



Ministry of Higher Education and Scientific Research
University of Babylon- College of Engineering
Materials Engineering Department



The Effect of Strain Rate and Heating Rate on the Mechanical and Thermal Properties of Thermoplastic Polyolefin's

By

Azhar Hadi Kadhim

Supervised By

Lect. Nabeel Hasan Hameed (Ph.D.)

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

{ يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ
وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ
بِمَا تَعْمَلُونَ خَبِيرٌ }

صدق الله العظيم



Dedications

To my dear parents, may God preserve them, who spent their lives in order to educate me, teach me, and guide me to the right path.

To my family members, brothers and friends, and those who accompanied and accompanied me during my academic career. To everyone who spared no effort in helping me. To everyone who contributed to my teaching and education, and if only with one letter.

Supervisor Certification

I certify that this project (**The Effect of Strain Rate and Heating Rate on The Mechanical and Thermal Properties of Thermoplastic Polyolefin's**) under my supervision at University of Babylon - College Materials Engineering in partial fulfillment of the Materials Engineering requirements for the Degree of Bachelor of Engineering In Department of Polymer Engineering and Petrochemical Industries

Signature.....

Lect. Nabeel Hasan Hameed (Ph.D.)

Supervisor

Acknowledgment

First, I should like Express my deep thanks to the almighty God, ALLAH JALLA. JALALUHU, for what I have been done Prays and peace to our messenger Mohammed.

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Abstract

Polymers are fundamental for most common materials of our modern society because they present several desired features like lightness, easy processability, softness and low cost. Also it is known that polymer properties are affected by several factors when it is used in different applications.

In this project three polymers were chosen (PE, PP, and PVC) and the effect of strain rate (10, 20, 50 mm/min.) and heating rate (10, and 20 C°/min.) on the mechanical and thermal properties were studied. Twin screw extruder were used for the preparation of samples.

In order to study the influence of strain rate and heating rate, the tensile strength and differential scanning calorimetry (DSC) were used.

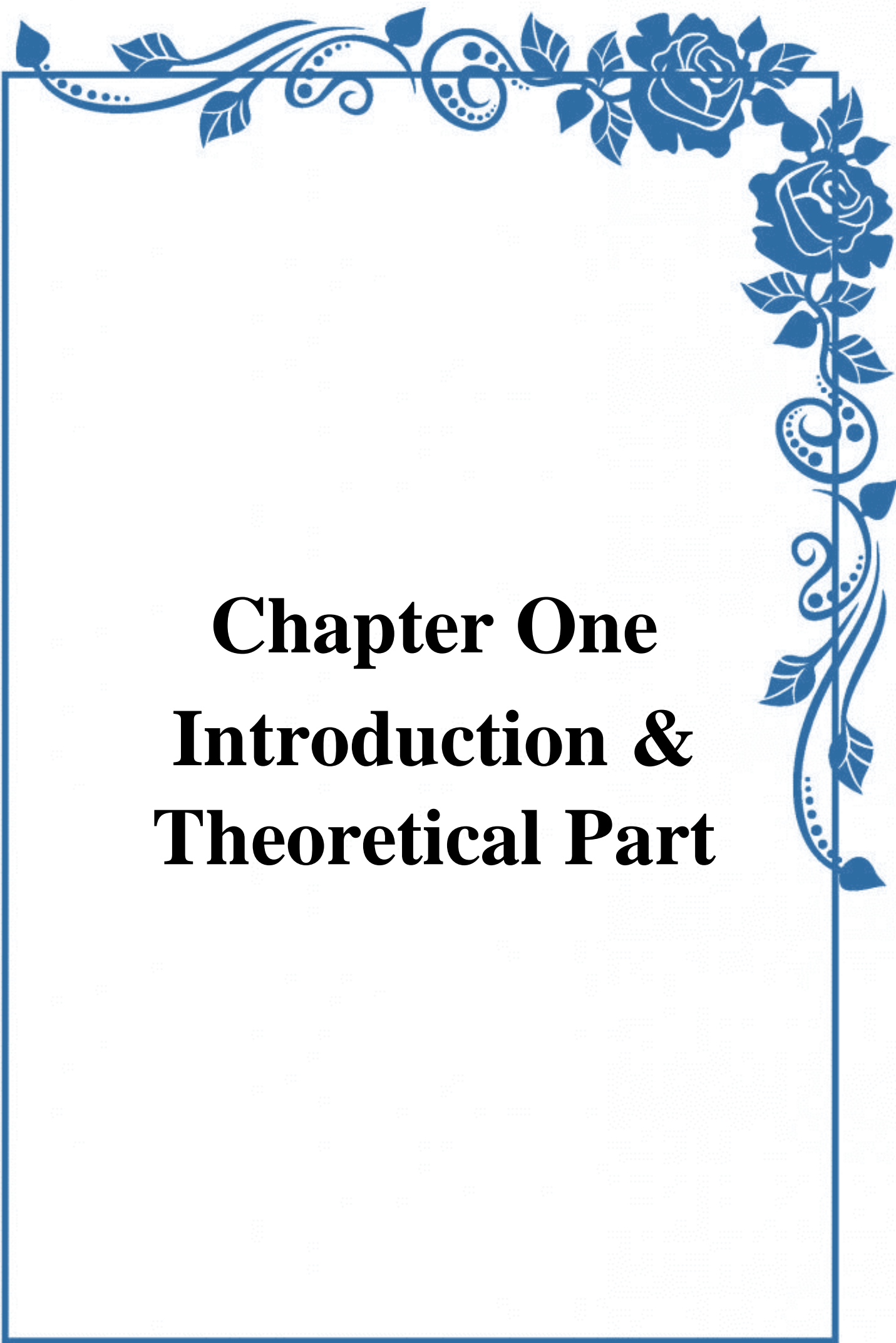
Mechanical properties results show that the tensile properties, tensile strength and elastic modulus, were increased by the increase in the strain rate, while the elongation at break was decreased.

Differential scanning calorimetry (DSC) results (T_g , T_m , ΔH , and T_c) show that as the heating rate increase the melting temperature and enthalpy were decreased for PE, PP, and PVC. In addition there is a slight change in the T_c .

