracturing into smaller pieces until the polymer chains reach sufficiently low molecular weight to be metabolized by microorganisms. The microorganisms convert the carbon of the polymer chains to carbon dioxide or incorporate it into biomolecules, but this process will take at least 50 years. So, a solution to these problems will be recycling, because most commodity polymers are relatively stable, making monomer recovery poor [39].

Recycling polymeric materials is one method for reducing environmental impact and resource depletion. Recycling can therefore decrease energy and material usage per unit of output, leading to improved eco-efficiency. The only way to decrease the environmental problems caused by polymeric waste accumulation produced from day-to-day applications of polymer materials such as those used in packaging and construction is by recycling. This helps to conserve natural resources because most polymer materials are made from oil and gas [40, 3].

2. 3. Various Stages of Recycling Polymer Wastes

There are different steps of recycling:

2. 3. 1. Collection: Polymer waste is collected from different locations. This can be achieved by keeping special containers at home, in public places, farms, and so on. These wastes are then collected by professional waste collectors and transported to the recycling sites.

2. 3. 2 Cleaning: The cleaning stage consists of washing and drying the polymer items. Cleaning is important since clean waste materials fetch better prices and they improve the quality of end products. Polymers can be washed at various stages of the recycling process: before, after, or even during sorting.

2. 3. 3 Sorting: This involves not only the separation of the polymers from recoverable foreign bodies but also the separation of these polymers themselves.

2. 3. 4 Size Reduction: It aims to reduce the size of the waste, which in turn facilitates not only the separation of different polymers but also recovery of the micronized powder which is used to feed processing machines. The end products of shredding can be irregularly shaped pieces of polymers, which can be sold to reprocessing industries and workshops.

After processing, these materials are further subjected to various techniques such as extrusion, injection moulding, blow moulding, and film moulding. Finally, the processed materials are converted into various products such as pipes, tubes, bags, sheets, and miscellaneous items [41].

The major polymers recycled are polyolefin (high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polypropylene (PP)) and poly-ethylene terephthalate (PET), poly-vinyl chloride (PVC), polystyrene (PS), and polycarbonate (PC). The recyclable polymers and the recycling codes are shown in Table. (2. 1) [41].

Table. (2. 1): Various Polymers with their Characteristic Recycling Codes for Particular Applications [41].

Symbol	Acronym	Full name and uses
	PET	Polyethylene terephthalate - Fizzy drink bottles and frozen ready meal packages.
	HDPE	High-density polyethylene - Milk and washing-up liquid bottles
	PVC	Polyvinyl chloride - Food trays, cling film, bottles for squash, mineral water and shampoo.
	LDPE	Low density polyethylene - Carrier bags and bin liners.
	PP	Polypropylene - Margarine tubs, microwave-able meal trays.
	PS	Polystyrene - Yoghurt pots, foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys.
	Other	Any other plastics that do not fall into any of the above categories. For example melamine, often used in plastic plates and cups.

2. 4. Recycling Techniques:

There are several methods of recycling: primary recycling, mechanical or secondary recycling, chemical or tertiary recycling and energy recovery or quaternary recycling.

2. 4. 1. Primary Recycling:

In this type of recycling, waste polymer is reprocessed into the same or similar types of products from which it was produced. The recycled scrap or waste is either mixed with virgin material to assure product quality or used as second-grade material. Primary recycling is very simple without any precautions except the proper and clean collection of waste in the plant [42, 16].

2. 4. 2. Secondary Recycling (Mechanical Recycling):

The polymer is grounded down and then reprocessed without affecting the basic structure of the material and compounded to produce a new component that may or may not be the same as its original use [43, 1].

2. 4. 3. Tertiary Recycling (Chemical Recycling):

Tertiary (chemical) recycling: the polymer waste is turned back into its oil/hydrocarbon component in the cases of polyolefin and monomers in the case of polyesters and polyamides, which can be used as raw materials for new polymer production and petrochemical industry, or into the pure polymers using suitable chemical solvents [1]. Chemical recycling is not commonly implemented on an industrial scale because present methods require sizable energy inputs [44].

2. 4. 4. Quaternary Recycling (Energy Recovery):

This method refers to the recovery of the polymer's energy content. The most effective way to reduce the volume of organic materials which involves the recovery of energy is represented by incineration. This method is a good solution because it generates considerable energy from polymers, but it's not ecologically acceptable because of the health risk from airborne toxic substances [16].

An overview of the different pathways for recycling is shown in Figure. (2. 4), including where their respective end products re-enter the lifecycle of polymers [45].

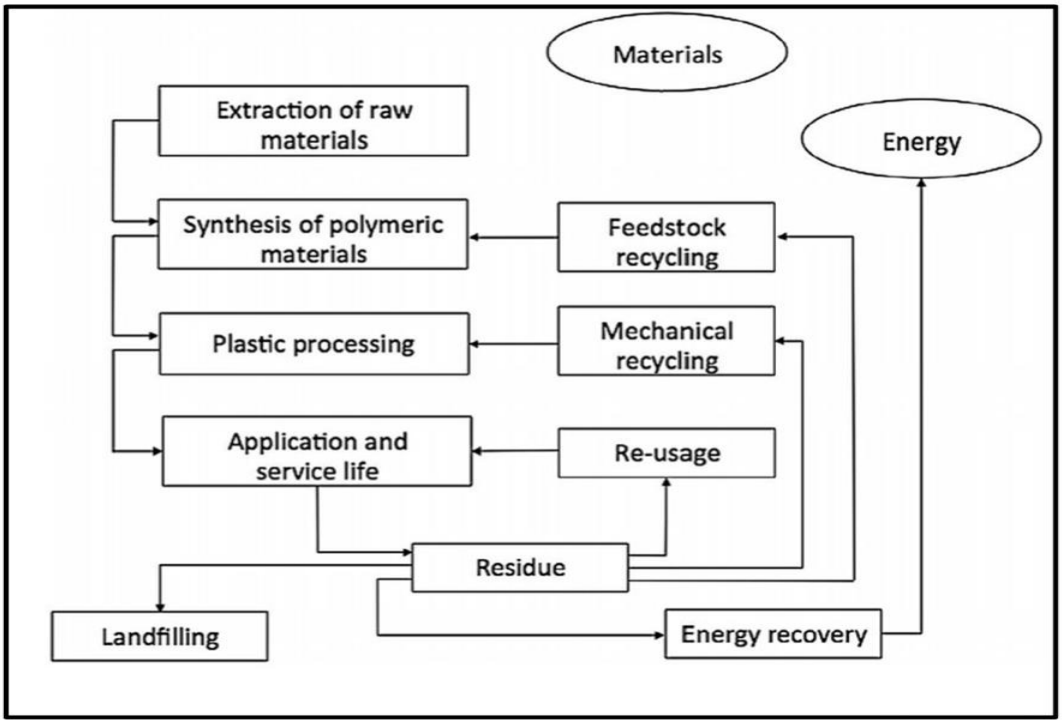


Figure. (2. 4): Polymer Waste Management Options in Terms of the Life Cycle of Polymeric Products [45].

In this study, mechanical recycling is adopted and will be explained below.

2. 5. Mechanical Recycling (or secondary recycling)

Mechanical recycling is the reprocessing of materials of waste polymers by physical means, like cutting, shredding, washing, and so on, into polymer products. In this approach, the polymer is separated from its associated contaminants, and it can be readily reprocessed into granules by conventional melt filtration extrusion. The size of the waste polymer is reduced after it is sorted, cleaned, and dried, and then directly processed into end products or flakes of consistent quality, which can be further used for manufacturing other goods. The succeeding steps for recycling can vary from operation to operation and the end use [46]. The basic polymer is not altered during the process. The main disadvantage of this type of recycling is the deterioration of product properties in every cycle. This occurs because the molecular weight of the

recycled resin is reduced because of chain-scission reactions caused by the presence of water and trace acidic impurities. Strategies for maintaining the polymer's average molecular weight during reprocessing include intensive drying, reprocessing with vacuum degassing, the use of chain extender compounds, and so on [47]. In mechanical recycling, only thermoplastics can be used because they can be re-melted and reprocessed into end products [46].

Thermoset polymer cannot be melted and reprocessed, so mechanical recycling is not suitable for recycling such polymers. Thermoset polymer can be processed through its use in cement kilns or tarring roads [46].

2. 6. Steps of Mechanical Recycling:

The following are the steps included in mechanical recycling [48]:

1. Cutting/ shredding: Large polymer parts are cut by shear or saw for further processing into chopped small flakes.
2. Contaminant separation: Paper, dust and other forms of impurities are separated from polymer usually in a cyclone.
3. Floating: Different types of polymer flakes are separated in a floating tank according to their density.
4. Milling: Separate, single-polymer plastics are milled together. This step is usually taken as the first step with many recyclers around the world.
5. Washing and drying: This step refers to the pre-washing stage (beginning of the washing line). The actual polymer 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 polymer), where caustic soda and surfactants are used.
6. 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.

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

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

During the grinding or melting phases, the reprocessed material can be blended with virgin material to obtain superior results. Mechanical recycling requires homogenous polymers and relatively clean material. It is one of the traditional and most used methods in many countries for polymer recycling. Its cost is relatively low but needs substantial initial investment [26]. In Figure. (2. 5), the stages of mechanical recycling are shown [49].

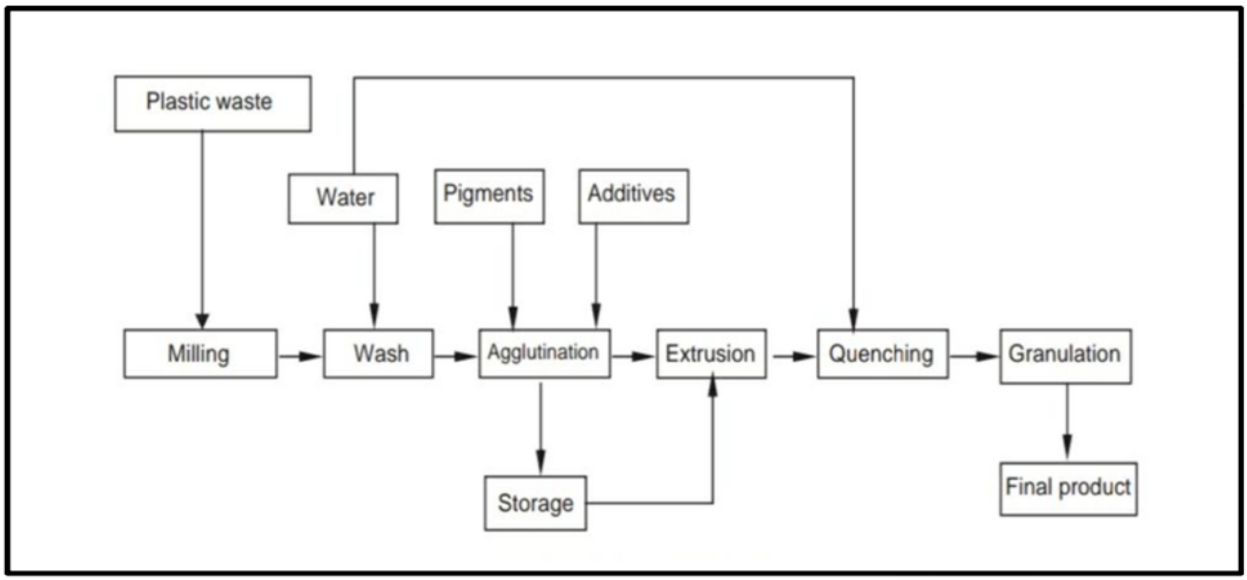


Figure. (2. 5): Stages of Mechanical Recycling [49].

2. 7. Advantages of Recycling and Reuse of Polymers

Recycling polymer wastes has so many advantages to human beings and the ecosystem when compared with all other methods of solid waste management adopted. Some of the numerous advantages of recycling polymer wastes are [50, 51, 52]:

1. As polymer wastes that litter the streets and choke drainages which serve as the breeding ground for mosquitoes and flies are reduced, diseases associated with these vectors will also reduce.
2. The emission of poisonous gases such as carbon dioxide, carbon monoxide, nitrogen-oxide and sulphur-oxide are reduced.
3. It creates job opportunities.
4. That recycling would reduce the amount of polymer wastes in the environment.
5. That recycling would create employment for the populace for collecting the polymer wastes thus bettering the economic status of the populace.
6. It reduces demand for virgin polymer.

2. 8. Polymer Blends

The study of polymer blends has expanded into a large topic with many different applications. The blending of polymers is an inexpensive route to the modification of various polymer properties. It is a viable and versatile way to control the performance of polymeric materials with available polymers [53]. There has been a significant increase in the use of polymer blends to obtain new high-performance organic materials without any synthesis, resulting in a new polymeric material. Polymer blends are composed of two or more polymers with or without compatibilizer, depending on the composition and viscoelastic properties of individual components. They have complicated properties which display elasticity and viscosity at different strain rates and temperatures [54, 55]. Polymer blending is a relatively simple process and cheaper than polymer synthesis. The blending of conventional polymers has been extensively employed to develop new polymeric materials. Polymer blends have become a traditional method for producing new, high-performance polymeric materials. Mechanical, optical and electrical properties of polymer blends depend on their morphological characteristics [56]. They are produced in order to achieve

improvements in properties such as thermal stability, mechanical properties or chemical resistance [57]. Many important polymer blends are incompatible polymers [58]. Due to its utility and simplicity, blending is currently a feasible method for improving polymer surface properties [59, 60]. Polymer blends and composites improve product performance by combining different polymers with specific properties in order to combine as one material [59].

2. 9. Classification of Polymer Blends:

Polymer blends are mixed systems of two or more finished polymers which can be modified through mixing two or more macromolecular compounds. Polymer blends are classified as [59]:

- Miscible blends.
- Immiscible blends

2. 9. 1. Miscible Blends

Various miscible polymer blends with strong specific interactions show an unusual compositional variation of their Tg [61, 62].

- Symmetric interfaces form miscible blends.
- Polymers interpenetrate into each other.
- Produce blends with good mechanical properties and good cohesion between phases.

Degree of miscibility of polymer blends depends on interpenetration and is generally neither easy to determine experimentally nor easy to predict theoretically. Polymer miscibility results in a mixture with two different chains/segments that are in proximity within a domain small enough. It may be several or tens of repeat units regardless of the types of interactions. A proton-donating polymer is likely to be miscible with a proton-accepting polymer [63].

2. 9. 2. Immiscible Blends:

Most of the polymer blends are immiscible with poor physical properties in comparison with their individual polymers. This is due to the lack of favorable interaction between phase blends. It leads to large interfacial tension in the melt blend which makes it difficult to deform the dispersed phase during mixing. In immiscible blends an increase in stress concentration at the interface is responsible for the decrease of tensile strength [64].

Immiscible polymer blends exhibit different types of morphologies which depend on composition, viscosity ratio and elasticity ratio between the components, interfacial tension, process conditions, etc. [65, 66]. Immiscible blends offer attractive developing materials with a useful combination of properties. Asymmetric interfaces form immiscible blends. Blend systems can be strongly limited by the incompatibility between the polymers. Blends have a multiple glass transition temperature with immiscibility. Generally there is immiscibility among the high molecular weight polymer pairs as well as mechanical incompatibility [67]. The types of immiscible polymer blends are:

- Blend having dispersed domain structure in matrix phase.
- Blend having co-continuous structure.

Asymmetric blend compositions with the minor component form the dispersed phase in the continuous phase of the major component [68, 69]. The control of microstructure is very important for determining the physical properties of multi component blends in immiscible polymer blends [70, 71]. Polymers are normally not miscible because of the large size of their molecules. Polymer-polymer interfaces are sufficiently narrow. There is little entanglement between the different polymers [72]. Mechanical properties of immiscible blends should be very sensitive to the phase morphology generated during processing and should be widely varied in chemical type. The chemical type of immiscible blends could be significantly improved by addition of certain block copolymers. Most polymer blends of high molecular weight polymers are

intrinsically immiscible, and therefore phase separate under appropriate conditions. Heterogeneous structures would result in the blend. In ternary blends containing block copolymers, formation of interlocking or inter penetrating network phases is the ideal morphology for an immiscible blend. It allows for equal sharing of imposed stresses by the component [59].

2. 10. Advantage of Polymer Blends:

There are advantages to using polymer blends to replace engineering polymers in the automotive industry [73, 74, 75]. The advantages of polymer blends and composites can be used to:

- Achieve an economic or property advantage;
- Exploit the unique properties of individual polymers for multi component systems.
- Improve the impact strength, resistance to environmental

stress cracking, optical properties, crystallization rate, low temperature impact strength, rheological properties and overall mechanical behavior [76].

2. 11. Polycarbonate (PC)

Among thermoplastic susbstance, polycarbonate has greater interest as a good base material. Polycarbonate is a transparent commercial engineering polymer that used in many applications due to its properties such as high among thermoplastic substances; Polycarbonate has greater interest as a shock resistance, thermal stability, toughness, low moisture absorption and good optical properties as well as other mechanical properties. It has highly transparent to visible light with better light permeability than many kinds of glass [77], Figure. (2. 6) explained the structure of polycarbonate.

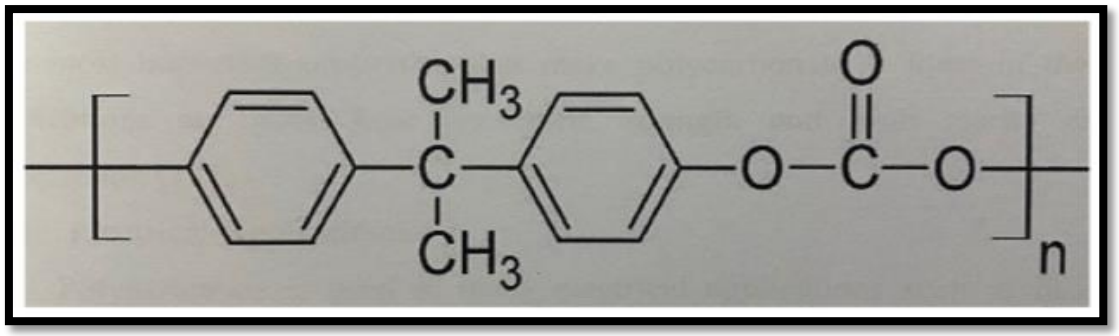


Figure. (2. 6): The Structure of Polycarbonate [77].

Polycarbonate is one of most important material that replaces the glasses in different application as in display panels of electrical tools, low weight eyewear lenses and compact disks, screen protectors for smartphone this goes back to physical and mechanical properties of polycarbonate [78].

Polycarbonate possesses several distinct properties such as dimensional stability, flame resistance and high heat distortion temperature. Therefore, it is an important and widely used engineering thermoplastic. However, PC exhibits high notch sensitivity, and it is susceptible to crazing or cracking on exposure to various solvents. Moreover, PC is relative soft and the surface of the polymer can be easily scratching. These disadvantages limit its use in some applications [79].

Table. (2. 2): Properties of Polycarbonate [80].

Parameters	PC
Chemical formula	$C_{15}H_{16}O_2$
Glass Transition Temperature (^{0}C)	145
Melting Temperature (^{0}C)	250
Density (g/cm^3)	1.2
Modulus of elasticity (GPa)	2.3

Polycarbonate does not have a unique resin identification code, instead falling under 7, or “other”. Show Figure. (2. 7) [81].

Figure. (2. 7): Polycarbonate Recycling Symbol [81].

2. 12. Polymethyl Methacrylate (PMMA)

Poly-methylmethacrylate is an essential and interesting polymer because of attractive optical and physical characterizations decisive about its area applications. PMMA is the thermoplastic polymer with the excellent hardness and tensile strength, transparency, high rigidity, good insulation hermal stability dependent on tactility. Poly(methylmethacrylate) has some disadvantages such as brittleness and low chemical resistance which can be eliminated by chemical or physical modification. It contains both hydrophobic (methylene) and hydrophilic (carbonyl) groups in each unit [82]. PMMA is often used as andalternative to glass andsold under anumber tradenames including Lucite, Plexiglas, Acrylex, Acrylite, Oroglass, and Vitroflex. When completely burned the products are carbon dioxide and water making it an environmentally positive material in this regard. PMMA is often used as an alternative to glass. PMMA is used in the exterior lenses of automobiles and trucks. The spectator protection shield in ice hockey stadiums is made of PMMA. The windows of many aircraft and windows of

police vehicles for riot control are PMMA as are many motorcycle helmet visors. PMMA is also used in medicine. PMMA has good compatibility with human tissue and has been used for replacement of intraocular lenses in eyes. Hard contact lenses are often composed of PMMA. Bone cement containing PMMA is used to connect bond implants and remodel lost bone. PMMA has Young's modulus near that of bone, so does a good job of load sharing with the native bone. Dentures are often PMMA [83]. A chemical structure of the repeating unit of PMMA polymer, as shown in Figure. (2. 8) [84]. Table. (2. 3) illustrates the most important properties of PMMA polymer [85].

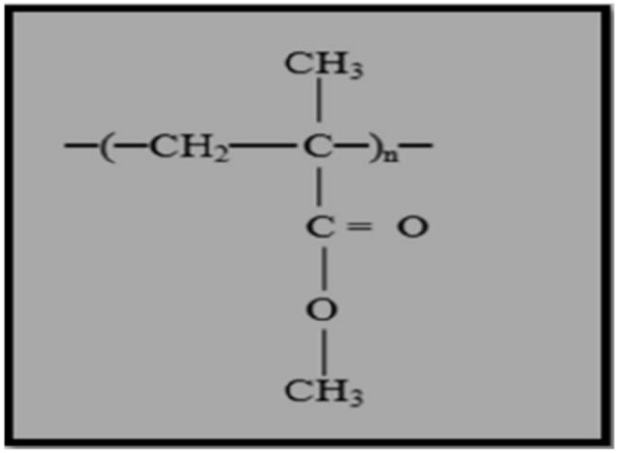


Figure. (2. 8): Chemical Structure of the Repeating Unit of PMMA Polymer [84].

Table. (2. 3): The Most Important Properties of PMMA Polymer [85].

Parameters	PMMA
Chemical formula	$(C_5O_2H_8)$
Glass Transition Temperature (^{0}C)	106
Melting Temperature (^{0}C)	160
Density (g/cm^3)	1.2
Modulus of elasticity (GPa)	3.2

2. 13. Processing Polymer Blends:

Devolatilization and mixing are the most important operations in the manufacturing of polymer blends and composites. Mixing yields compositional uniformity, which is required to obtain good properties in the final product. Certain characteristics of the final product are to be achieved by process control parameters [59].

1. Devolatilization

In many polymer processing operations, it is necessary to remove the volatile components from polymer melts or solutions in order to improve product quality, reduce product cost, and eliminate health hazards. The volatile species can be residual monomers, reaction by-products, or solvents. Devolatilization involves the application of a reduced pressure or vacuum to extract volatile vapors and often the injection of a stripping agent to enhance the devolatilization performance. As a result, the devolatilization process often generates bubbles of the volatile component and the stripping agent. Water and nitrogen are two commonly used stripping agents [86].

2. Mixing

Mixing during polymer blending and reactive extrusion is critical because the final properties of a polymer product depend on the quality of mixing.

A physically homogeneous mixture can occur due to intermolecular association that provides a favorable energetic contribution to the mixing process. The properties of polymers also depend on the type of equipment used for blending and on mixing conditions. Mixing can be accompanied by the formation of a transition layer owing to strong shear deformations. Mixing of incompatible polymers is a simple and efficient method for designing of new materials with improved properties. The technological and service properties of polymer blends are determined by mutual distribution of the components, and the type, size distribution, and shape of structures formed by one polymer in the other. In this case, varying the intensity of mechanical action makes it possible to change

the degree of heterogeneity of polymer blends at various structural levels and obtain materials with properties other than those of the initial blend components [21, 87]. The polymer blending operation is likely to be straightforward and without incident, and the resulting single-phase miscible blend will have a transparent melt and a single composition-dependent glass transition temperature [88, 89]. Polymer blend processing is characterized by high temperature, heating rates and short reaction times. The blend constituents are capable of specific interactions with sufficient strength to promote miscibility, and individually possess comparable stabilities and melt viscosities at the processing conditions. Processing of polymer blends are widely used to convert polymeric materials into finished products.

- Melt blend of polymers use batch mixer or continuous extruder.
- End products use fabrication equipment such as injection molding machine, extruder, etc [59].

2. 14. Extrusion Process:

Extrusion is basically the transformation of the raw material into a specified shape product by forcing it through a die. Many different materials can be formed through an extrusion process, such as metals, ceramics, clays, foodstuffs, and plastics either in the molten or solid state. Extrusion is a high volume manufacturing process in which raw plastic material is melted and formed into continuous profile [90].

The polymer powder or pellet is melted or softened in a heated barrel and conveyed forward, homogenized, and pressurized by a rotating screw under high shear into a metal die having a shape that is similar to the shape of the desired article. The main operating variables are the frequency of screw rotation and the barrel temperature profile which is controlled by thermocouples placed inside the metal barrel wall. Sections of the barrel are at times cooled to remove excessive heat generated by viscous dissipation. The die continuously shapes the melt into the desired form and the product is formed which is infinite in one

direction. The molten profile produced is cooled either by air water quench or by running it over chill rolls [91].

2. 14. 1. Twin Screw Extruder:

A twin screw extruder is a machine with two screws which can be categorized by the intermeshing structure, the rotation direction into (co-rotating and counter- rotating), by the functions of screws designed to perform, or by screw speed. Two main areas of application for twin screw extruders are profile extrusion of thermally sensitive materials (e.g. PVC), and specifically polymer processing operations, such as compounding, chemical reactions [90].

The most important process parameters are melt temperature and pressure. Other parameters related to the extruder are[90]:

I. Screw speed,
II. Motor load,
III. Barrel temperatures,
IV. Die temperatures,
V. Cooling rate.

There are many parameters affecting the resulting structure, such as annealing temperature, polymer molecular weight, feed rate, screw configuration, and screw speed. All of them directly or indirectly affect the shearing intensity and the residence time during processing, and consequently the structure of the obtained product [90].

Twin screw extruders have the benefits of reduced energy usage, increased tolerance for challenging materials, and flexibility in creating many smaller amounts of various products [92].

2.15. Rheological Properties

Rheology is the science field that studies fluid conduct during deformation caused by flow. Polymers were discovered to be the most interesting and complicated of the variety of materials studied by rheologists. Shear thinning polymer melts are viscoelastic and their flow properties depend

on temperature. When determining the behavior of polymers during processing, viscosity is the most commonly used material parameter. Because most polymer processes are dominated by shear rate, the melt's viscosity is usually measured using shear deformation measuring equipment. However, there are polymer processes, such as blow molding, thermoforming, and fiber spinning, which are dominated by either elongational deformation or by a combination of shear and elongational deformation. Additionally, during deformation, some polymer melts show important elastic effects [93].

2.15.1 Melt Flow Rate (MFR):-

The melt flow Rate (MFR) is basically defined as the weight of the polymer (in grams) extruded in 10 min. through a capillary of specific diameter and length by pressure applied through dead weight under prescribed temperature conditions. Also it is a measure of the ease of flow of the thermoplastic polymer melt. The method is described in the standards of ASTM D1238 and ISO 1133 [94].

Melt flow rate is an indirect measure of molecular weight, viscosity, shear rate, high melt flow rate corresponding to low molecular weight. Melt flow rate is inversely proportional to viscosity of the melt at the conditions of the test, and the viscosity for any material depends on the applied force. Ratios between two melt flow rate values for one material at different gravimetric weights are often used as a measure of the broadness molecular weight distribution [95].

2.16 Mechanical Properties of Polymer

The mechanical properties are often the most important sources to make a decision about product specifications. The material selection for a variety of end-use applications is mostly dependent on these properties, such as tensile strength, modulus, elongation and impact strength [96]. Polymers are viscoelastic material which emphasizes their intermediate position between viscous liquid and elastic solid. An ideal linear elastic solid obeys Hooke's low:

stress is preoperational to strain. An ideal viscous obeys Newtonian's law: stress is preoperational to the rate of change strain. The mechanical properties of polymers are highly dependent on temperature and on the time-scale of any deformation. At low temperatures or high frequencies a polymer may be glass-like, with a value of Young's modulus in the region 10^9–10^{10}Pa, and it will break or yield at strains greater than a few per cent. At high temperatures or low frequencies it may be rubber-like, with a modulus in the region 10^5–10^6 Pa, and it may withstand large extensions of order 100% or more with no permanent deformation. At still higher temperatures the polymer may undergo permanent deformation under load and behave like a highly viscous liquid. In an intermediate temperature range, called the glass-transition range, the polymer is neither glassy nor rubber-like; it has an intermediate modulus and has viscoelastic properties [97]. The following structural factors, in addition to the chemical composition, affect all of the major mechanical properties of polymers:

l. Molecular weight.

2. Cross-linking and branching.

3. Copolymerization (random, block, and graft).

4. Molecular orientation.

5. Fillers.

In addition to the structural and molecular factors listed above, the following environmental or external variables are important in determining mechanical behavior:

1. Temperature.

2.Time, frequency, rate of stressing or straining.

3. Pressure.

4. Type of deformation (shear, tensile, biaxial) [98].

2.16.1 Tensile Properties:-

Tensile test is a measurement of the ability of a material to applied forces tending to pull it apart and observe the extent of material stretches before breaking. Different types of plastic materials are often compared based on tensile property data (i.e. strength, modulus, and elongation data) [96]. The tensile strength of a material is a measure of its performance limit. It is the breaking point of a brittle material or the yield point of a ductile material. The tensile modulus is an alternative way of characterizing behavior in tension. It is the ratio of stress to strain, and in a proportional material it is known as Young's modulus. Tensile modulus is a measure of elasticity [99].

Speed of test is defined as the relative rate of motion of the grips or test fixtures. It is specified for different types of specimens, varying typically from 1 to 500 mm/min. The specimens are dumbbell-shaped or straight sided under defined pretreatment conditions, such as temperature, humidity and deformation rate [96].

There are two essential properties determined each time. One is the engineering stress which is defined as:

$\sigma = F/A$ [100] (2. 1)

Where:-

σ: the stress and its unit (N/m^2).

F: the force applied on the sample to cause elongation along the axis of the sample and its unit is (N).

A: is a cross-sectional area of the sample and its unit (m^2).

The other key property is the engineering strain (also known as nominal tensile strain) defined as:

$\varepsilon = \Delta L / L$ [100] (2. 2)

The tensile strength can be calculated by dividing maximum load in Newton by the original minimum cross sectional area of the specimen in square millimeters, and the result can be explained in the term of mega Pascal (MPa).

Tensile Strength = Force (N)/Cross Section Area (mm^2) [100] (2. 3)

Tensile modulus (the modulus of elasticity) can be determined by extending the initial linear portion of the load-extension curve and dividing the difference in stress obtained from any segment of section on this straight line by the corresponding difference in strain, expressing the result in the unit of mega Pascal (MPa) [100].

2.16.2 Impact Strength

The impact properties of the polymeric materials depend mainly on the toughness of the material. Toughness can be described as the ability of the polymer to absorb applied energy. The molecular flexibility has a great significance in determining the relative brittleness of the material. Impact energy is a measure of toughness, and the impact resistance is the ability of a material to resist breaking (fracture) under a shock-loading [100].

Two basically different test methods, namely Izod and Charpy type, are used generally. In Izod type testing, the specimen is clamped vertically to a cantilever beam and broken by a single swing of the pendulum released from the fixed distance from the specimen clamp [100].

The impact strength is calculated by dividing the impact values obtained from the scale by the cross section area of the specimen. One point indicating the advantages of the Charpy test over an Izod test is that the specimen does not have to be clamped; therefore, it is free of variations in clamping pressures. Impact resistance can be obtained from the following relationship [101]:-

$I.S=U_C/A$ [101] (2. 4)

Where:-

I.S: impact resistance of the material (J/m^2).

U_C: impact energy (J).

A: cross-sectional area of the sample (m^2).

2.16.3 Hardness Property

Hardness can be defined as the resistance of the solid material to cut, scratching, wear, indentation, penetration and workability. In other words, it is the resistance of the material to scratching by tools and machine harder than it, which enable them to maintain its surface intact and holding together under the influence of external forces so that no permanent deformation occurs in the latter [102].

Hardness of the materials depends on the type of the linking force between molecules or atoms, the type of the material surface to which hardness should be measured, temperature and other circumstances affecting it. The hardness of materials were measured previously by their ability to cut other materials, the one which cuts the other is the hardest and the most important methods used in the measurement of hardness are:

1. Brinell hardness
2. Vickers hardness
3. Rockwell hardness
4. Shore Hardness (A, D) [103].

2. 16. Literatures Review:

In 2008, Alan W. Biehn, studied the Compact Discard: Finding Environmentally Responsible Ways to Manage Discarded Household CDs and DVDs. More than 200 billion optical discs have been manufactured and distributed worldwide. As electronicstorage media evolve, these discs are becoming obsolete. Most unwanted household discs end up in landfills or incinerators. Recycling options for waste discs exist, but public awareness and participation are low.

This study examines the possibilities for responsible environmental management of the growing waste stream of optical discs from households around the world. It reviews options for reducing materials used in disc manufacture, models for collection and processing of waste discs, and the

differing policies and practices of various countries with respect to e-waste in general and optical discs in particular.

The study concludes that environmentally responsible management of optical discs is lacking in all nations, and that optimal implementation of best practices will require the cooperation of governments, corporations, and consumers. It recommends implementation of curbside pickup and corporate mail-in programs for unwanted discs. It also concludes that effective policy-making and process design will require more and better quantitative data about the efficacy of various regulatory models and responsibility structures, and about the environmental impacts of various waste processing and recycling methods [9].

In 2009, Dr-Vishal-Mathur, et. al, studied the Morphology, miscibility and mechanical Properties of PMMA/ PC blends. This study deals with some results on morphology, miscibility and mechanical properties for polymethyl methacrylate/polycarbonate (PMMA/ PC) polymer blends prepared by solution casting method at different concentration between 0 and 100 wt%. Dynamic storage modulus and tan δ were measured in a temperature range from 30 to 180^0C using dynamical mechanical analyzer (DMA). The value of the storage modulus was found to increase with the addition of the PC in the matrix. Transition temperature of pure PMMA and pure PC is found to be 83.8 and 150^0C, respectively. The result shows that the two polymers are miscible for whole concentration of PC in PMMA. The distribution of the phases in the blends was studied through scanning electron microscopy (SEM), also the mechanical properties like elongation at break and fracture energy of the PMMA/PC blends increase with the increase in concentration of PC in PMMA [104].

In 2013, Ferenc Ronkay, studied the Effect of recycling on the rheological, mechanical and optical properties of polycarbonate. The research was aimed at analyzing the polycarbonate scrap arising during production and

its possible secondary utilization. The analysis of morphological, rheological and thermal data revealed significant differences between the original pellets and the reground material obtained from injection molded parts. Test specimens were injection molded from various mixtures of the virgin and the reground material, and their mechanical and physical properties were analyzed. Based on the results the reground material may be used in less than 20% proportion, as the mechanical properties of the products do not deviate significantly from those of the products made from virgin polycarbonate [105].

In 2013, Ashok kumar Gupta and Gautam Kumar Sah, Studied the miscibility studies of PC/PMMA blends in tetrahydrofuran by viscometry, FTIR and SEM analysis. The coefficients of viscosity for polycarbonate/poly-methyl methacrylate (PC/PMMA) blends in tetrahydrofuran at 303.15 K and 313.15 K have been measured. The measured parameters were used to estimate other related physical quantities, like Huggins constants and the interaction parameters μ and α, proposed by Chee and Sun et al. to identify the molecular interaction arising in solutions of the mentioned polymer blends. The peculiar deviation confirmed the structural changes in the solutions of the blends. FTIR and SEM studies confirm the formation of physical blends [106].

In 2016, Saber Ibrahim, et. al, Studied the environmental recycling of compact disc using industrial wastewater. An environmental method was performed to recycle compact discs using tannery industrial wastewater effluent. This study includes thermogravimetric analysis (TGA), mechanical properties and wastewater characterization before and after treatment. The final recycled compact disc was completely free of ink, and its mechanical properties were slightly enhanced after ink removal. The crystallization behavior of the compact disc remains the same after the de inking process. After the de-inking procedure, the study was continued to the treatment of tannery effluent by conventional coagulation-flocculation followed by Fenton's treatment process. The coagulation-precipitation process removed 42%. 77%, 86%, 99%, 84%

85% and 98% of BOD, COD, TSS, HS, TKN, P and (O&G). respectively. Unfortunately, due to its solubility in water, the coagulation process did not affect the concentration of phenols. Therefore, Fenton's oxidation process was able to remove 100% of phenols, hydrogen sulfide and phosphorus. The removal of BOD, COD, TSS, TKN, and (O&G) were 92%, 91%,84%, 80% and 90%, respectively [107].

In 2018, Prashant Kumar, et. al, studied the recyling of waste plastic using extrusion process. The main aim of this work is to reduce the plastic waste that is rising in the present world and to achieve this; a system is designed and fabricated incorporating a plastic extruder which plays a prominent part in recycling waste plastic into useful products. This study uses waste plastics and converts them into useful product with the help of an extruder, thereby reducing the plastic waste which is a key factor for environmental pollution. Presently waste plastics are effectively converted into useful materials like coatings of wire pipe, bricks, interlocks, roof tiles, railway sleepers, paving slabs, retaining blocks etc., using either single origin plastic waste material or a mixture of different plastic wastes along with waste rubber powder as filler.