Aim of this Project

The aim of this project is to study the effect of strain rate change on the tensile properties (tensile strength, elastic modulus, and elongation at break) of three polymer PE, PP, and PVC. In addition investigate the effect of heating rate change by DSC on the thermal properties (glass transition temperature T_g , melting temperature T_m , melting enthalpy ΔH , and crystallization temperature T_c)

No.	Title	Page
	Abstract	IV
	Aim of the project	V
Chapter one		
1.1	Introduction	1
1.2	Polymer Classification	2
1.3	Polypropylene (PP)	3
1.4	High Density Polyethylene (HDPE)	5
1.5	Polyvinyl Chloride (PVC)	7
1.6	Factors affecting polymers	9
Chapter two		
2.1	Introduction	14
2.2	The Materials Used in this Study	14
2.3	Preparation of Polymer Blends	15
2.4	Characterization of Polymeric Samples	17
Chapter three		
3.1	Introduction	19
3.2	Effect of Strain Rate on Tensile Properties	19
3.3	Effect of Heating Rate on Thermal Properties	22
Chapter Four		
4.1	Conclusions	24
4.2	Recommendations	24
	Reference	26



Chapter One
Introduction &
Theoretical Part

1.1. Introduction

In the last century, new materials have contributed immensely to industrial and technological development. The list of materials includes a large number of metals, alloys, composites ceramics and polymers. Out of these, polymers have made an important contribution to this developmental process and have established themselves as an important class of engineering materials. The structure of polymers consists of a great number of repeating units and high molecular mass compounds. These days, polymer materials are very important in human life that entity of human life depends on these polymers.

Polymers offer a wide variety of properties that make them ideal materials for a broad range of applications, from polyethylene in garbage and sandwich bags to poly (p-phenylene terephthalamide) in bulletproof jackets . Polyolefins have received significant attention recently because of their combination of flexibility, toughness, excellent barrier properties, easy manufacturing, and good chemical resistance; this has made them excellent materials for various packaging applications, especially in food packaging such as polypropylene (PP) and polyethylene (PE) which are extensively used in commodity and packaging applications. The use of PP is continuously increasing in the plastic packaging industries due to their low cost, lightweight, high mechanical strength, water resistance, and good barrier properties.

Polymers have come to play an essential and holistic role in everyday life due to their unique properties .

They are essential materials in everyday industrial sectors, such as adhesives, building materials, paper, apparel, fibers, plastics, ceramics, concrete, liquid crystals, photoresists, and coatings.

Polymers are also found in most soil components, plants, and living organisms. They are important in nutrition, mechanical engineering, the structure of organisms, medicine, computers, space exploration, health, and the environment.

Synthetic polymers save energy when compared to metals. Its light weight reduces fuel consumption in vehicles and aircraft. It is superior to most metals in relation to its strength-to-weight ratio. Polymers have been developed and have good properties and have become economical in manufacturing .

It can also be used for engineering purposes, so we use gears, rollers, and structures made of polymers

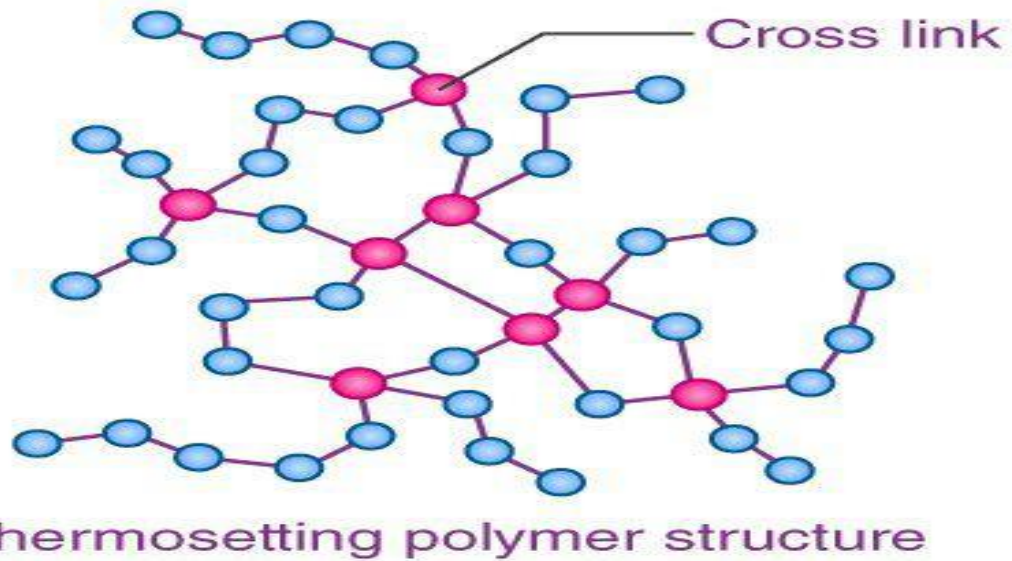
1.2. Polymer classification

1.2.1. Thermoplastic Polymers

All the plastic materials which can be softened and melted by heating, but they set again when cool are called thermoplastics.

Thermoplastic polymers can be very broadly classified as amorphous or crystalline. Most thermoplastics suitable for use as matrices for high performance composite exhibit some degree of crystallinity because this type of structure has better resistance to chemical attack by field, hydraulic oil and paint stripper.

With regard to behaviour at elevated temperatures, polymers are classified as either thermoplastics or thermosetting. Thermoplastic polymers have linear and branched structures they soften when heated and harden when cooled. In contrast, thermosetting polymers once they have hardened, will not soften upon heating; their structures are cross-linked and network.



1.2.2. Thermoset Plastics

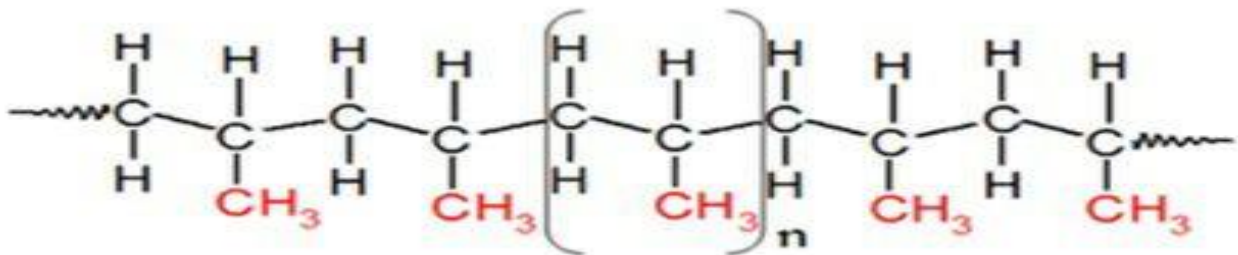
Thermoset plastics, also called thermosetting resin or thermosetting polymers, are typically liquid at room temperature and then harden once heated or with a chemical addition. They are usually produced using reaction injection moulding (RIM) or resin transfer moulding (RTM) and form permanent chemical bonds during the curing process. Thermoset plastics are ideal for use in situations where heat is a factor, such as with electronic housings and appliances or chemical processing equipment, due to their greater structural integrity and resistance to both heat and chemicals. Able to resist deformation and impact, common thermosets include epoxy resins, polyimide, and phenolic, which are often used in composites.