The waste plastics are used to convert it into pellets or powder and this act as raw material. The conversion takes place by forming a homogeneous molten mass in the extruder and forcing it under pressure through an extrusion die orifice that defines the shape of the products cross section. The formed material, or extrudate, is cooled and drawn away from the die exit at a controlled rate. The extrudate can then be wound on a spool, cut to a specified length, or directed into another in-line process [108].

In 2019, Tobias Bubmann, et. al, studied the Transparent PC/PMMA Blends Via Reactive Compatibilization in a Twin-Screw Extruder. As a result of the decrease in Mw of the PC, the mechanical properties (e.g., tensile strain at break and impact strength) of the obtained blends were significantly deteriorated rather than improved as targeted by the polymer compatibilization;

therefore, the produced transparent PC/ PMMA blends are considered not yet technically suitable for any industrial applications. Different manufacturing process strategies that do not inherently result in PC degradation as a side effect of PC-graft (g) -PMMA-copolymer formation have to be developed to potentially achieve transparent PC/ PMMA blends with a useful balance of properties. Based on the experimental observations of this study, a new mechanism of the transesterification reaction occurring during reactive compounding of PC and PMMA in the presence of the effective catalysts is proposed [109].

In 2020, Pedreño-Rojas, et. al, studied the Reuse of CD and DVD Wastes as Reinforcement in Gypsum Plaster Plates. In trying to create a recovery solution for those pieces, research in which polycarbonate (PC) waste from recycled discs have been used to develop new gypsum coating materials and products has been conducted. In a previous study, the physical and mechanical properties of new gypsum plasters, with PC waste as aggregate, were studied. Following that study, this article aims at creating new gypsum plaster false ceiling plates, using CD and DVD residues in different scenarios: as crushed aggregate in the gypsum matrix, as full reinforcement pieces of the plates and as a combination of both. The mechanical behaviour and the thermal conductivity of the new pieces have been analysed in this paper. The results showed an important improvement in the mechanical and thermal properties of the plates when the PC waste was used in many scenarios [14].

In 2020, Van Thanh Hoang, et. al, studied the Mechanical Properties of PMMA/PC Blend by Injection Molding Process. Polycarbonate (PC) has the high impact strength, whereas Polymethyl methacrylate (PMMA) possesses the high tensile strength. Both of them have been widely used for optical elements in illumination. This paper aims to investigate mechanical properties including tensile and impact strengths of PMMA/PC blend with 50 percent of PC concentration by injection molding process. Tensile and impact specimens were

designed following ASTM, type V and were fabricated by injection molding process. Taguchi technique was employed to figure out the optimal process conditions for maximum tensile and impact strengths. The processing conditions such as melt temperature, mold temperature, packing pressure and cooling time were applied and each factor has three levels. As a results, melt temperature has been found to be the most significant parameter for both tensile and impact strengths and cooling time is the least significant parameter for the mechanical properties [110].

In 2020, Sufiyan Ahmed, et. al, studied the Extrusion Process for Recycling of Plastics. Applications with existing machinery to boost the percentage recycling of plastics with an introduction to extrusion process integrated with controlling system, use of extrusion system to recycle different types of plastics at different temperature and need for recycling and problems encountered while recycling have been discussed. Advancements in science and technology, effective plastic recycling and advanced ways of manufacturing pavement tiles for the need to fulfill the societal expectations and to provide them better waste management has let to these developments. With invent and help of these methods to recycle shows better performance output and increased durability of pavement tiles [111].

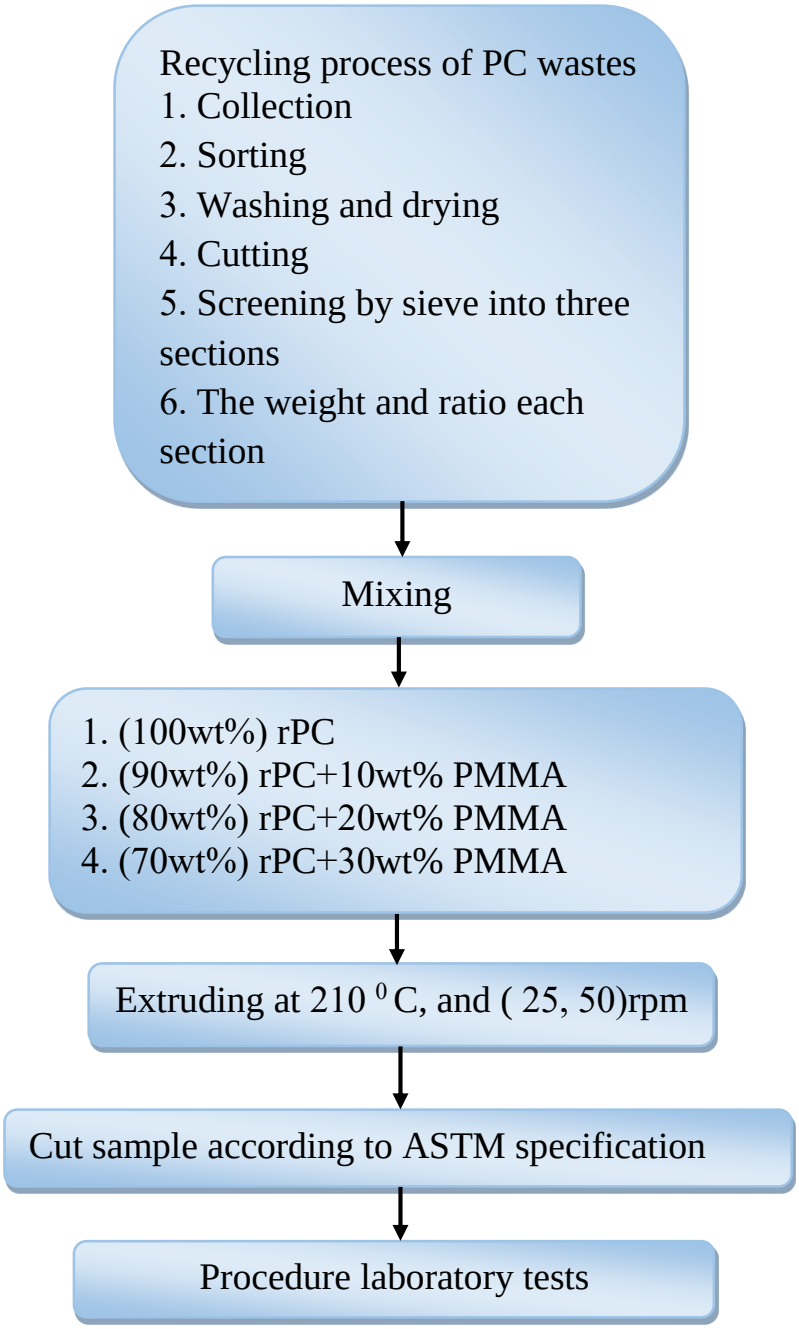
In 2021, Ali A. A. Al-Zubiedy and Adnan H. A, studied This work deals with the study of the effect of the irregular crumbling (Instability of cutting) for recycled polyethylene terephthalate (PET) bottles on the extrusion process using a twin-screw extruder and as a result its effect on the mechanical properties of the product and the amount of electrical energy consumption. The extrusion process was performed for cutting sizes of PET bottles (4.75, 6.75, 7.15, and 10 mm) in addition to raw material to compare, at temperature ranges between (200–205 °C) at speed of 50 rpm. Results showed that the cutting size has a direct effect on the crystallinity which affects mechanical and thermal properties, such as elongation and tensile strength decreases with increase

cutting size but the elastic modulus increase with increase cutting size. The impact and hardness test proved that the impact strength and hardness decrease with increase cutting size, also, it was observed during the extrusion process when placing an equal amount of different sizes in the machine and ensure that the materials enter the machine at once for the sake of comparison, it is found that the lower volumes consumed less electrical energy, compared to the rest of the other different sizes, except the raw material from (PET) [112].

3. Introduction:

This chapter contains the methods and devices used to prepare and characterize polycarbonate blend with different proportions of pure PMMA. Figure. (3. 1) shows the practical steps used in this research to gain a complete idea about the production of samples and tests.

3. 1. Procedure of the work:



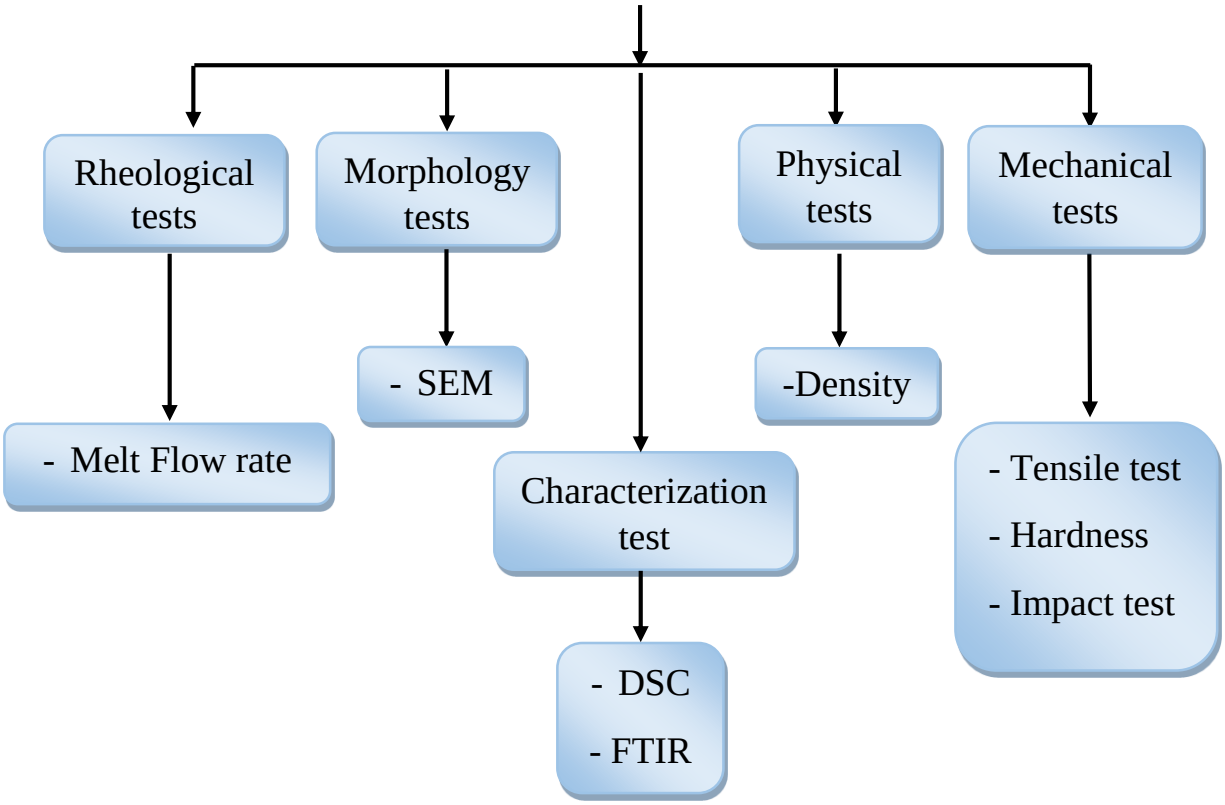


Figure. (3. 1): Flow chart of experimental part steps.

3. 2. The Used Materials:

3. 2. 1. Recycled Polycarbonate (rPC):

Recycled polycarbonate was provided from Compact Disc (CDs) waste, which were collected from various places (government departments, universities, offices) as seen in Figure. (3. 2), and the properties of this polymer are obtained from the tests that shown in Table. (3. 1).

Figure. (3. 2): Compact disc Waste.

Table. (3. 1): Properties of the used recycled rPC.

Properties	Unite	Value
Density	g/ cm^3	1.15
Melting point ™	^0C	239
Glass Temperature (Tg)	^0C	143.5
MFR	g/10min	2.94

3. ٢. 2. Polymathy Methacrylate (PMMA): Pure Polymathy methacrylaty (PMMA), as shown in the Figure. (3. 3), and the properties of this polymer are obtained from the tests that shown in Table. (3. 2).

Figure. (3. 3): Pure PMMA.

Table. (3. 2): Properties of the Used PMMA.

Properties	Unite	Value
Density	g/ cm^3	1.18
Melting point	^0C	130-140
Glass Temperature (Tg)	^0C	100
MFR	g/10min	4.34

3. 3. The Sample Preparation

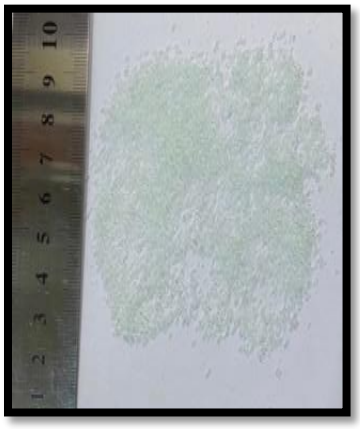
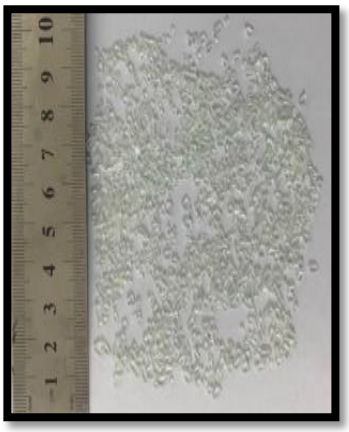
The 100 compact disc (CDs) from polycarbonate (rPC) was collected and then cleaned in the laboratory with sodium hydroxide (NaOH), Acetone solvent and warm water and dried through direct exposure to sunlight ($\approx 50^0$C) as shown in Figure. (3. 4). Then, they are cut by machine is used in the Department of Polymer and Petrochemical Industries/ College of Materials Engineering/ University of Babylon. Then a coffee grinder is used to cut compact disc into a smaller size and ground into a powder, after the cutting stage, the product is sorted to different pieces size by sieving, through this process, three types of (rPC) size were obtained as shown in Table.(3. 3).

Before

After

Figure. (3. 4): Shows the disk before and After clean (CDs) by sodium hydroxide (NaOH) and acetone and warm water and dry.

Table. (3. 3): The Particle Sizes (cutting sizes) of rPc (CDs).

CDs (rPC) materials		
Type of crumbling for polymer materials		
Sieve dimensions for small pieces(≈1.18mm)	Sieve dimensions for medium pieces (≈2.36mm)	Sieve dimensions for big pieces(≈4.75mm)
		

The first type is small pieces with a length (≈1.18mm), the second type is medium pieces with a length of (≈2.36mm), and the third type is big pieces with a length of (≈4.75mm).The polymer blends are prepared in the following procedures: rPC with 100, 90, 80 and 70wt% and PMMA with 10, 20 and 30wt%. These polymers were mixed at room temperature according to the ratios displayed in Table (3. 4) to produce sheets for testing. At the same time, the mixed materials were placed in a co-rotating twin-screw extruder model (SIJ-30A) as shown in Figure (3. 5). The diameter of the screw is 30 mm, and the screw speed are (25 and 50 rpm) at a constant temperature 210^0C the resulting sheets were ready to be used in mechanical

tests as shown in Figure. (3. 6). Every 50 old plastic pieces (CDs) weight (750 g).

Table. (3. 4): Blends Ratios that were Used in this Work.

Sample No.	rPC (wt%)	PMMA (wt%)
1	100	0
2	90	10
3	80	20
4	70	30

Figure (3. 5): Co-rotating Twin Screw Extruder Machine.

(a)

(b)

Figure. (3. 6): The Sheets Manufactured from the rPC/ PMMA Blend by Twin-Screw Extruder: (a) The Sheets with Speed (25 rpm), (b) Sheets with Speed (50 rpm).

3. 4. Tests:

3. 4. 1. Characterization test:

3. 4. 1. 1. Infrared Fourier Transform Spectrometer (FTIR) Analysis:

To characterize very complex mixtures, Fourier transform infrared spectra via FTIR analysis (IR Affinity-1) instrument made in Kyoto, Japan has been used, which is existing in the lab of the College of Materials Engineering /Babylon University, illustrated in Figure (3. 7). Sample measurement can be done by calibrating the device utilizing KBr, then preparing the tested sample powder and mixing it with 99% KBr in ratio. A semitransparent tablet-shaped material that is radioactive penetration-prone was created after a thorough mixing process.

Figure. (3. 7): Shows the FTIR Analysis Device.

3. 4. 1. 2. Differential Scanning Calorimeter (DSC):

Thermal transfers between extruded sheets resulting from PC compact discs that have been cut into different sizes for recycling are measured using differential scanning calorimeter (DSC). The test was performed using the device (SH1MADZ-4 DSC-60, Japan) as shown in Figure. (3. 8), according to the ASTM (D3418-03). A powder weighing 0.004 g was prepared from the samples to be tested, then it was pressed into the mold, after that it was placed in the device to perform the test. The samples were examined at the presence of nitrogen gas and the heating rate for each sample is 10 ^{0}C/ min. The heating temperature used in the test is 360 ^{0}C.

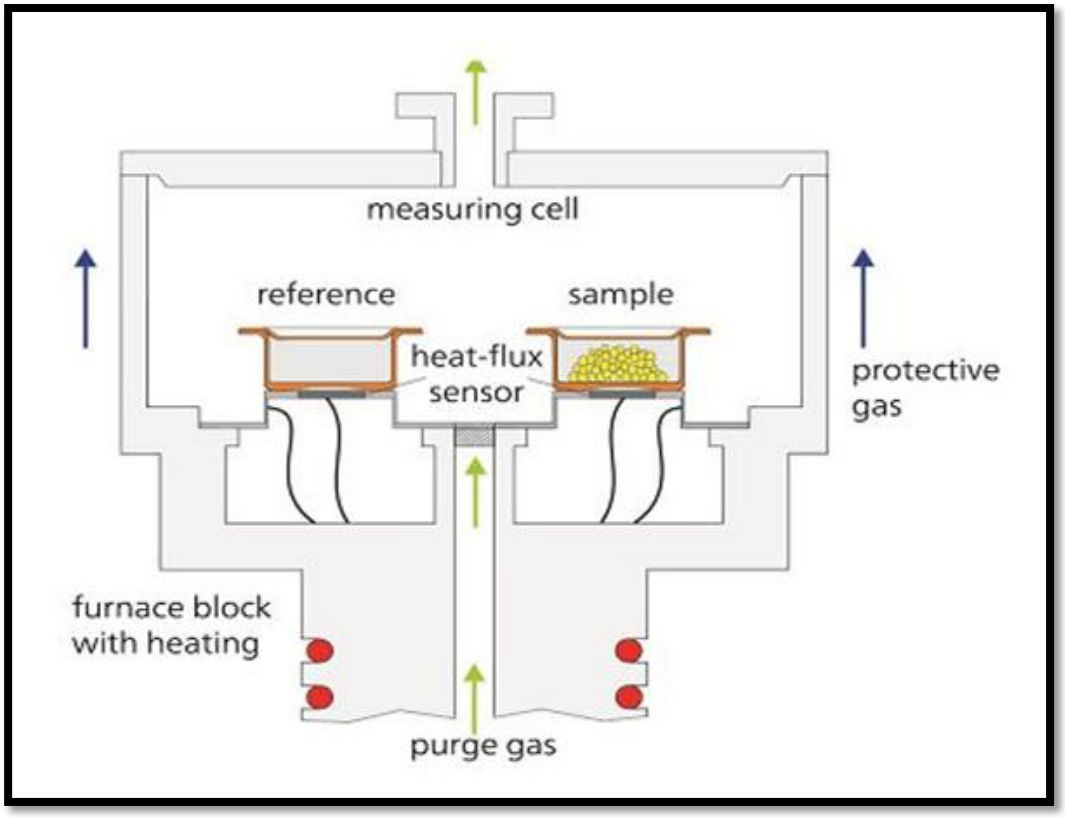


Figure. (3. 8): The Differential Scanning Calorimeter (DSC) Device.

3. 4. 2. Physical Tests:

3. 4. 2. 1 Density Test

According to the ASTM D-792 [113], density is measured at room temperature via a digital accuracy of ± 0.0001 g/cm^3 using Matsu Haku High Precision DENSITY TESTER GP-12OS as shown in the Figure. (3. 9). This method can be used with a sheet, rod, tube, molded articles and powders. The specimen was weighed in both the air and distilled water at 23°C using a sinker and wire to hold the specimen completely submerged as required.

Figure. (3. 9): Density Measurement Device.

3. 4.3. Morphology Test:

3. 4. 3. 1. Scanning Electron Microscopy (SEM):

In both organic and inorganic materials, scanning electron microscopes provide effective approaches for monitoring and characterization surfaces, providing significant data regarding sample morphology. In this work, the homogeneity of the was blend examined. Samples were examined with (VEGA III Series / TESCAN/SEM/Belgium/ University of Babylon/ the Laboratory of the College of Materials Engineering) as shown in Figure. (3. 10).

Figure. (3. 10): The Principle of SEM.

3. 4. 4. Mechanical Properties

3. 4. 4. 1. Tensile Test:

Instron 5556 Universal testing device type (WDW/5E) as shown in Figure. (3. 11) was used to test the tension properties according to ASTM D638-IV [114]. Range load (1-5) KN with velocity range (0.1-50) mm / min is implemented by a tensile instrument. The load was introduced after the sample was fixed by shifting the upper grip kept up at a velocity of (5 mm / min) whereas the reduced grip remained stationary until failure occurred. A graph paper acquired the relationship between stress and strain from the

device. The elastic modulus was also calculated depending on the data from the tensile test.

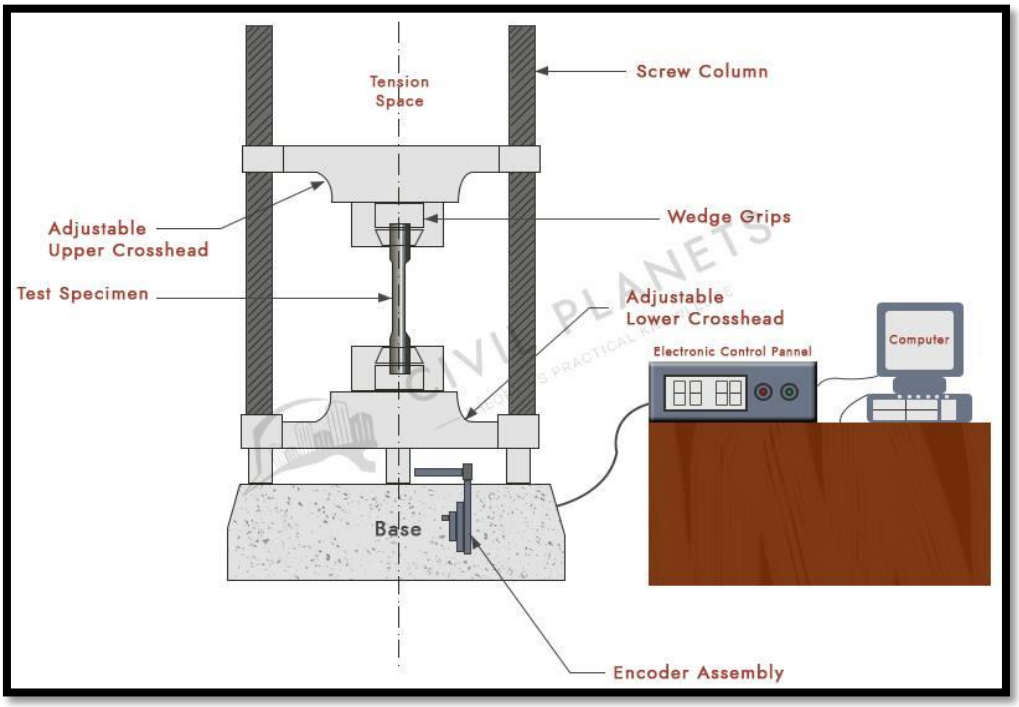


Figure. (3. 11): The Tensile Test Device.

Figure. (3. 12): The Jaws of the Tensile Tester.

3. 4.4. 2 Impact Strength:

CEAST Resil impact German, gant (HAMBURG) company, Model WP 400 charpy type instrument according to ASTM D-256, at ambient temperature was used to analyze the effect of (PMMA) content on the impact strength of recycled polymer (rPC). The testing method of this instrument includes lifting of the pendulum to its maximum height and fixing it firmly. The specimen is fixed in its pertaining place, and then the energy gauge is initialized (on zero position) after that, the pendulum is freed where its potential energy would be change to kinetic energy, five sample are tested and then take the average of these values. Impact strength (I.S.) is calculated by applying the relationship as shown in eq. (2. 4).

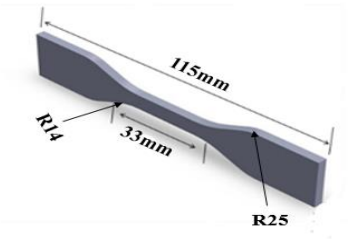
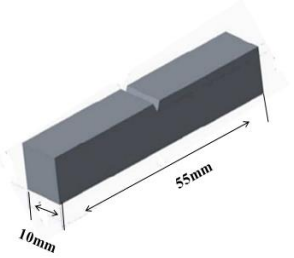
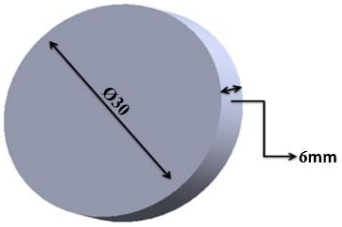
Figure. (3. 13): The impact test device using a Charpy method.

3. 4. 4. 3. Hardness Test:

Hardness test was performed on the sample using ASTM D-2240 standard at room temperature in order to analyze the effect of (PMMA) content on the hardness of recycled polymer (rPC). Shore instrument is containing needle placed in a position perpendicular to sample and it take waiting (0.5 min) to read the value and to have some accuracy an average of three reading have to be taken in different locations for each sample. The standard samples dimensions are shown in Table (3. 5).

Figure. (3. 14): Shore D Hardness device.

Table. (3. 5): The Standard samples dimension.

NO.	Property	Sample	ASTM
1	Tensile test		D 638IV
2	Impact		D 256-87
3	Hardness		D 2240

3.4.5. Rheological Properties

3.4.5.1. Melt Flow Rate (MFR) Test

Melt index device (SHI JIA ZHUANG ZHONG SHI TESTING MACHINE CO., LTD), which is available in Laboratory of College of Materials Engineering/University of Babylon as shown in Figure (3. 15). International Standard (ISO 1133:2005) is used to measure the melt flow rate (MFR) of polymer melt through capillary die with diameter of 2.095

mm and length 8 mm. Therefore, according of (ASTM 1238) the polymer blends testing at 255 °C and under load of 2.16 Kg .

$$\text{Melt flow rate (MFR)} = t_{ref} * w / t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where:

t ref: 10min/ 600sec.

W: average weight of cutting time of the sample.

T: time.

To calculate the shear rate on the aperture walls at which the polymer flows at a constant temperature and constant load, the following equation is used:

$$\gamma = (1840/\rho) * MFR \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

Where:

γ: The shear rate at the wall (s^{-1}).

ρ: density of polymer g/cm^3.

MFR: melt flow rate g/10min.

Figure. (3. 15): Melt flow index device.

4. Introduction:

The results obtained from the experimental tests and their discussion are shown in this chapter. This chapter contains the description of the effect of (PMMA) percentage, volume change and the speed on the morphology, physical and mechanical properties of rPC/ PMMA blends.

4. 1. Characterization test

4. ١. ١. FTIR analysis

Figure. (4. 1), shows the FTIR spectrum of rPC showed absorption bands at 2970 cm^{-1} attributed to $–CH_3$ stretching vibration. Characteristic C=O stretching band was at 1774 cm^{-1}. The ring (C–C) vibrational mode appeared at 1504 cm−1. Peaks at 1080 and 1010 cm^{-1} were attributed to C–C–C (bending) O–C–O stretching vibrational modes. These results were comparable to those given by Ashok and Gautam [106]. In addition to comparing it with pure PC as in the Figure.(4. 2).

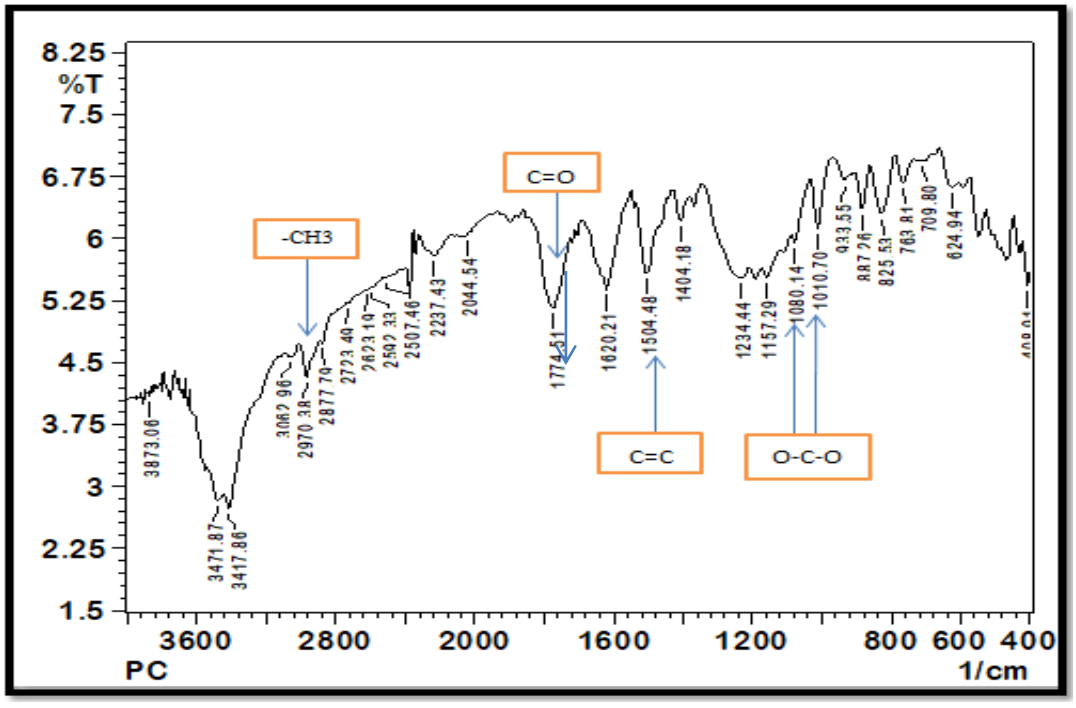


Figure. (4. 1): FTIR Spectrum of CDs (rPC).

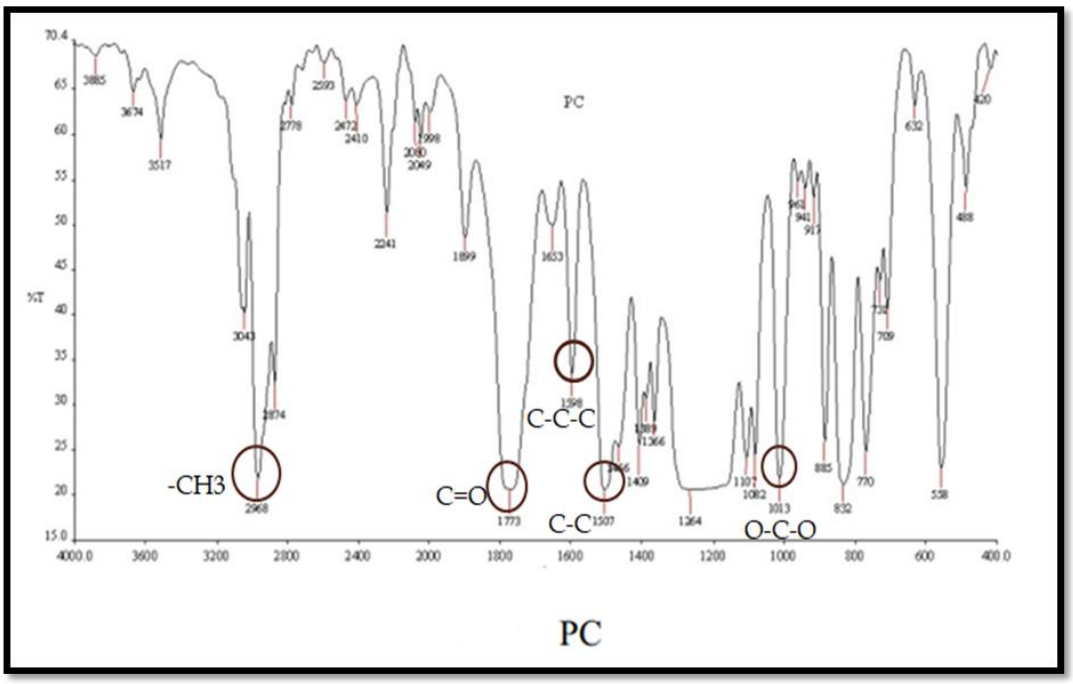


Figure. (4. 2): FTIR Spectrum of pure PC [106].

Figure. (4. 3), shows the FTIR spectrum of PMMA Peaks at 3440 and 1725 cm^{-1} corresponded to the stretching vibrations of CH_2 and C=O groups, respectively, while the peak at 2993 cm^{-1} belongs to the asymmetrical stretching of C-H bonds of the CH_3.

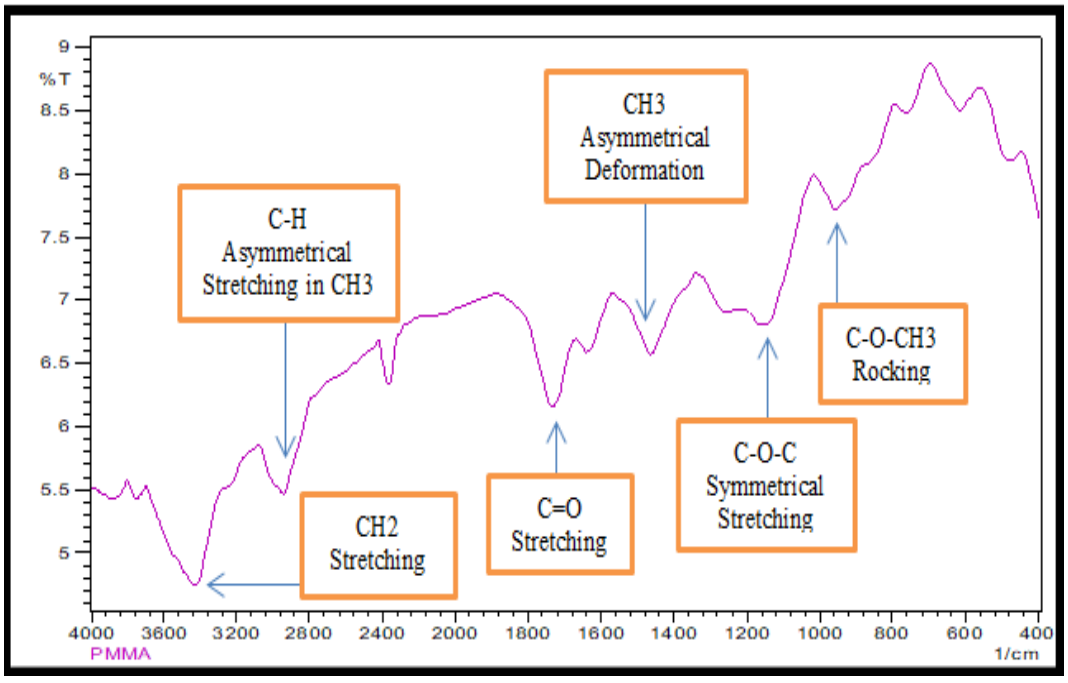


Figure. (4. 3): FTIR Spectrum of pure PMMA.

The asymmetric deformation vibration of methyl group is appeared around 1465 cm^{-1} [115], and the C-O-C symmetrical stretching appeared at 1160 cm^{-1}. Band at 960 cm^{-1} is due to the C-O-CH_3 rocking [116, 117, 118].

Figure (4. 4) shows no new band; which means that there is no chemical reaction between rPC and PMMA polymeric chains and there is only physical interaction among their chains.