1.3. Polypropylene (PP)

Polypropylene (PP) is a tough, rigid, and crystalline thermoplastic. It is made from propene (or propylene) monomer. This linear hydrocarbon resin is the lightest polymer among all commodity plastics. PP comes either

as homopolymer or as copolymer and can be greatly boosted with additives.

Polypropylene is a type of polyolefin which is slightly harder than polyethylene. It is a commodity plastic with low density and high heat resistance. Its chemical formula is $(C_3H_6)_n$.



Polypropylene has a slippery, tactile surface, making it ideal for plastic furniture

low friction applications, such as gears in machinery and vehicles.

It is highly resistant to chemical corrosion, making it an excellent choice for packaging for cleaning products bleaches and first-aid products

1.4.2 Some medical applications include

- Syringes
- medical vials
- Petri dishes
- pill containers
- specimen bottles

1.4.3 Advantages

- Light weight
- High tensile strength
- Shock resistance
- High pressure resistance

- Excellent dielectric properties
- Withstands most acids and alkalis
- Resists stress cracking
- Maintains toughness and elasticity
- Low moisture absorption
- Non-toxic
- Non-staining
- Easily fabricated
- High heat resistant.

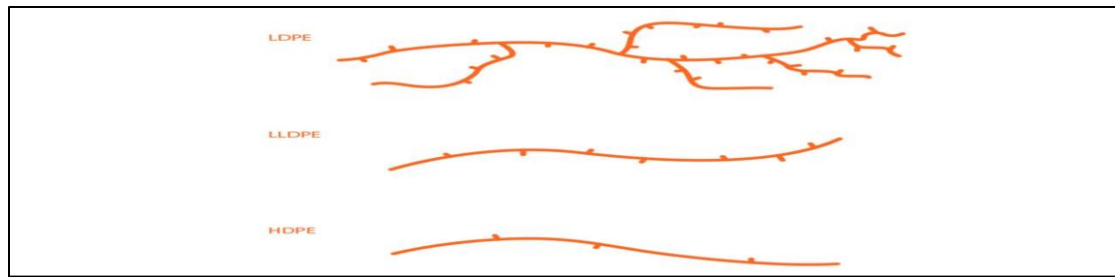
1.4.4 Types of Polypropylene & How to Select Them?

Homopolymers and Copolymers are the two major types of polypropylene available in the market.

1.4. High Density Polyethylene (HDPE)

Polyethylene (Polythene) is one of the world's most popular plastics. It is an enormously versatile polymer which is suited to a wide range of applications from heavy-duty damp proof membranes for new buildings to light, flexible bags and films.

Two major types of PE are in use in the films and flexible packaging sector – LDPE (Low Density) used generally for trays and heavier duty films such as long-life bags and sacks, poly tunnels, protective sheeting, food bags etc and HDPE (High Density) which is used for most thin gauge carrier bags, fresh produce bags and some bottles and caps.



Main Types of PE

1.4.1 Advantages

- Cost-effective
- Can withstand temperatures from -148 to 176 degrees Fahrenheit
- Non-leaching
- UV-resistant
- Dishwasher safe
- Resistant to most chemical solvents
- Stiff material

1.4.2 Disadvantages

- Poor weathering resistance
- Flammable
- Sensitive to stress cracking
- Difficult to bond

1.4.3 Applications

- Acid/Caustic Lines
- SX Acid Mining
- Factory Mutual Piping - Fire loops and mains
- Organic Chemicals
- Inorganic Chemicals
- Hazardous Waste

- Wastewater
- Process Water
- Dual Contained Systems
- Cooling Water
- Acid bath
- Chemical drums
- Jerricans
- Carboys
- picnic ware,
- household and kitchenware
- cable insulation
- carrier bags
- food wrapping material.

1.5. Polyvinyl Chloride PVC

Polyvinyl Chloride (PVC or Vinyl) is a high strength thermoplastic material widely used in applications, such as pipes, medical devices, wire and cable insulation...the list is endless. It is the world's third-most widely produced synthetic plastic polymer

Polyvinyl Chloride (PVC or Vinyl) is an economical and versatile thermoplastic polymer widely used in the building and construction industry to produce door and window profiles, pipes (drinking and wastewater), wire and cable insulation, medical devices, etc. It is the world's third-largest thermoplastic material by volume after polyethylene and polypropylene

It is a white, brittle solid material available in powder form or granules. Due to its versatile properties, such as lightweight, durable, low cost and easy processability, PVC is now replacing traditional building materials like wood, metal, concrete, rubber, ceramics, etc. in several applications.

1.5.1 Applications

- PVC is a versatile material that offers many possible applications, these include
- window frames
- drainage pipe
- water service pipe
- medical devices
- blood storage bags
- cable and wire insulation
- resilient flooring
- roofing membranes
- stationary
- automotive interiors and seat coverings
- fashion and footwear
- packaging
- cling film
- credit cards
- vinyl records
- Synthetic leather and other coated fabrics.
- PVC is a material that has many uses, but with the passage of time a number of defects began to appear for this material, which are as follows:

PVC is not suitable for use in various fields, for example, it is not ideal

for use in the manufacture of sewage pipes' is an unsafe material and contains potentially toxic materials' is not environmentally friendly and cannot be easily recycled.