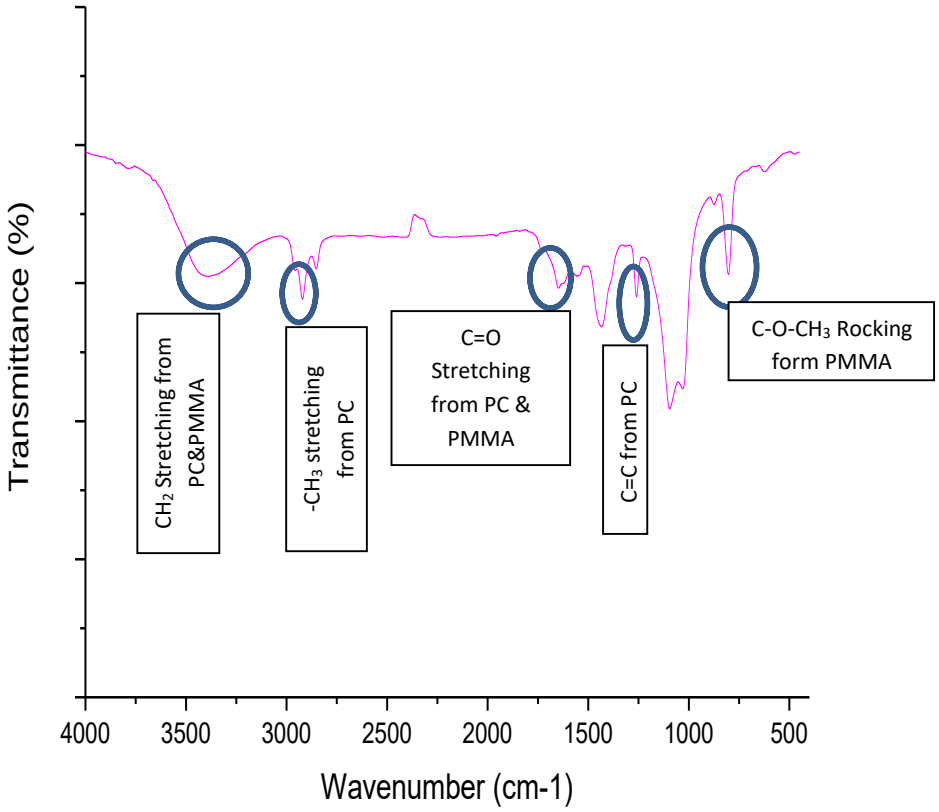


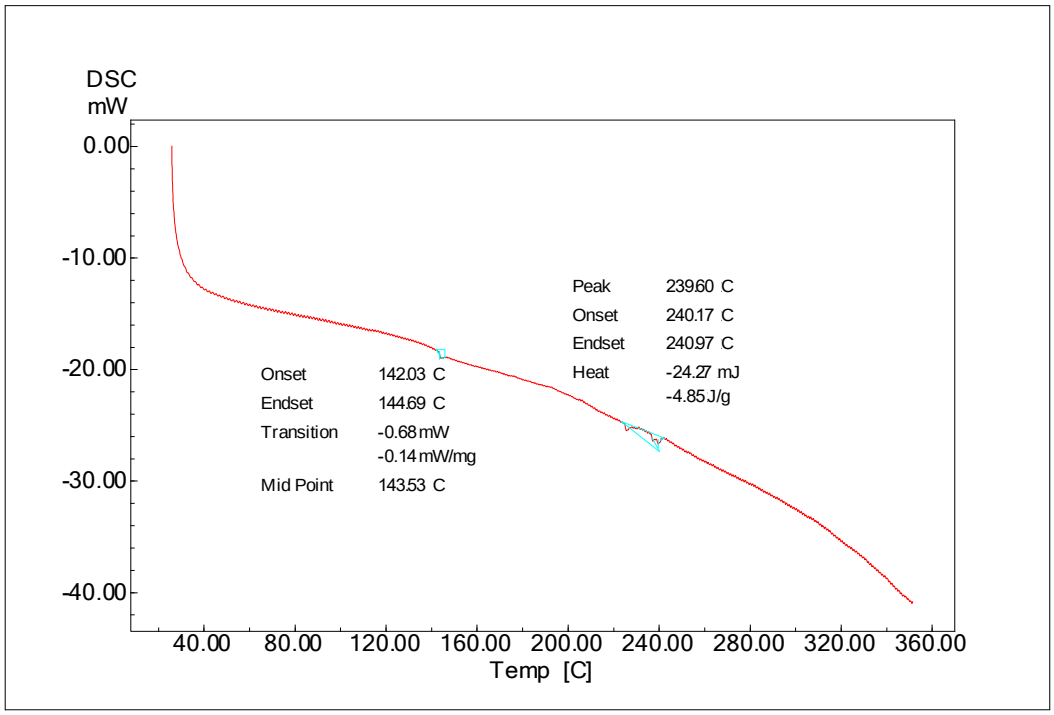
Figure. (4. 4): FTIR Spectrum of rPC/ PMMA Blend in the Speed 50rpm for Medium Size (2.36 mm).

Table.(4. 1): The FTIR analysis.

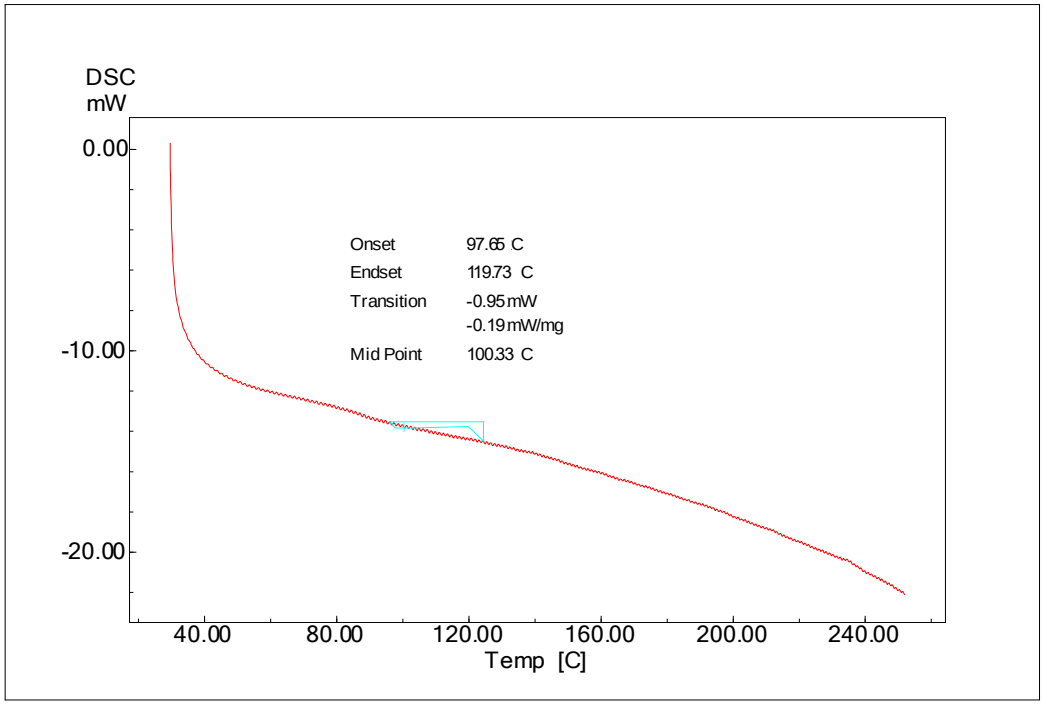
rPC		
Functional group	Wave number (cm^{-1})	Characteristics
$-CH_3$	2970	Stretching Vibration
C=O	1774	Stretching
C-C	1504	Stretching Vibration
C-C-C	1080	
O-C-O	1010	
PMMA		
Functional group	Wave number (cm^{-1})	Characteristics
CH_2	3440	Stretching Vibration
C=O	1725	Stretching
C-H	2993	Asymmetrical Stretching in CH_3
Methyl group	1465	CH_3 Asymmetrical Deformation
C-O-C	1160	symmetrical Stretching
$C-O-CH_3$	960	Rocking

4. 1. 2. DSC analysis

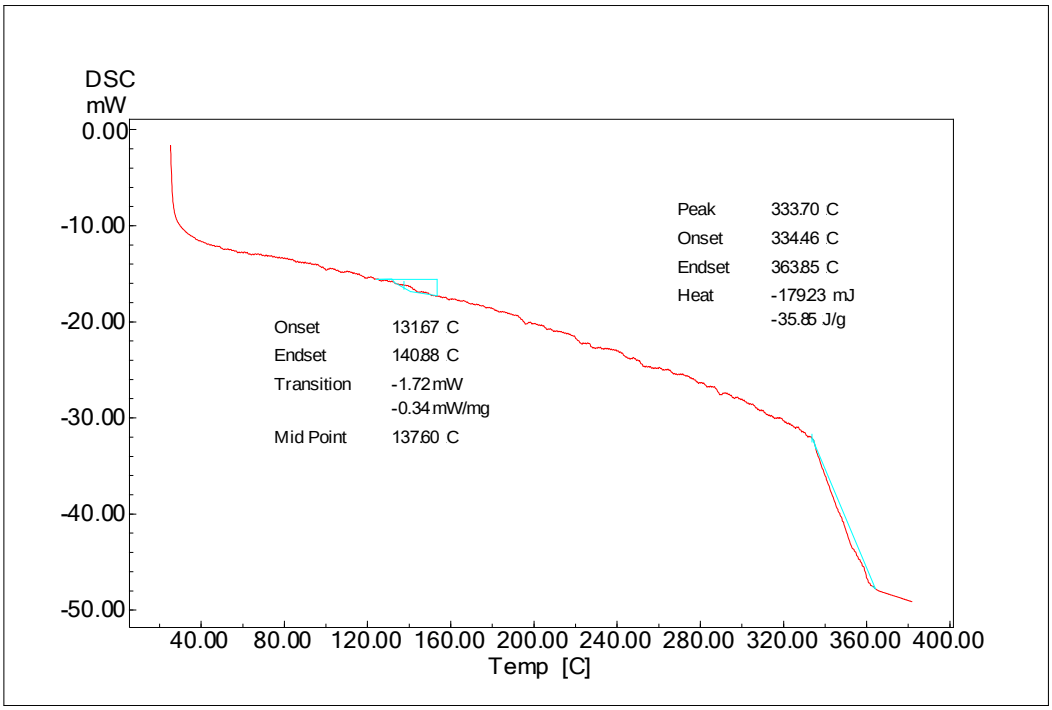
Figure (4. 5) shows the Tg of rPC, PMMA and rPC / PMMA (70/30) for (25 and 50) rpm in medium size. The results shows that the glass transition temperature (Tg) for rPC before extrusion emerges to be 143.53 ˚C and the melting point 239.60 ˚C as shown in the Figure. (4. 5- a), while the (Tg) for pure PMMA is 100 ˚C as shown in the Figure. (4. 5- b). When after extrusion process for rPC the (Tg) is decrease for both speeds (25 and 50) rpm as shown in the Figure. (4. 5- c and e). It is known that rPC and PMMA blend are partially miscible: two regions of slightly glass transition appeared, which means that they are a physical blend, as shown in the Figure. (4. 5- d and f).



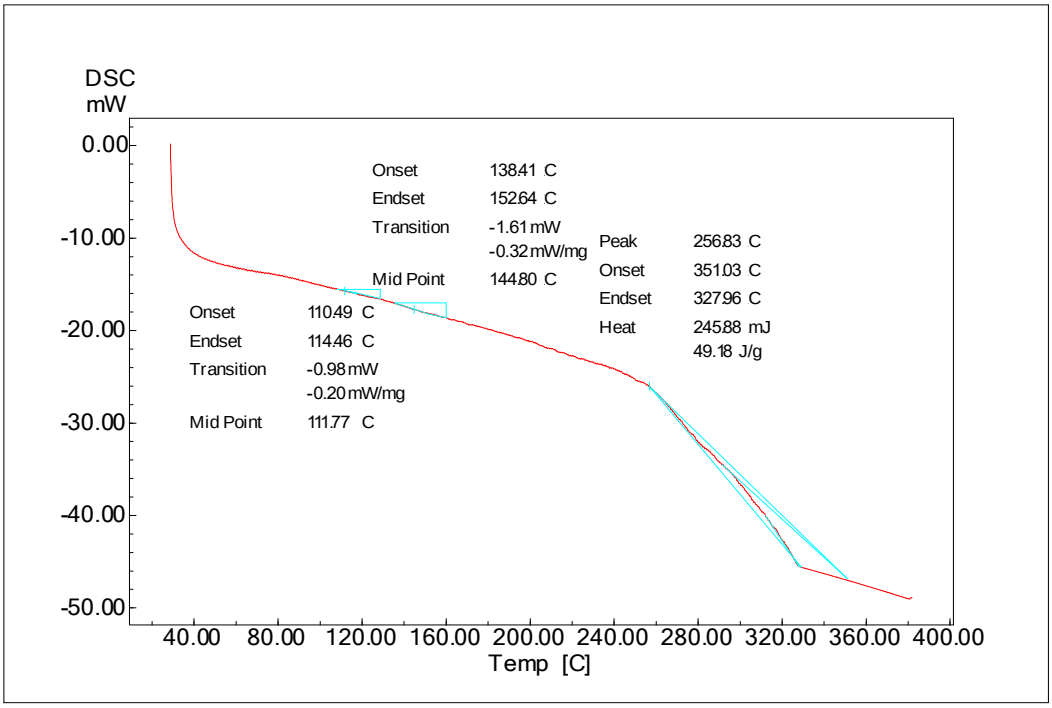
(a) CDs (rPC) before extrusion.



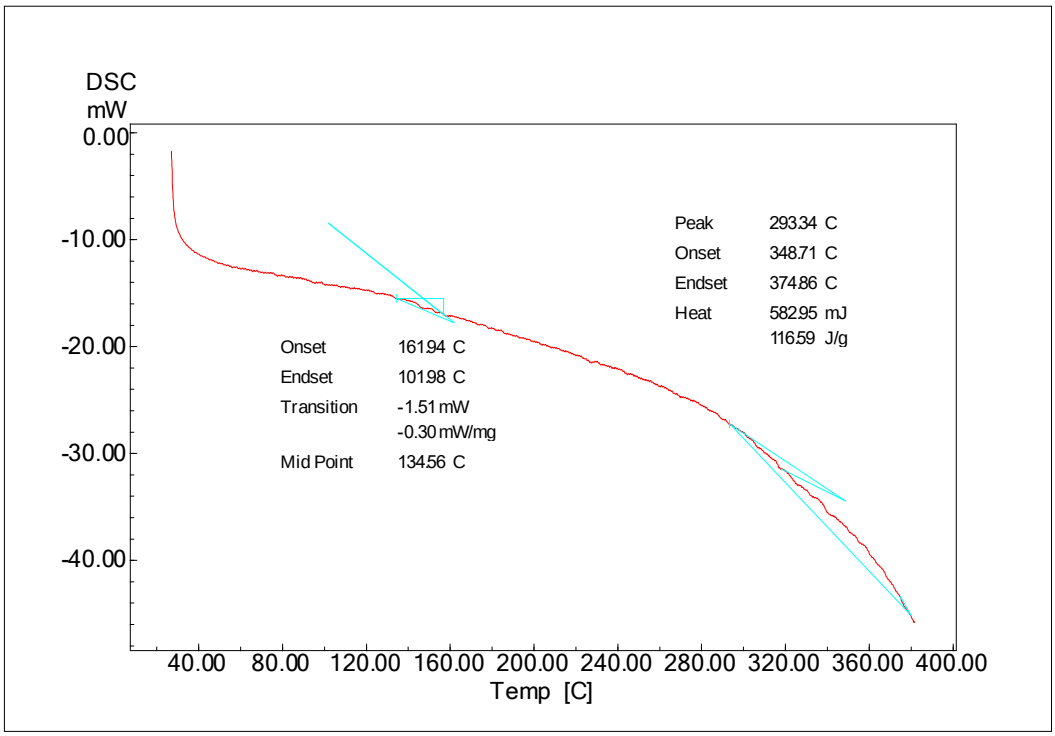
(b) Pure PMMA before extrusion.



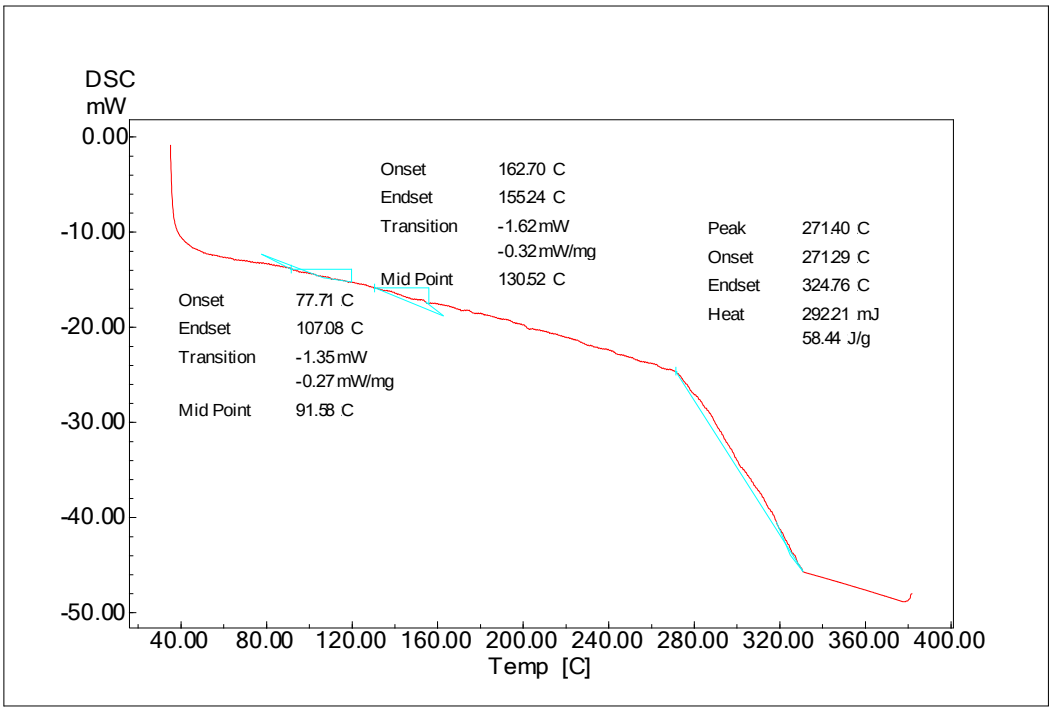
(c) rPC after extrusion in medium size and speed 25rpm.



(d)70rPC/ 30PMMA in medium size and speed 25rpm.



(e) rPC after extrusion in medium size and speed 50rpm.



(f) 70rPC/ 30PMMA in medium size and speed 50rpm.

Figure. (4. 5): The DSC Results Analysis.

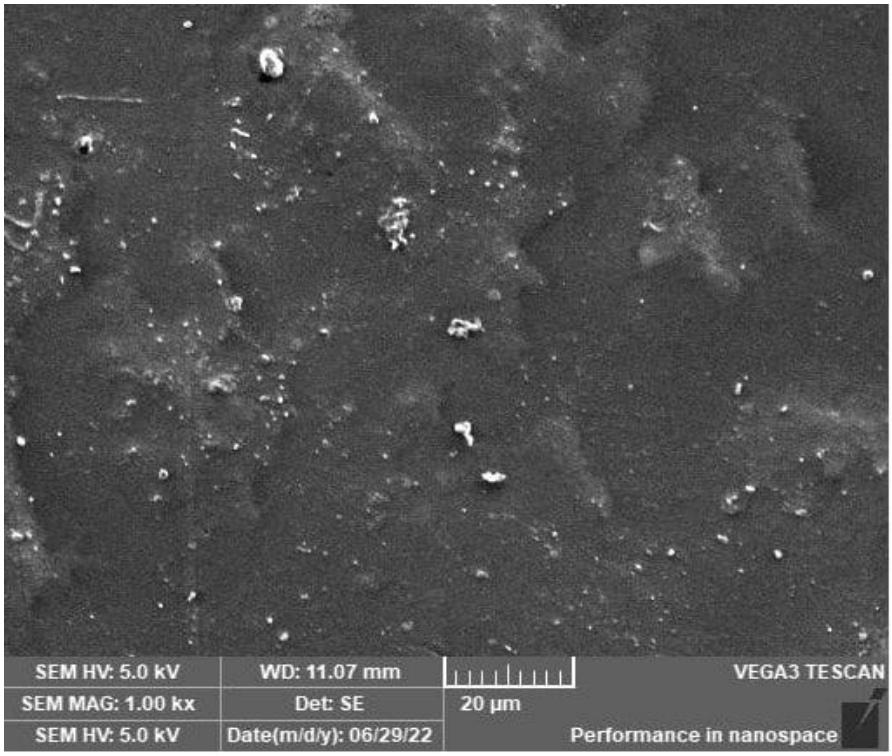
Table.(4. 2): The DSC analysis.

N. Sample	ΔHf (J/g)	Tm (^{0}C)	Tg_1(^{0}C)	Tg_2(^{0}C)	% crystallinity
PC(CDs)	-4.85	239.60	143.53	-	0.016
PMMA	-	-	100	-	
rPC at (25)rpm	-35.85	333.70	137.60	-	0.116
70rPC/30PMMA at (25)rpm	49.18	256.83	111.77	144.80	1.110
rPC at (50)rpm	116.59	293.34	134.56	-	0.38
70rPC/30PMMA at (50)rpm	58.44	271.40	91.58	130.52	1.93

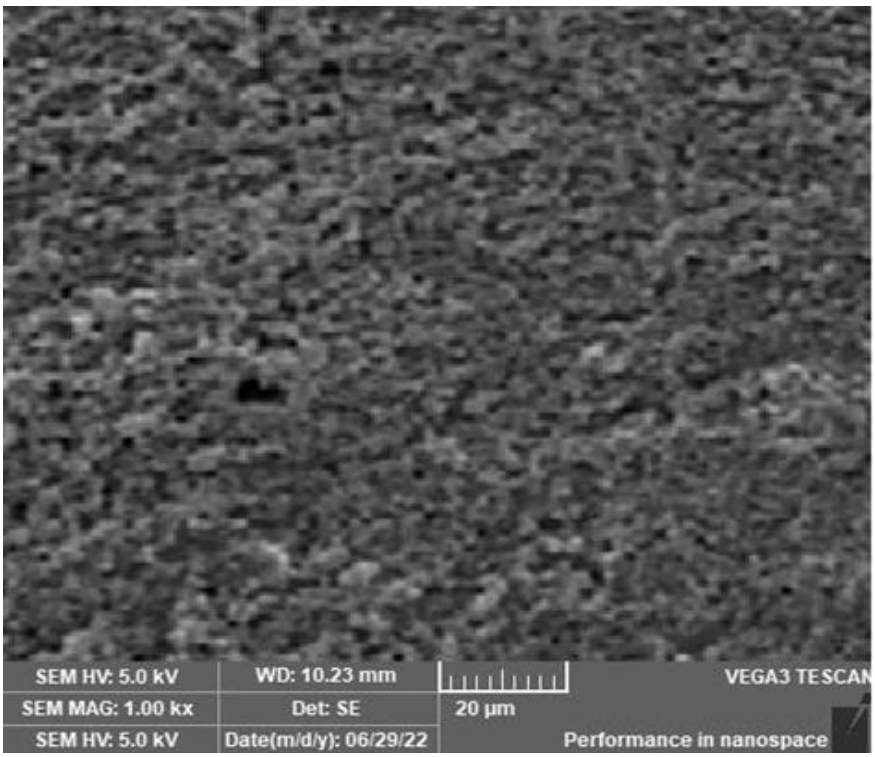
4. 2. Morphology Test:

4. 2. 1. SEM Analysis:

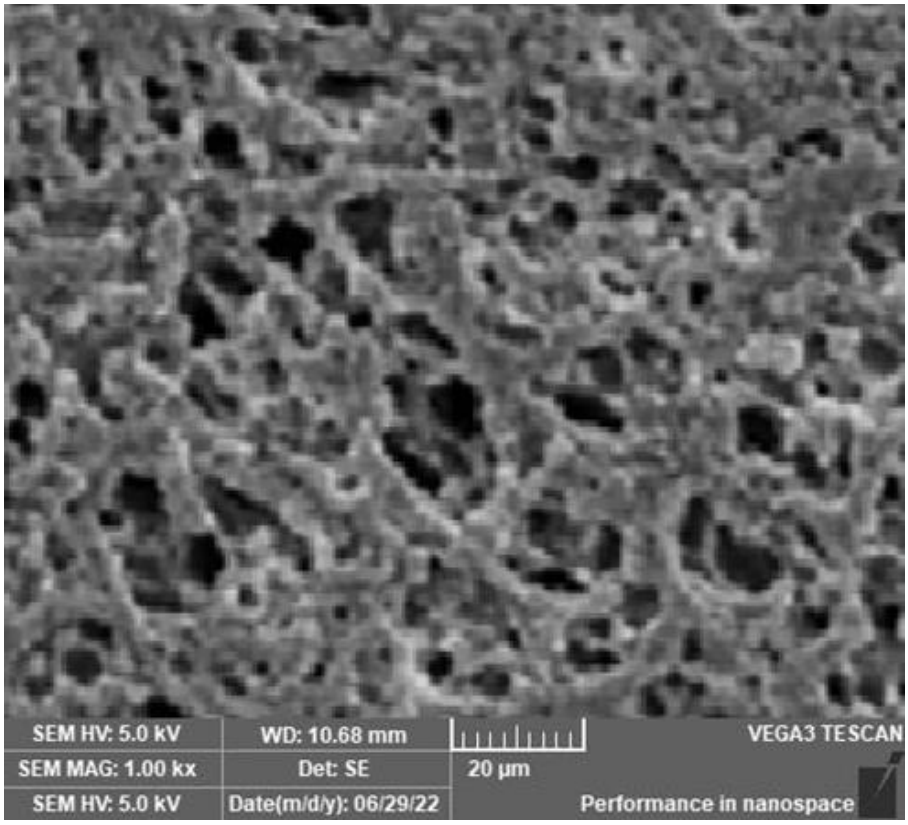
The scanning electron microscope (SEM) images the surface of a sample by scanning it with a high-energy beam of electrons in a raster scan pattern. These electrons interact with surface atoms of sample, producing signals, which reveal information about the surface topography of sample. Figure. (4. 6- a) show the SEM images of rPC. (4. 6- b and c) exhibit SEM images of blends rPC/ PMMA of 70/ 30 w/w % for speeds (50 and 25) rpm respectively. in the Figure. (4. 6- b) showed co-continues phase Figure morphology, but Figure (4. 6, - c) showed dis-continues phase morphology, as can be seen from the images of blends in the Figure c, that the blend at speed of 50rpm and a temperature of 210°C has a relatively smoother surface and less porosity and roughness surface than the surfaces of the blend at 25rpm. The result means that the rPC is compatible with PMMA in the morphological sense.



(a) rPC in medium size and speed 50rpm.



(b) 70rPC/ 30PMMA wt% in medium size and speed 50rpm.



(c) 70rPC/ 30PMMA wt% in medium size and speed 25rpm.

Figure. (4. 6): The SEM Micrographs.

4. 3. Rheological tests:

4. 3. 1. Melt Flow rate

Figure (4. ٧) shows the melt flow rate of the rPC/PMMA mixture with different concentrations of PMMA and a 2.16 kg loading at 255 °C. The MFR value increases gradually with increasing PMMA content and increasing speed at a cut size of 2.36 mm in 210, where MFR is inversely proportional to the viscosity of the polymer melt and directly proportional to the shear rate. This result agreement with Nizar and et. al [119].

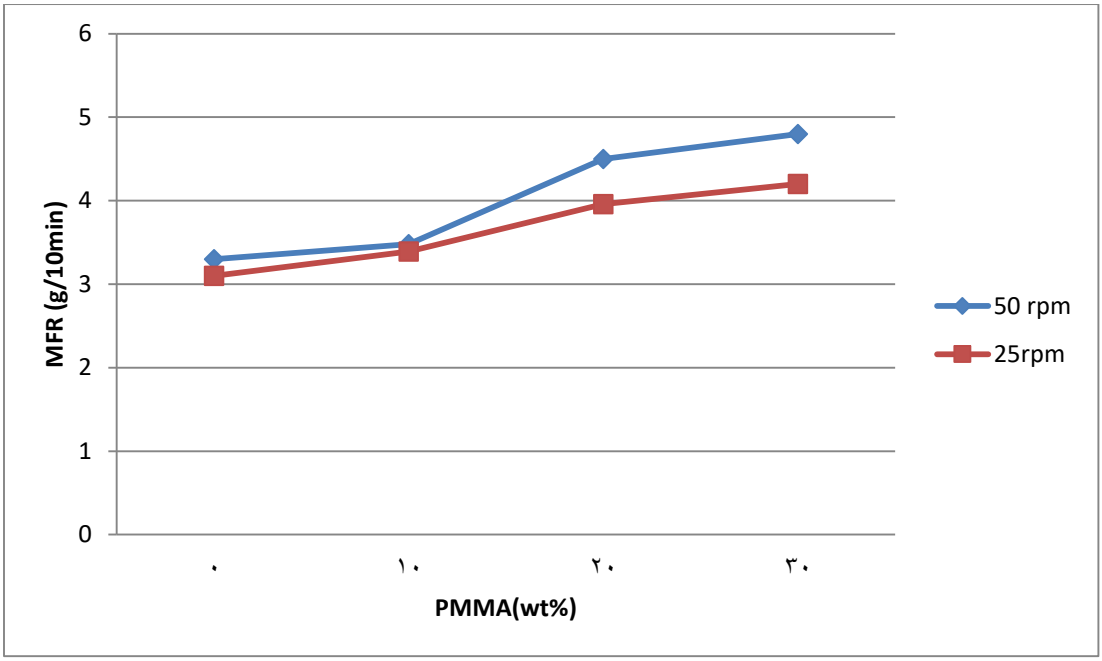


Figure. (4. 7): Melt flow rate of the rPC / PMMA blends as a function of the PMMA concentration at speed (25, 50)rpm in the medium size 2.36mm.

٤. 4. Physical Tests:

٤. 4. 1. Density Test

Figure. (4. 8) indicates an increase in the density of all mixtures by adding different proportions of PMMA because their density is greater than that of rPC. The density values shown in this Figure are reasonable based on the densities of materials in Tables (3. 1 and 3. 2), where the highest density is 1.1701 g/cm^3 when cut size is medium (2.36mm) and an addition ratio of 30% PMMA at 50 rpm . The crystallinity of polymeric materials is directly proportional to their density and inversely proportional to the branching of their chains. This means that an increase in the percentage of crystallization reduces the proportion of branching, as observed by SEM examination of Figure. (4. 6-b). This change in the composition of the mixtures directly affects the remaining mechanical, physical and thermal properties. Therefore, it is possible to predict what might happen with the two characteristics of tension and impact

resistance. When they were examined, the first increased and the second decreased. From the foregoing, density testing can be used to either limit the most acceptable options or obtain initial indications about products .

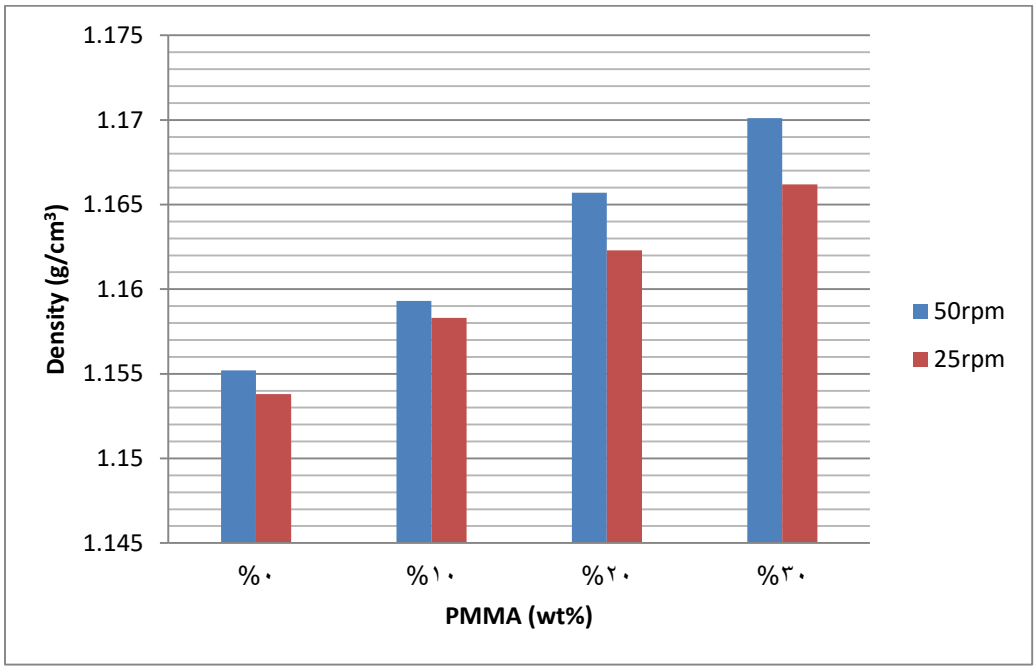


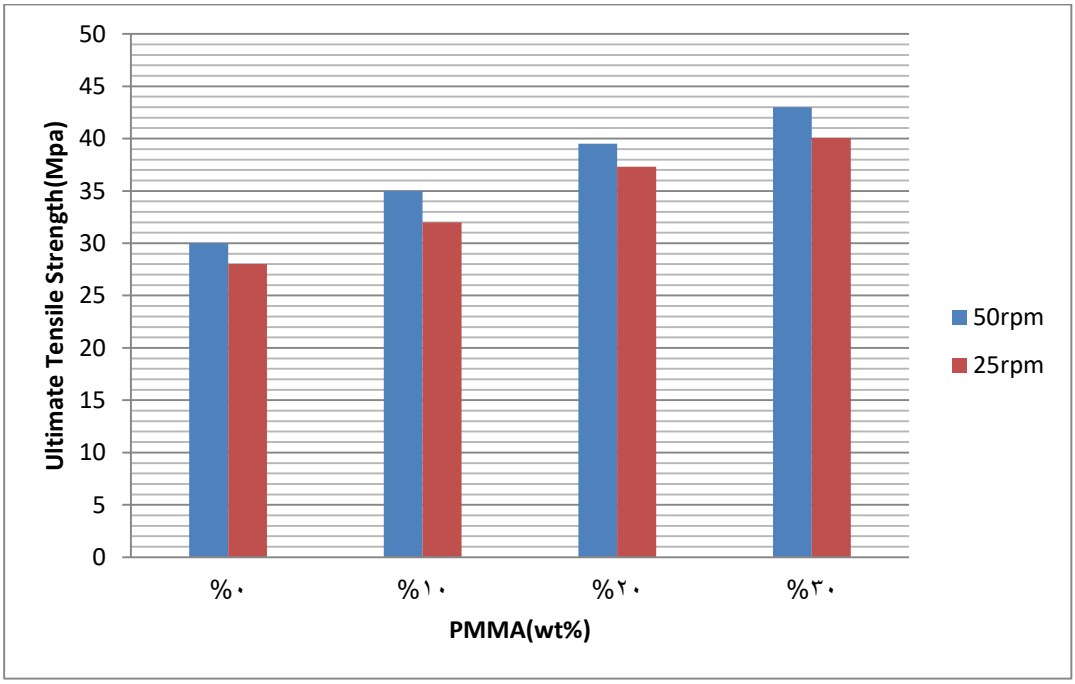
Figure. (4. 8): Density of the rPC / PMMA blends as a function of the PMMA concentration in medium size 2.36mm.