1.6 Factors Affecting Polymers

1.6.1. Temperature

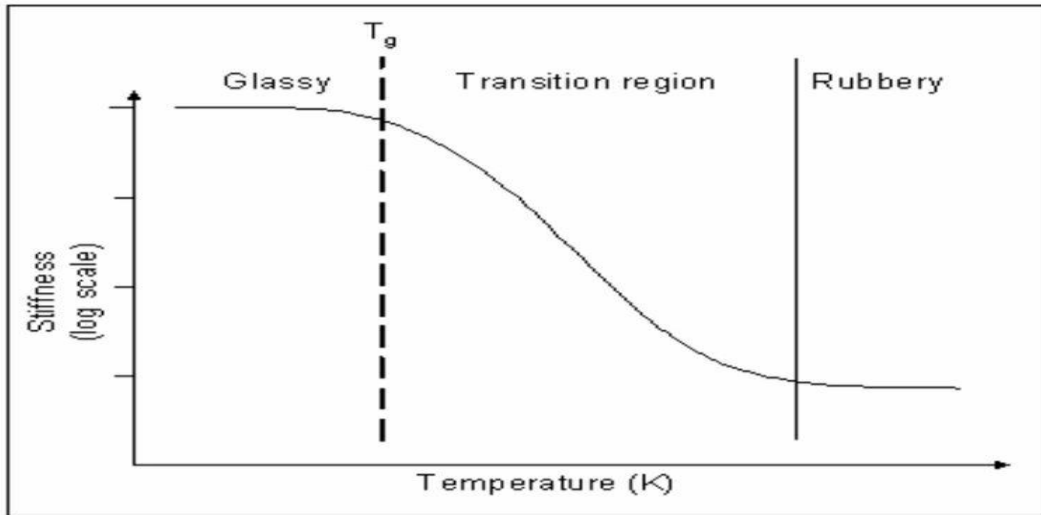
Most plastics at room temperature show their familiar properties of flexibility (a low Young's modulus) and high resistance to cracking but when the temperature decreases this can change and many common plastics become brittle with low failure stresses. Low temperatures can be more harmful to plastics than high temperatures. Catastrophic failures can occur if materials selection does not take account of the low temperature properties of plastics.

Plastics consist of long chain molecules that are entangled with one another. The degree of entanglement varies with the length and exact shape of the polymer molecule. A basic model to visualize this is to consider a bowl of cooked spaghetti – it is tangled up and each strand of spaghetti can be thought of as a long chain polymer molecule. When spaghetti has just been cooked and is still warm the long strands can 'slither' over one another and the spaghetti easily takes up the shape of the plate or bowl.

However, when the spaghetti is cooled then the strands begin to stick to one another and the individual strands of spaghetti no longer slither about the spaghetti becomes fixed in the shape of the bowl and is much easier to handle but less tasty. Similarly, long chains in most polymers at moderate temperatures are able to slither over one another and the material is flexible and does not crack – they are considered to be in a 'rubbery' state.

As the temperature is decreased, most polymers begin to stiffen up and they go through what is known as the 'glass transition' to become effectively glassy solids with all the properties of glass i.e. they become very hard and also very brittle.

This is shown in the graph below for a typical polymer and the stiffness can rapidly increase by a factor of 10000 or more in the glass transition region:



The Phases of Polymer Behavior The temperature of this transition is called the glass transition temperature (T_g) but it is important to note that there is rarely a clear transition between the rubbery and glass regions – the glass transition takes place over a range of temperature (between 10 to 50°C) and in design terms the glass transition is as much a region as a definite temperature.

Once a plastic has been cooled below T_g then, in general, it is stable and no other transitions occur. In these terms, low temperatures for plastics can be easily defined – it is any temperature below T_g for the particular plastic.

Below T_g , commodity plastics begin to act as stiff and glassy solids ,impact resistance is hugely decreased and low energy brittle failure .becomes the main cause of failure.

Polymer Family	Glass Transition Temperature (°C) (approx)
PCTFE*	120 - 215
PTFE*	130
PS	100
PMMA	100
PVC	90
PET*	70
PA (Nylon)*	50
Room Temp.	20
POM	-15
PP	-20
PVDF*	-45
PE-LD	-120 to -100
Note: Specific grades and types will vary	
* = Samples Available	

Low temperatures are not necessarily benign in terms of the performance of plastics. T_g in Real Plastics The actual value of T_g for real plastics will

vary greatly with the, specific molecular structure of the base polymer, the molecular weight and the molecular weight distribution of the polymer, the additives incorporated into the mix and a variety of other factors. The table gives some typical values for T_g for some common polymer families but these should be regarded as indicative rather than definitive.

Polymers that have a T_g greater than room temperature are in the glassy state at room temperature and examples of these are plastics such as PS, PMMA and PET. These plastics tend to be brittle and easy to break at room temperature. PVC is in the glassy state at room temperature but is a special case because it can be easily modified to be rubbery by the addition of plasticizers. Polymer Family Glass Transition Temperature

Note:

Specific grades and types will vary * = Samples Available Polymers that have a T_g less than room temperature are in the rubbery state at room temperature and examples of these are plastics such as PP and PE of most varieties (LD, HD, UHMW etc.). These plastics tend to be flexible and difficult to break at room temperature. One of the most significant special cases is that of PTFE which has a T_g of approximately 130°C. On the basis of conventional plastics PTFE should be brittle at room temperature and below but this is not strictly the case. PTFE has a unique structure and even at the nominal melting point of around 400°C it has considerable strength, equally at temperatures considerably below T_g it can deform plastically to a limited extent.

1.6.2 The Strain-Rate Effect in Polymers

The mechanical behavior of polymers depends on the microstructure or morphology which in turn is strongly influenced by many structural and environmental factors. The time and temperature dependency of polymers is more pronounced compared to metals and ceramics. This can be attributed to the viscoelastic nature of the polymers.

The mechanical response of polymers differs due to temperature and stress levels and may result in linear elastic material behavior, plastic deformation, yielding of the material or cold drawing effects.

Some amorphous polymers with glass transition temperature below room temperature may exhibit nonlinear but recoverable deformation or even viscous flow material behavior.

In general various structural and environmental factors such as molecular weight, cross-linking, crystallinity, copolymerization, plasticizers, polarity, pressure, and as already mentioned temperature affect the mechanical properties. In addition, polymers are sensitive to the rate of loading.

An increase of the strain rate often results in a decrease of the ductility of the polymer. In contrast, the modulus and the yield or tensile strength increase with increasing loading rate. Polymers are very sensitive to the deformation rate.

In general, polymers show an increase of the yield strength with increasing strain rate accompanied with a decrease in ductility. A similar response can be seen by reducing the temperature. In literature this is discussed as the time-temperature superposition principle. The decreasing of the temperature is equivalent to the increasing of the strain rate. At low temperatures or at high strain rates the molecular movement of the polymer chains are restricted and consequently the overall material behavior shows a rigid and brittle response.

With increasing temperatures the rotations and translational displacements of side groups or small molecular groups or repeat units in the main polymer chain are possible.

At the glass transition temperature the mobility of the molecular chains over the whole length is no longer restricted and the solid polymer becomes softer and softer until it melts

DMA experiments show that with high strain rates the secondary and primary transition temperatures are shifted to higher temperatures, that means that the polymer chains are stiffer and distinct degrees of freedom for the molecular motion are blocked.

Thus, the macroscopic polymer behaves stiffer and the material strength increases.

Many authors examined the influence of temperature and strain rate on the material behavior of polymers.