4. 5. Mechanical Properties:

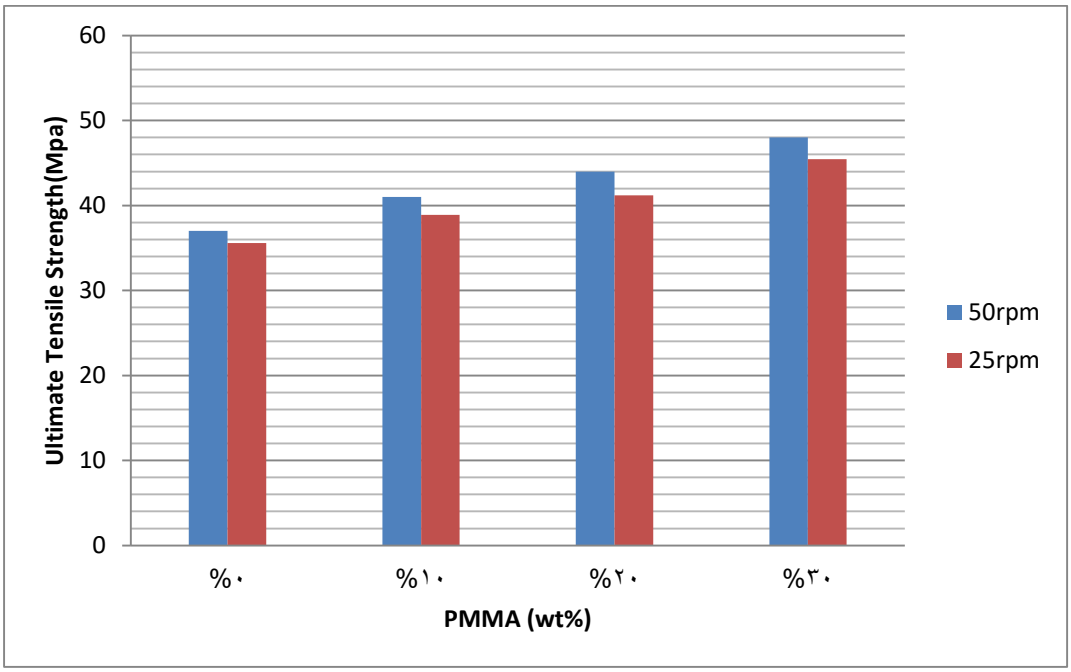
4. 5. 1. Ultimate Tensile Strength

Figure. (4. ٩) shows that the tensile strength increases in all combinations with an increase in PMMA to 30% by weight and velocity 50 and a decrease in cutting size. Its highest value is 48 MPa at cutting size 2.36mm. This increase is due to the increase in crystallinity, density, decrease in viscosity, and percentage of branched chains in the compounds. Therefore, these results are identical to the results of the density test, which are consistent with the previous analysis in Figure. (4. 8). The melting points of each polymer in Tables (3.1 and 3.2), in addition

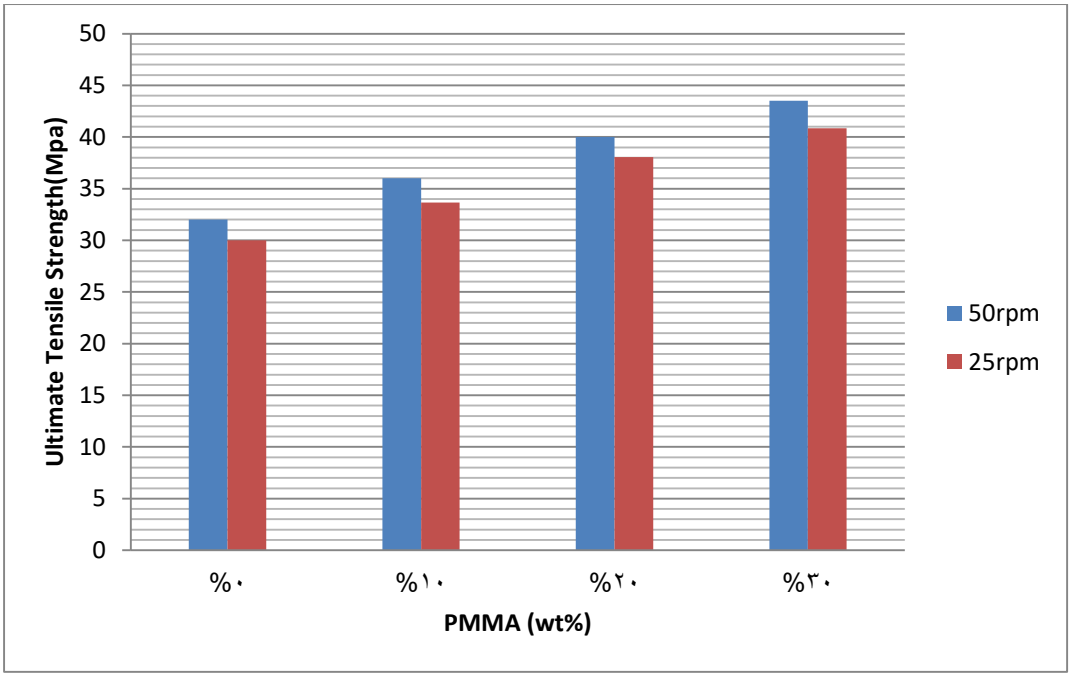
to the DSC results in Table. (4. 2), are another indicator of the crystallization content.



(a)

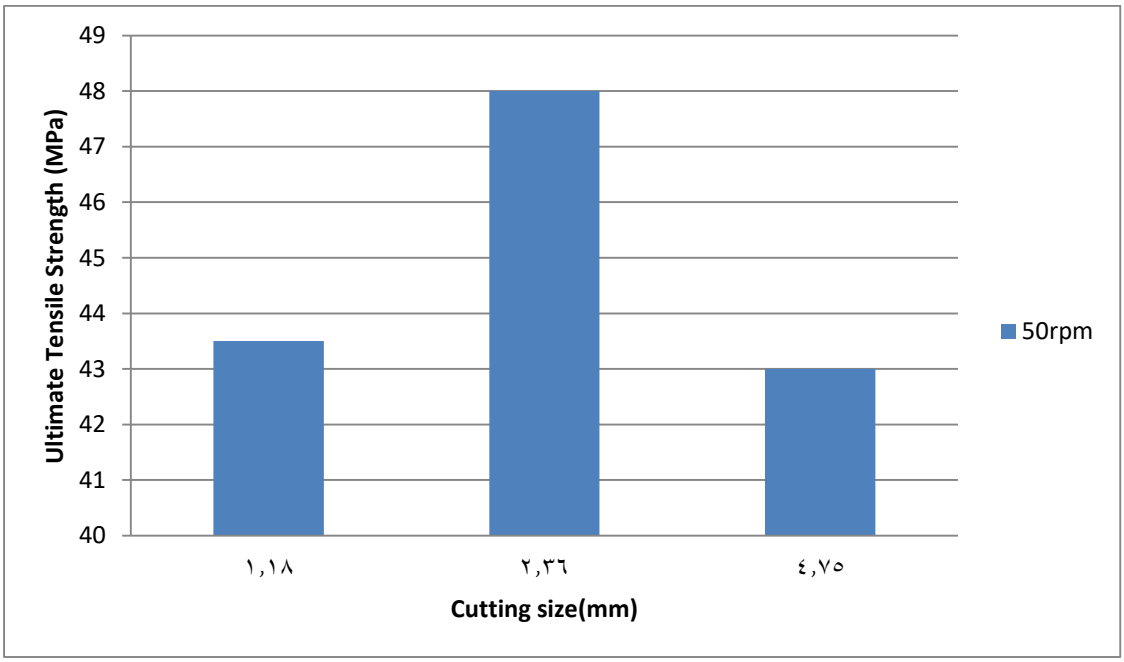


(b)

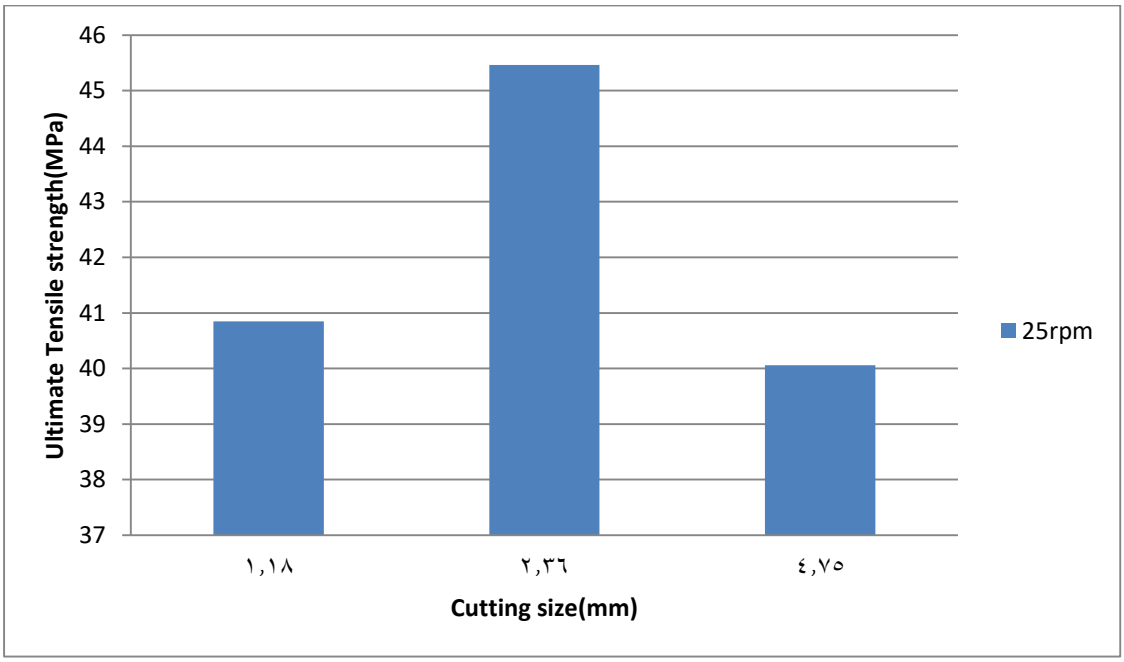


(c)

Figure. (4. 9): The ultimate tensile strength of the rPC/PMMA blend at different speeds (50, 25 rpm) in the cutting size: (a) big size 4.75 mm, (b) medium size 2.36mm., (c) Small size 1.18mm.



(a)

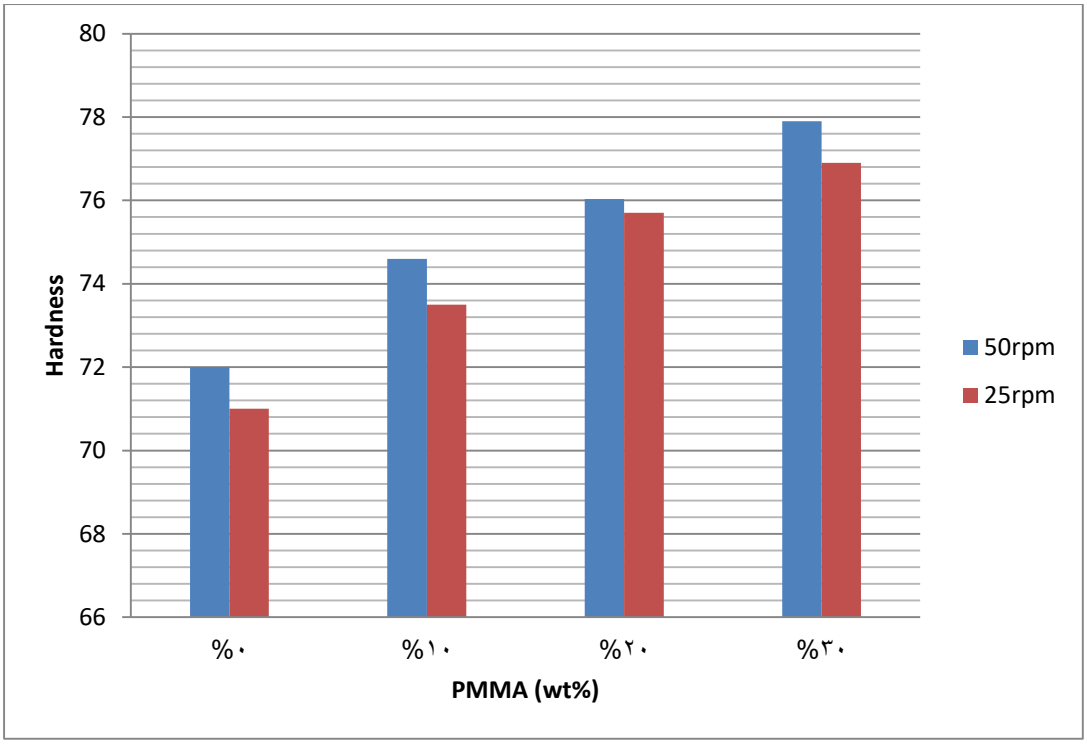


(b)

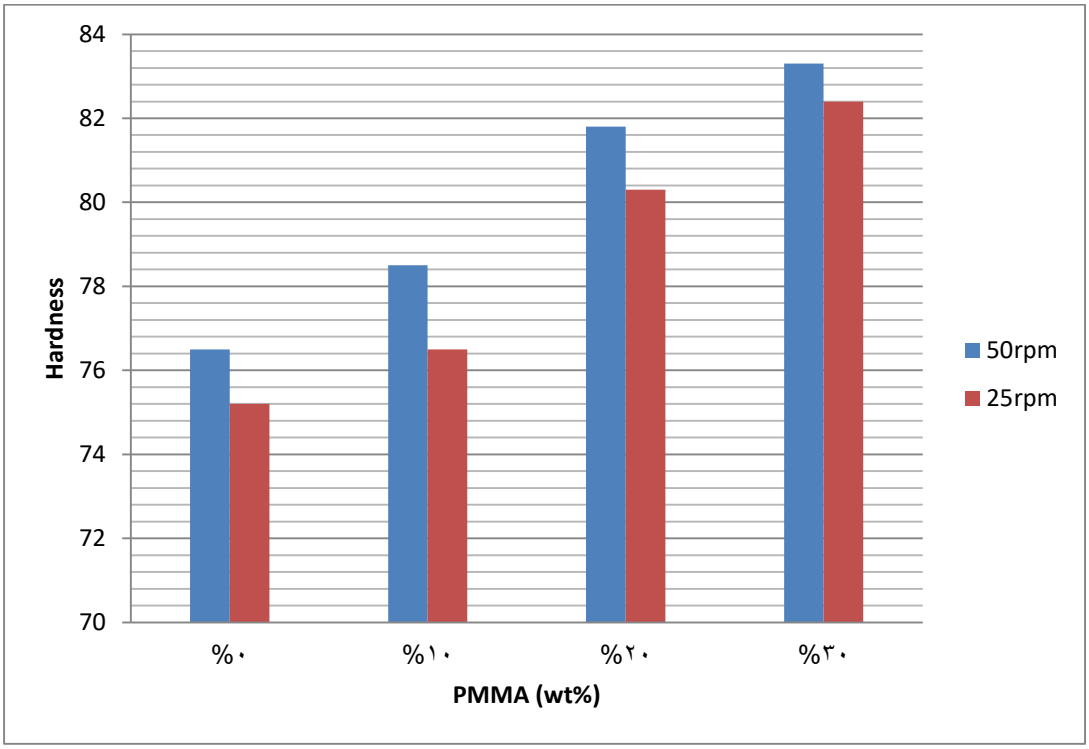
Figure. (4. 10): The tensile strength of extruded sheets resulted from rPC cut different size for recycling: (a) at speed 50rpm, (b) at speed 25rpm.

4. 5. 2. Hardness:

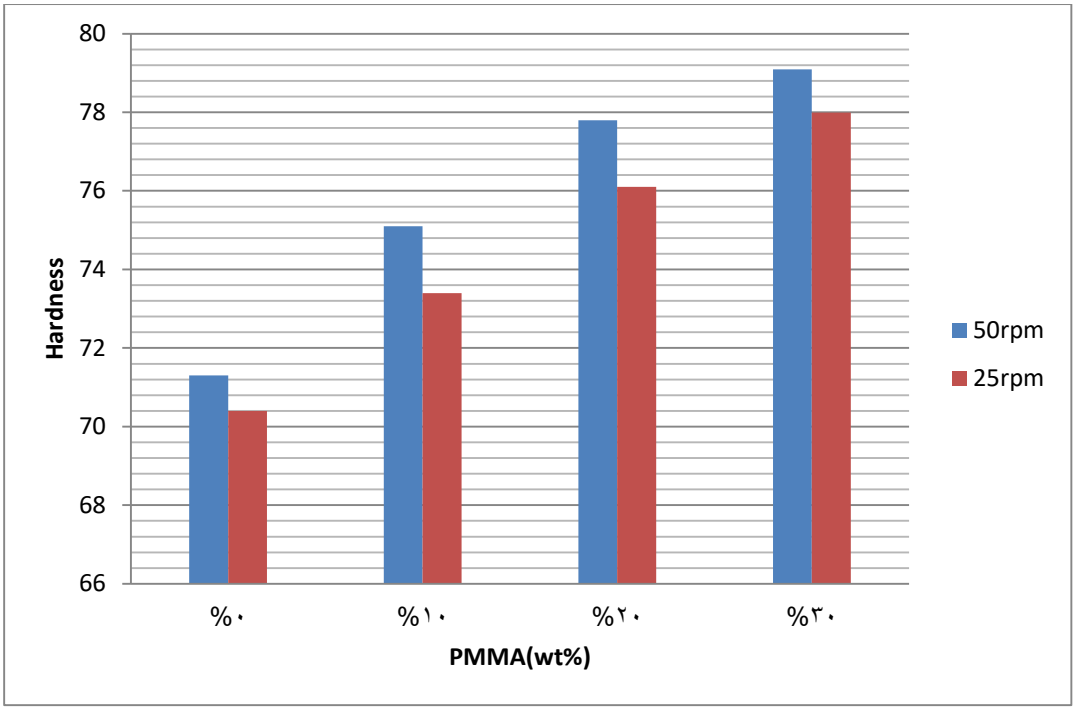
Figure. (4. 11), shows that the hardness increases in all blends with an increase in the PMMA to 30 wt%. Its highest value is 83.3 at speed 50rpm in the medium size 2.36mm. This increase is due to the PMMA polymer addition, blend of densities, and decrease in the proportion of the chains branching in the compounds. Also, the hardness value drops noticeably with increased cutting length.