Walley and Field performed tests at room temperature over strain rates ranging from 10^{-2} s^{-1} to 10^4 s^{-1} .

They used suitable lubrication and specimen sizes to avoid friction and inertia effects on the results.

Due to the results of yield stress as a function of logarithmic strain rate, which were measured for various polymers in this work, they concluded that the different materials can be categorized into three different group:

- Polymers with a linear relationship of yield stress and strain rate with no change at higher strain rates.
- Polymers with a bilinear behavior with a sharp increase in gradient at a strain rate of 10^3 s^{-1} .
- Polymers with a decrease in maximum stress at a strain rate of 10^3 s^{-1} possibly followed by an increase.



Chapter Two
Experimental Part

2.1. Introduction

In this chapter, a detailed description of the experimental methodology is presented, which includes, materials selection, preparation of samples and detailed description of test instruments used. The flow chart (2-1) the present work:

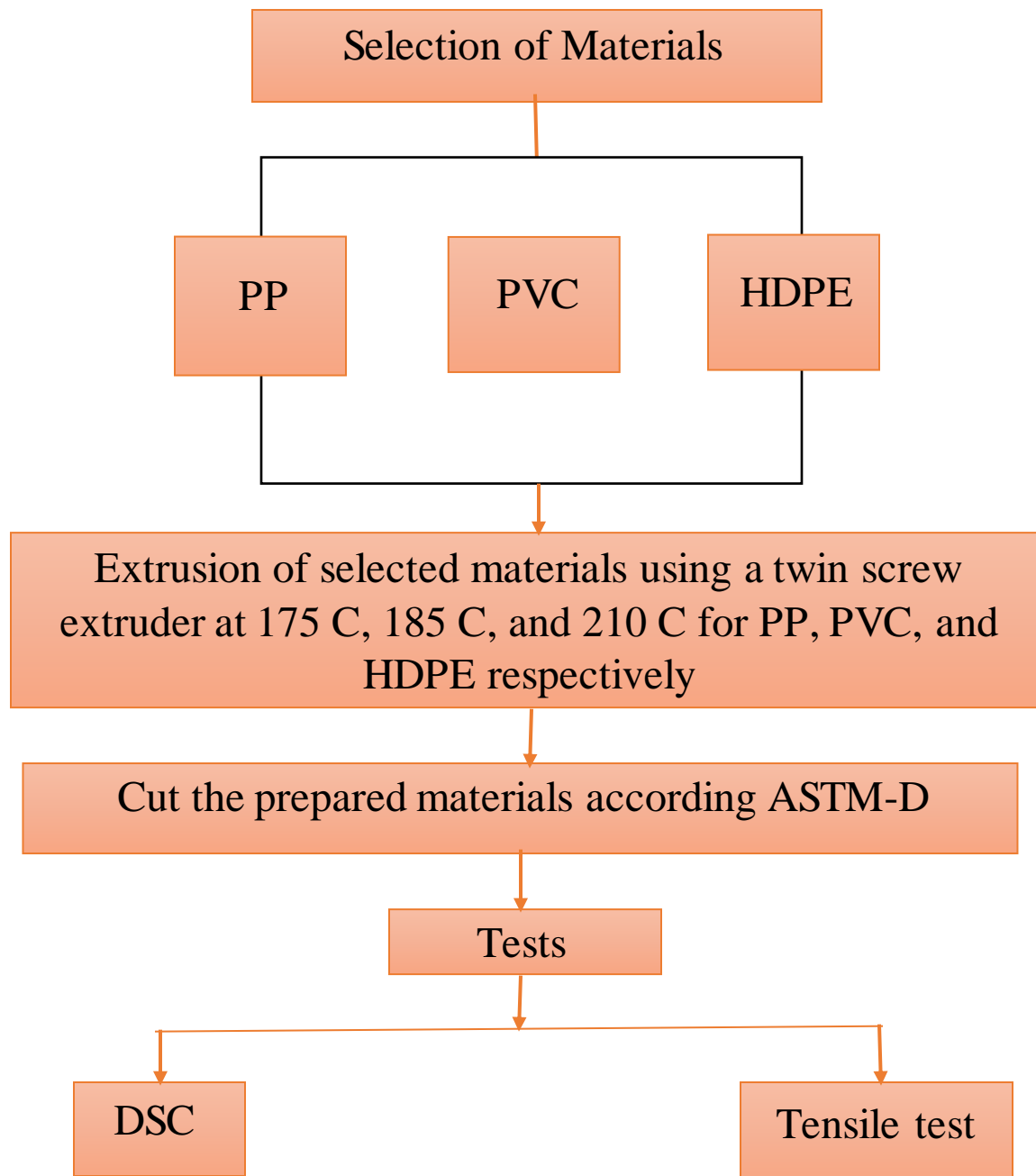


Figure (2-1): the flow chart of work steps.

2.2. The Materials Used in this Study

2.2.1. Polypropylene (PP)

Polypropylene used as a semi-crystalline material in the preparation of polymeric samples provided from Saudi Basic Industries Corporation (Subic). The physical and mechanical properties of PP are shown in Table (2-1).

Table (2-1): The physical and mechanical properties of PP.

Property	Test method	Data	Unit
Tensile Strength	ASTM D-638	35-37	MPa
Elastic Modulus	ASTM D-638	0.12-0.13	GPa
Density	ASTM D-1505	0.89-0.90	Kg/m ³
MFR	ASTM D-1238	9	g/10 min

2.2.2. Polyvinyl Chloride (PVC)

Polyvinyl chloride used as an amorphous material in the preparation of polymeric samples provided from Saudi Basic Industries Corporation (Subic). The physical and mechanical properties of PVC are shown in Table (2-2).

Table (2-2): The physical and mechanical properties of PVC.

Property	Test method	Data	Unit
Tensile Strength	ASTM D-638	20	MPa
Elastic Modulus	ASTM D-638	0.1-0.3	GPa
Density	ASTM D-1505	1.1-1.35	Kg/m ³
MFR	ASTM D-1238	12	g/10 min

3.2.3. High Density Polyethylene (HDPE)

Polyvinyl chloride used as a crystalline material in the preparation of polymeric samples provided from Saudi Basic Industries Corporation (Subic). The physical and mechanical properties of HDPE are shown in Table (2-3).

Table (2-3): The physical and mechanical properties of HDPE.

Property	Test method	Data	Unit
Tensile Strength	ASTM D-638	27	MPa
Elastic Modulus	ASTM D-638	0.5-1.2	GPa
Density	ASTM D-1505	0.94	Kg/m ³
MFR	ASTM D-1238	0.45	g/10 min

2.3. Preparation of Polymer Blends

2.3.1. Weighting

100 g of PP, PVC, and HDPE material pellets were weighted to prepare the batches for Extrusion.

2.3.2. Extrusion

Forming process was carried out using a twin-screw extruder model (SLJ-30A) which is available in laboratory of Materials Engineering college /University of Babylon. The mixed materials were fed from a hopper on the screw. The materials then conveyed along the barrel where it is heated by conduction from the barrel heaters and shear due to its movement along the screw flight. The depth of the twin-screw channel is reduced along the length of the screw so as to compact the material. At the end of the extrusion, the melt passes through a die in the form of sheet. The extruder operation conditions were 25 rpm in the beginning then increased to 50 of screw speed. The temperatures used for zones 1 and 2 were 165-175°C for preparing PP sample and 170- 180 °C for preparing PVC sample,

and 200-210 °C for preparing HDPE sample respectively. Figure (3-1) shows a cross section of twin-screw extruder and Table (3-4) shows the specifications of twin-screw extruder used for blend preparation.

2.3.3. Rolling and cutting

After the material melts and out from the extruder, it passes through two co-rotating rollers that pressurize the material to give high molecular orientation and eliminate from any voids.

The samples are cut according to required shapes by using laser CNC machine Chinese device. Cutting was done according to international standard specifications (ASTM) for tensile test as shown in Table (2-5).

Table (2-4): Twin-screw extruder specifications.

Specifications of the twin-screw extruder	Data
Model	SLJ – 30 A
Diameter of screw	30mm
Speed of screw	0 to 320 rpm
Output	20 Kg / h
Weight	450 Kg
Screw length	16D
Screw design	Double screw
Place of origin	Shandong - China
Certification	ISO9001

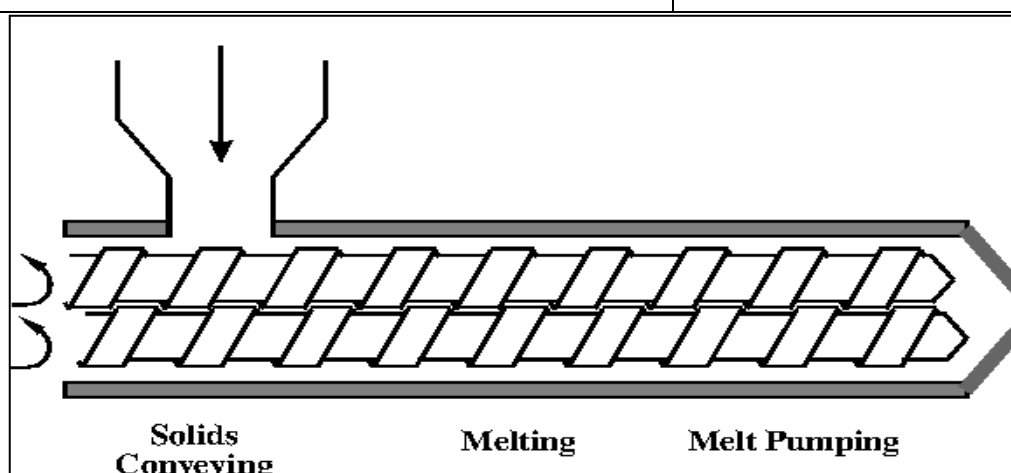
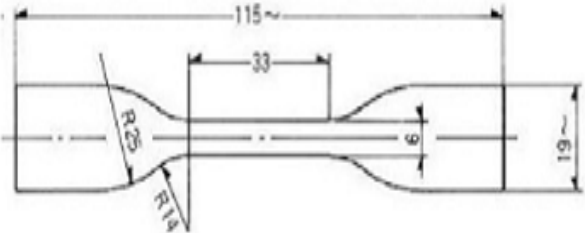


Figure (2-2): Co-rotating twin-screw extruder diagram.

Table (2-5): The standard sample dimensions.

Property	Sample	ASTM
Tensile		D 638

2.4. Characterization of Polymeric Samples

2.4.1. Tensile Test

The machine used for the testing of tensile properties is micro computer controlled electronic universal testing machine model (WDW-5E) China, located in the laboratory of Materials Engineering college/University of Babylon, according ASTM-D 638. Three samples are tested and the mean values were considered. The test was conducted at applied load (5KN) and speed value (10, 20, and 50 mm/min) for all the samples at room temperature. Tensile stress was applied until the failure of the sample and stress-strain curve was obtained. All the results for tensile strength, elastic modulus and elongation at break were achieved from the device.



Figure (3-3): The tensile test device

2.4.2. Differential scanning calorimetry (DSC)

The thermal characteristics of samples were evaluated using a differential scanning calorimetry DSC type TA-60 WS instrument (Shimadzu, Japan) which is available in laboratory of Materials Engineering College /University of Babylon. The samples with an average weight of $(8-10 \pm 0.5)$ mg were mounted in aluminum pans and heated at a heating rate of 10, and 20 °C/min from 30 to 250 °C, then cooled down at the same rate from 250 to 30 °C under an inert gas.



Figure (3-4) : DSC Test device.



Chapter Three

Results & Discussio

3.1. Introduction

This chapter includes all the experimental results that are obtained from the mechanical and thermal tests for the three polymers (PP, HDPE, and PVC) under investigation. It includes the description of the effect of strain rate and heating rate on the mechanical, and thermal properties of the three polymers.

3.2. Effect of Strain Rate on Tensile Properties

Figure (3-1) shows the effect of different strain rates on the tensile strength of PE, PP, and PVC. It is found that the tensile strength increases as the strain rate increase. For PE it is found that tensile strength is 16 MPa and it increase with the increase of speed from 10 to 50 mm/min, the tensile strength increase by 11 MPa, and 6 MPa as the strain rate increase from 10 to 50 mm/min. For PP it is found that it has 16 MPa tensile strength and it increase by 9 MPa, and 7 MPa as the strain rate increase from 10 to 50 mm/min. While for PVC it is found it has 12.4 MPa tensile strength and it increase by 3.9 MPa, and 1.6 MPa as the strain rate increase from 10 to 50 mm/min. These behavior occur because as the strain rate increase the chain in polymers does not have enough time to align themselves in the force direction so the material break.