80
78
76
74
72
70
68
66
Hardness
%٠
%١٠
%٢٠
%٣٠
PMMA (wt%)
50rpm
25rpm

(a)

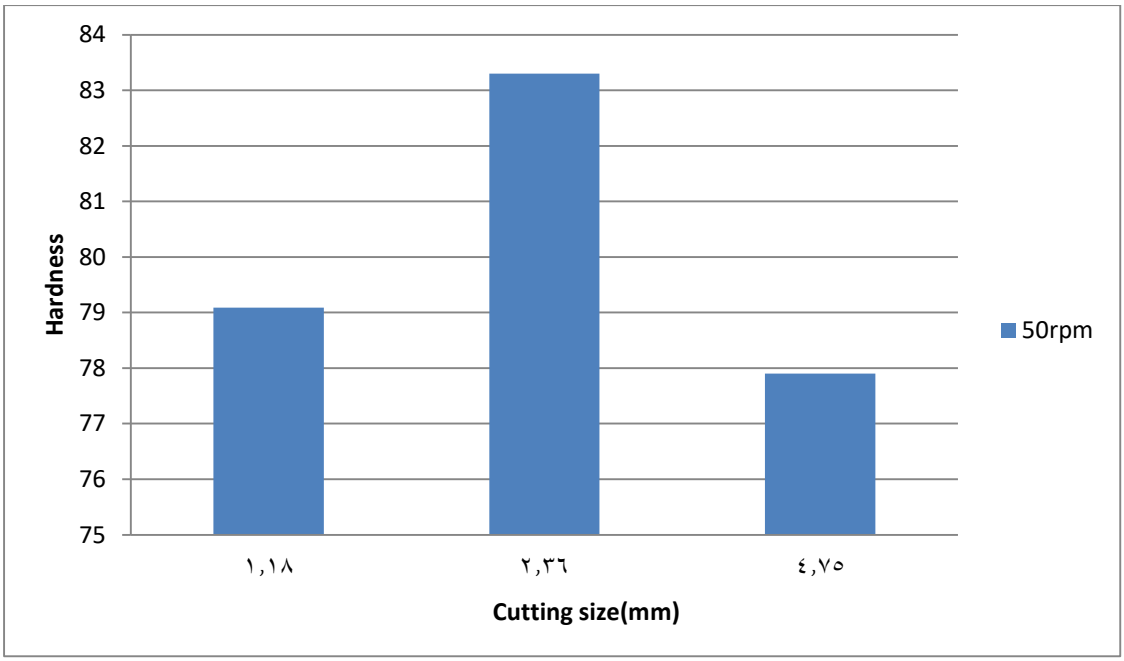

84
82
80
78
76
74
72
70
Hardness
%٠
%١٠
%٢٠
%٣٠
PMMA (wt%)
50rpm
25rpm

(b)

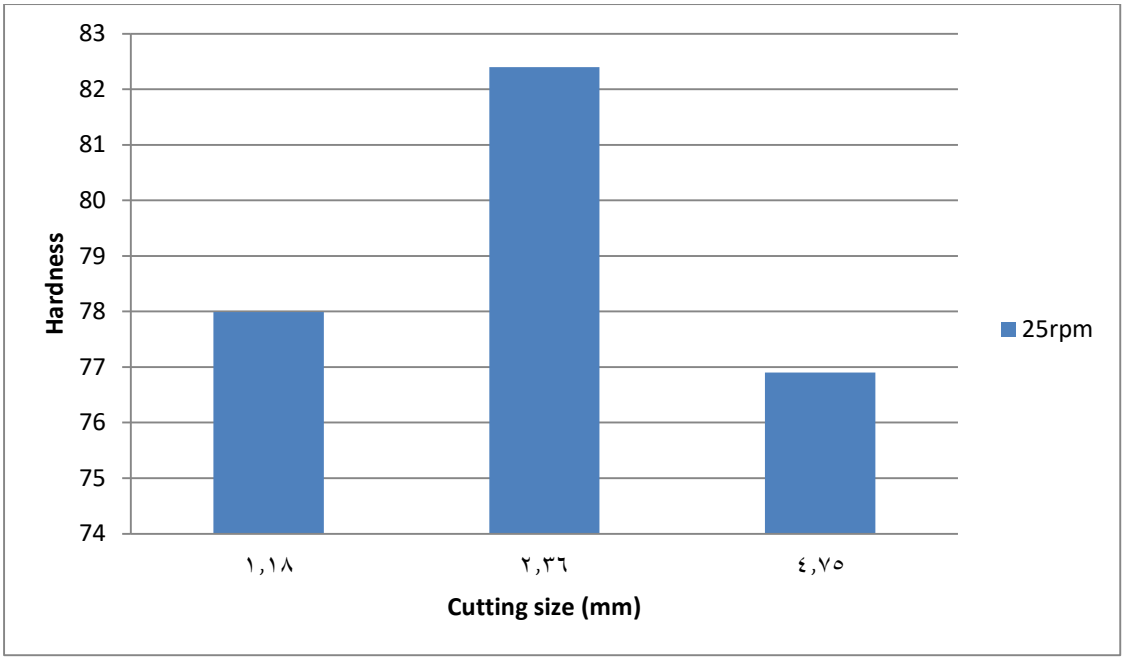


(c)

Figure. (4. 11): Hardness shore D of the rPC/ PMMA blend at different speeds (50, 25rpm) in the cutting size: (a) big size 4.75mm, (b) medium size 2.36mm, (c) Small size1.18mm.



(a)



(b)

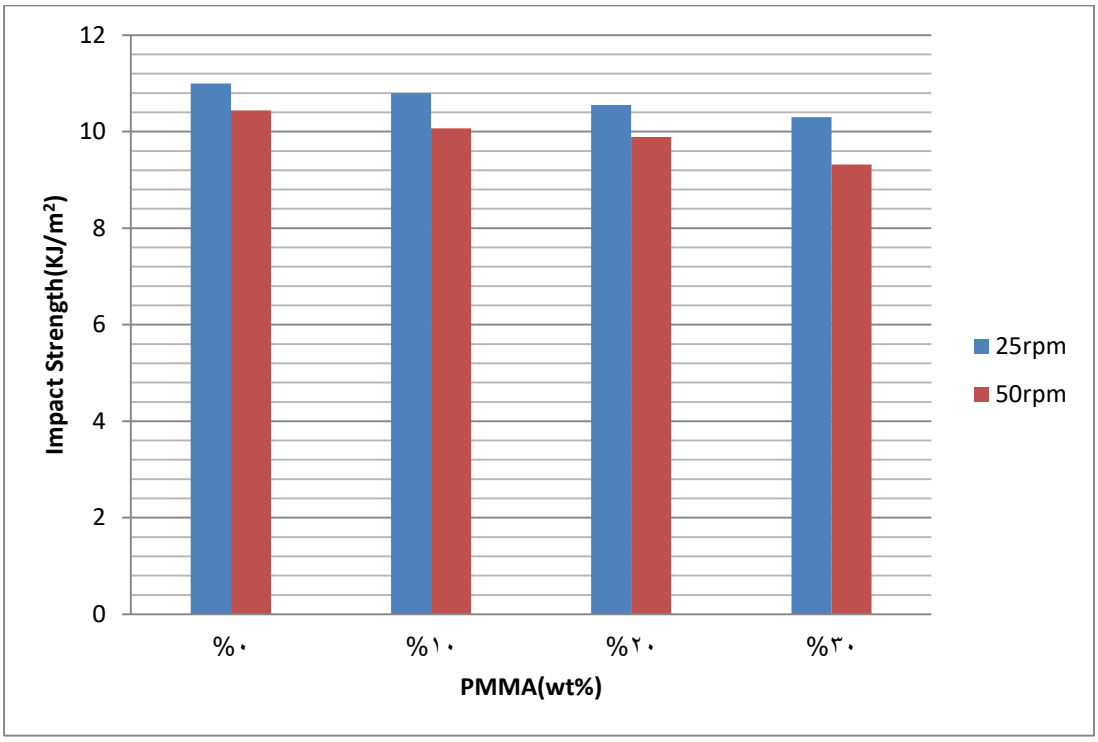
Figure. (4. 12): The Hardness of extruded sheets resulted from PC cut different size for recycling: (a) at speed 50rpm, (b) at speed 25rpm.

4. 5. 3. Impact Strength

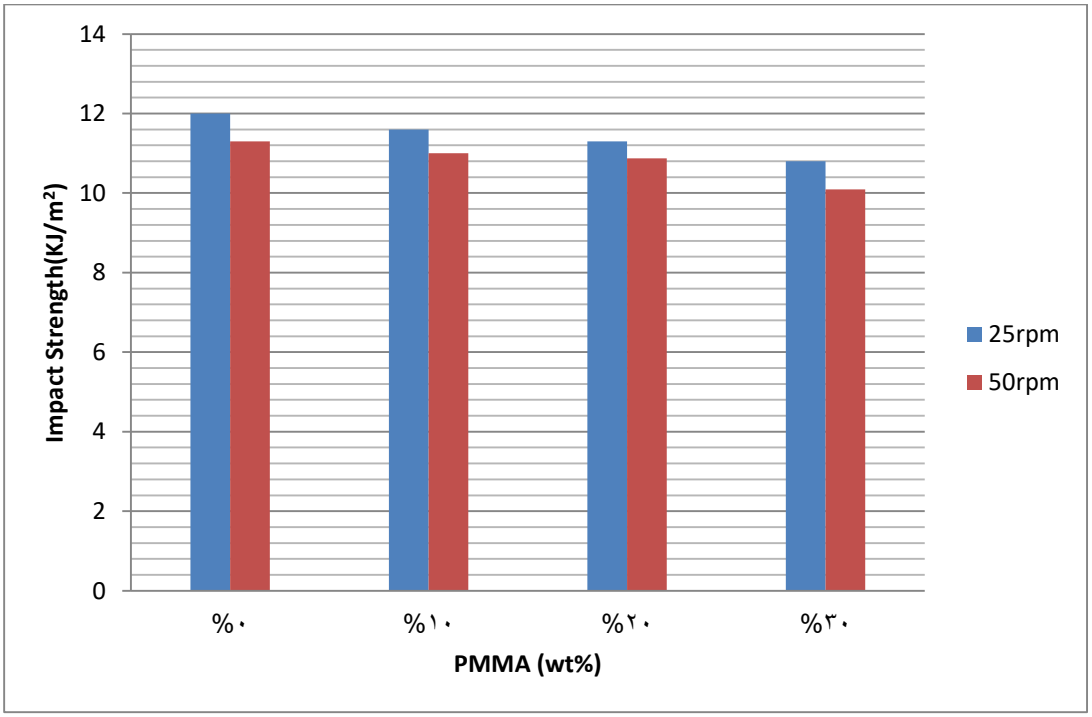
Figure. (4. 13), the impact strength decreases gradually and slightly at 10% and 20% PMMA before reaching its lowest value at 30% PMMA. This decrease is attributed to the increase in the hardness of the blend, as shown in the Figure. (4. 11). This result is identical to the tensile, density, and MFR tests. The impact strength decreases with the viscosity, and chain branching decreases.

We also note that the impact force decreases with increasing the cutting length and increasing the speed, as it is higher at the speed of 25rpm compared to the speed of 50rpm due to the increase in the porosity of the mixture, which acts as a chamber to absorb the impact force, as shown in the Figure. (4. 6-c) for the SEM test.

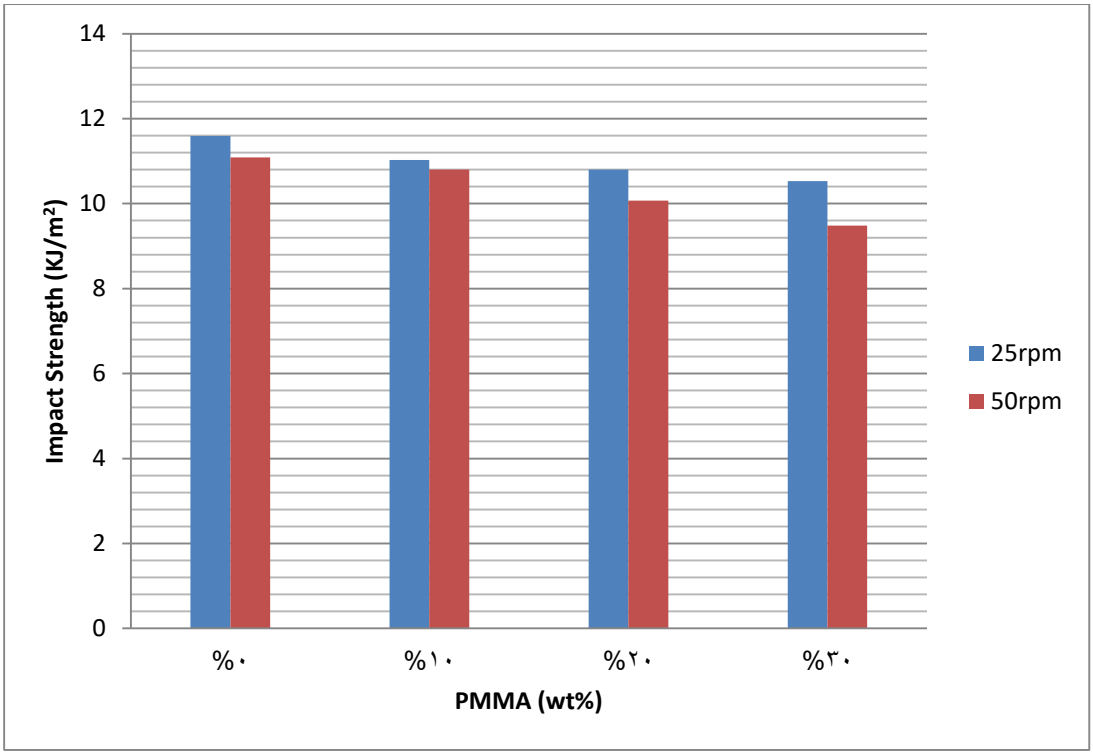
The results of the mechanical properties are in agreement with the study [109, 112].


12
10
8
6
4
2
0
Impact Strength(KJ/m²)
%٠
%١٠
%٢٠
%٣٠
PMMA(wt%)
25rpm
50rpm

(a)

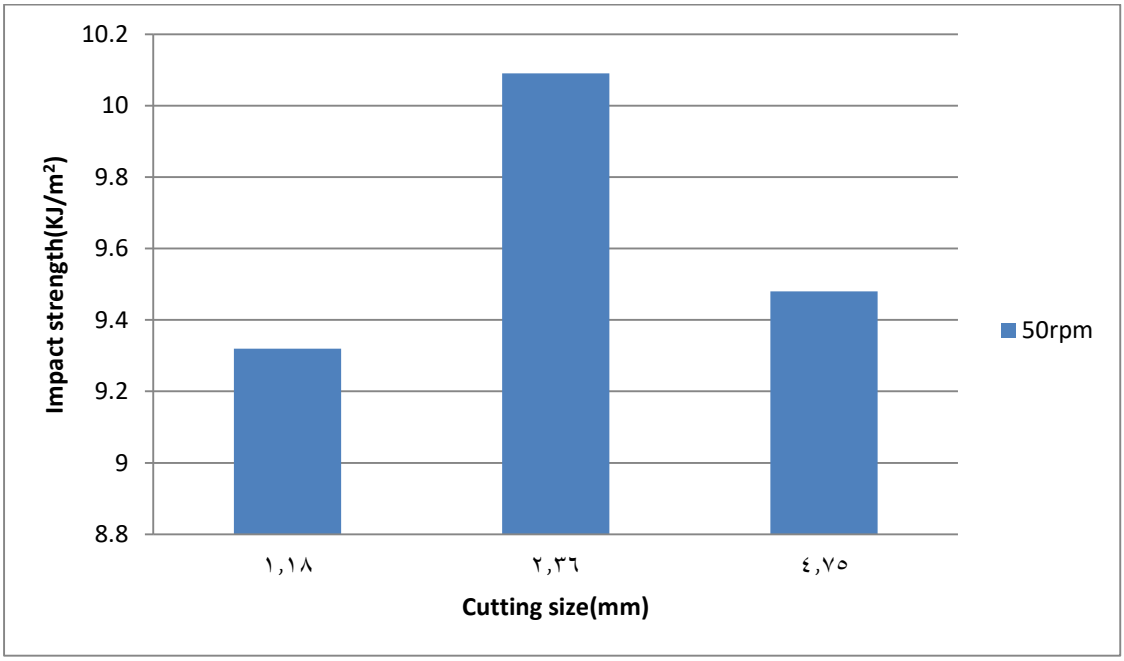

14
12
10
8
6
4
2
0
Impact Strength(KJ/m²)
%٠
%١٠
%٢٠
%٣٠
PMMA (wt%)
25rpm
50rpm

(b)

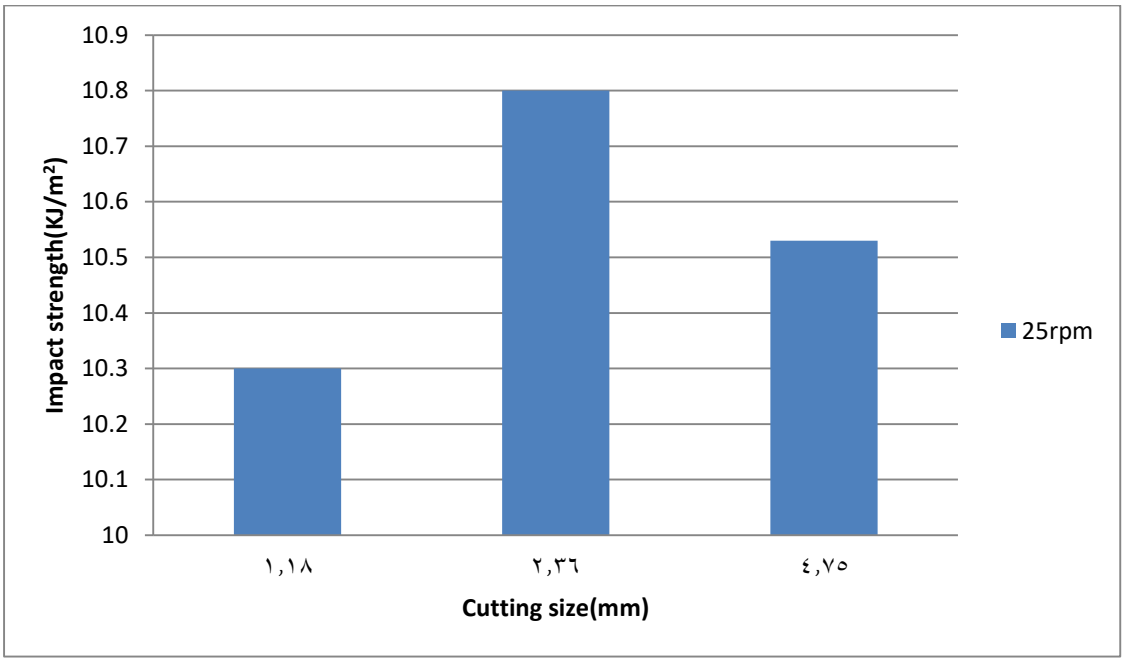


(c)

Figure. (4. 13): The impact strength of the rPC/PMMA blend at different speeds (50, 25 rpm) in the cutting size: (a) big size 4.75mm ,(b) medium size 2.36mm,(c) Small size1.18mm.



(a)



(b)

Figure. (4. 14): The Impact strength of extruded sheets resulted from rPC cut different size for recycling: (a) at speed 50rpm, (b) at speed 25rpm..

5. Introduction

This chapter includes the main conclusions we reached Through this study, the effect of adding PMMA to rPC as well as the effect of velocity and volume on the properties of the blend will be explored. This chapter also includes top recommendations for subsequent studies.

5. 1 Conclusions:

From the present work, it can be concluded the following:

1. In general, the mechanical properties show that the ultimate tensile strength and hardness of (rPC/ PMMA) blends is influenced by the cutting size, Speeds, and percentage addition (PMMA). The higher value of mechanical properties for 70rPC/30PMMA indicates the better quality of this blend.
2. The impact strength decreasing with increases PMMA ratio and particle size at both speeds 25 , 50 rpm at 210^0C.
3. The DSC results showed the appearance of two regions of Tg, which indicates that the blend is of the type immiscible.
4. The FTIR study showed that rPC/PMMA blends are physical blends, because there is no obvious interactions between the components.
5. The SEM studies supported the formation of physical blends of rPC and PMMA.
6. The best parameters of extrusion are temperature 210^0C, speed 50rpm and particle size average (2.36 mm).

5. 2 Recommendations:

Below are some recommendations for future studies:

1. Examination of the rheological and other mechanical properties such as (flexibility, fatigue, compression) of the rPC/ PMMA blend.
2. Using an injection process instead of an extrusion process for CDs recycled polycarbonate (rPC) with different cutting lengths.
3. Adding a catalyst or Nano-material's to blend rPC/PMMA during the extrusion process to facilitate the extrusion process and improve product properties.
4. Replacing PMMA with other types of plastics such as ABS, PET and checking the rheological, mechanical and thermal properties.

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