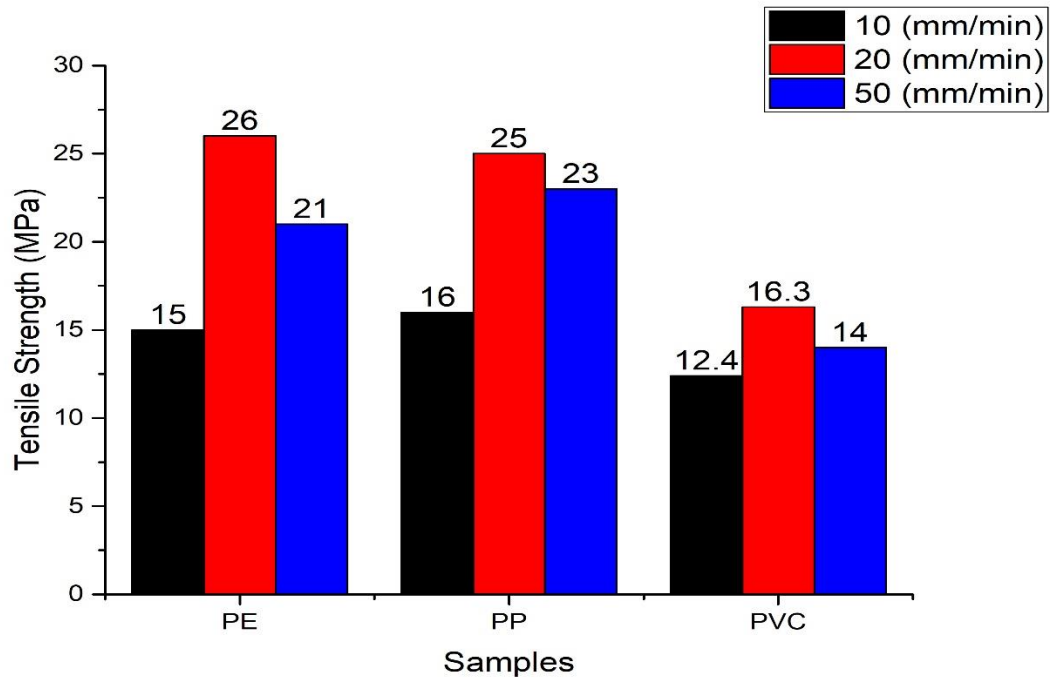


Figure (3-1): The tensile Strength of HDPE, PP, and PVC at different Strain rate.

Figure (3-2) shows the effect of different strain rates on the Elastic modulus of PE, PP, and PVC. It is found that the Elastic modulus increases as the strain rate increase. For PE it is found that Elastic modulus is 0.5 GPa and it increase with the increase of speed from 10 to 50 mm/min, the Elastic modulus increase by 0.19 GPa, and 0.11 GPa as the strain rate increase from 10 to 50. For PP it is found that it has 0.36 GPa Elastic modulus and it increase by 0.49 GPa, and 0.1 GPa as the strain rate increase from 10 to 50 mm/min. While for PVC it is found it has 0.128 GPa Elastic modulus and it increase by 0.182 GPa, and 0.192 GPa as the strain rate increase from 10 to 50 mm/min. These behavior occur because as the strain rate increase the material behavior change from ductile to brittle and causes an increase in the Elastic modulus.

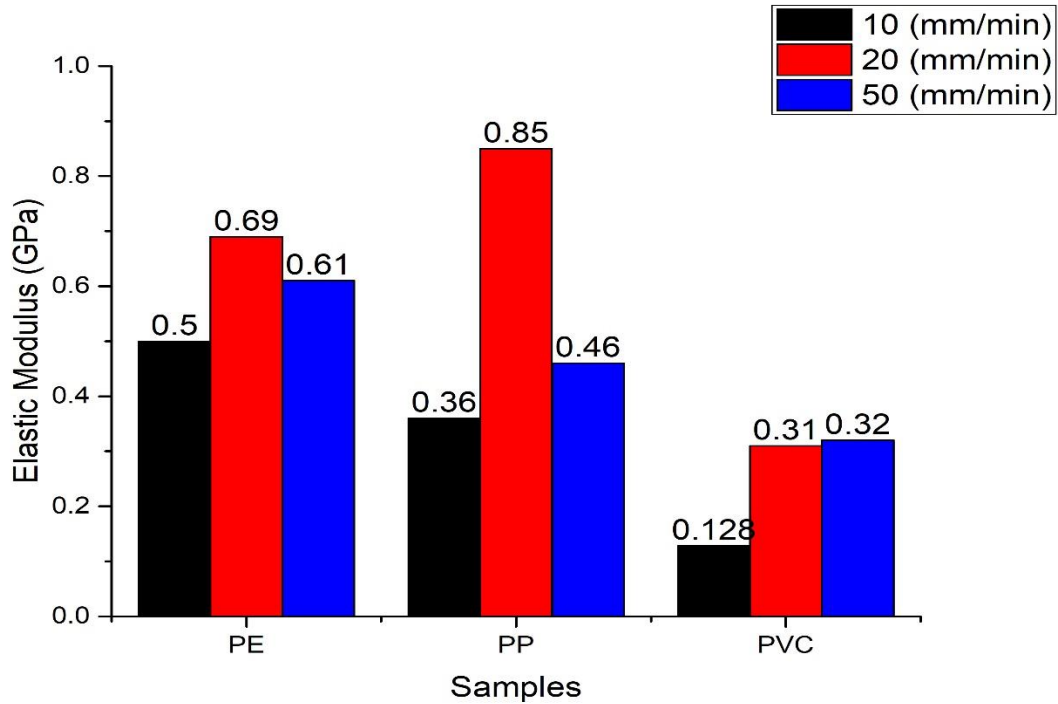


Figure (3-2): The elastic Modulus of HDPE, PP, and PVC at different Strain rate.

Figure (3-3) shows the effect of different strain rates on the elongation at break of PE, PP, and PVC. It is found that the elongation at break decrease as the strain rate increase. For PE it is found that elongation at break is 37.5 % and it decrease with the increase of speed from 10 to 50, the elongation at break decrease by 5%, and 11.5 % as the strain rate increase from 10 to 50. For PP it is found that it has 16.5 % elongation at break and it decrease by 0.5 %, and 7% as the strain rate increase from 10 to 50. While for PVC it is found it has 362 % elongation at break and it decrease by 78.5 %, and 168 % as the strain rate increase from 10 to 50 mm/min. These behavior occur because as the strain rate increase the material behave as a rigid material and thus it has lower elongation than flexible.

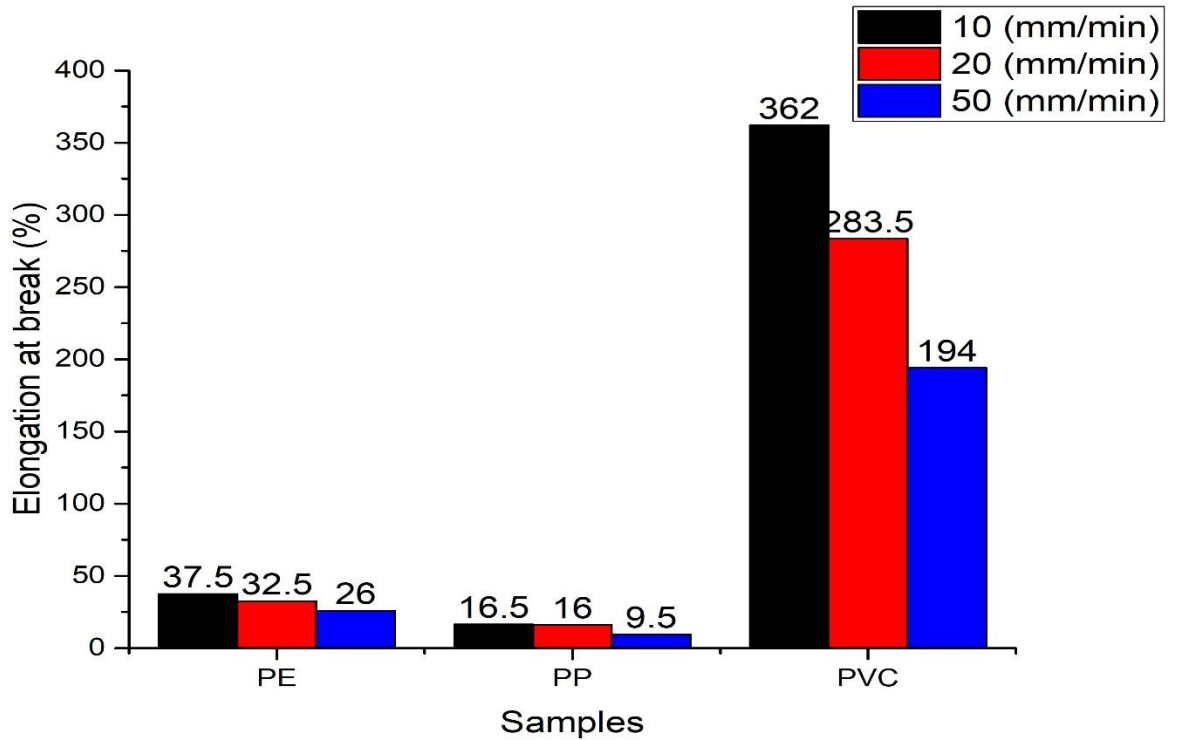


Figure (3-3): The Elongation at break of HDPE, PP, and PVC at different Strain rate.

3.3. Effect of Heating Rate on Thermal Properties

Figure (3-4) to Figure (3-6) show the thermal behavior of PE, PP, and PVC at different heating rates. The glass transition temperature T_g , melting temperature T_m , crystallization temperature T_c and, melting enthalpy ΔH were investigated for the three polymers at two heating rates (10 and 20 $^{\circ}\text{C}/\text{min}$).

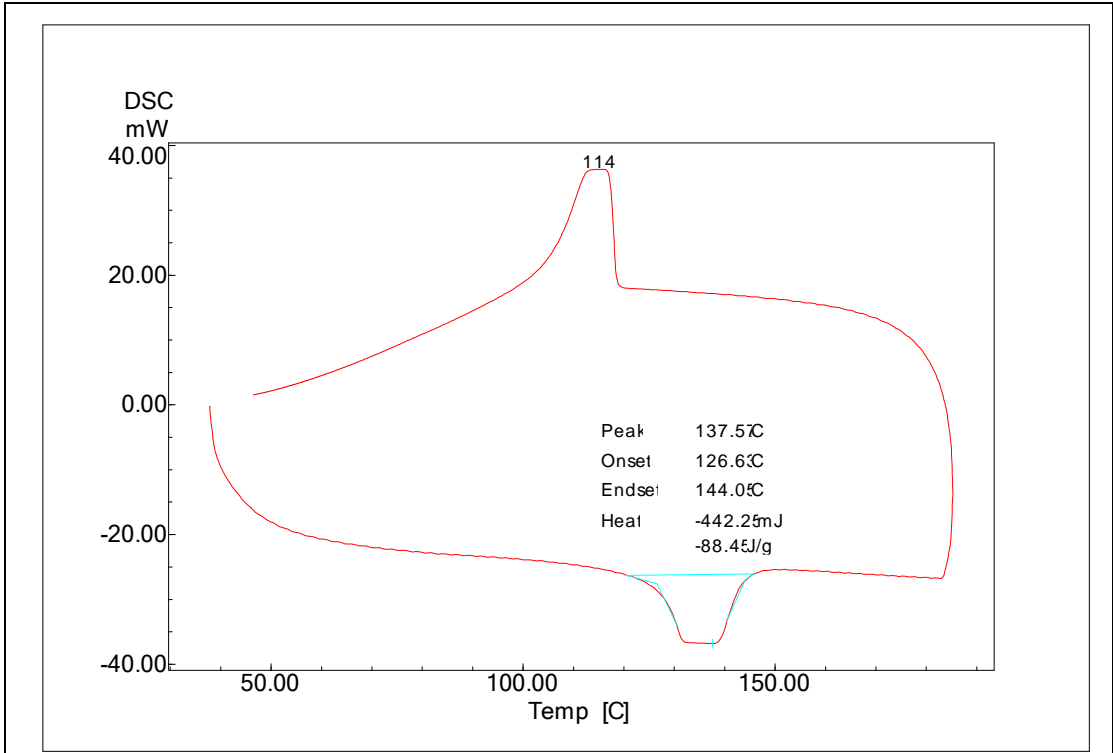
At 10 $^{\circ}\text{C}/\text{min}$, it is found that PE has a melting point of 137.57 $^{\circ}\text{C}$, melting enthalpy 88.45 (J/g) and the crystallization temperature appeared at 114.2 $^{\circ}\text{C}$. For PP, it is found that the melting temperature is 163.39 $^{\circ}\text{C}$, melting enthalpy 107.10 J/g and the crystallization temperature appeared at 111.64 $^{\circ}\text{C}$. For PVC, it is found that the glass transition temperature is 142.21 $^{\circ}\text{C}$, melting temperature is 291.26 $^{\circ}\text{C}$, and melting enthalpy 95.43 J/g.

At 20 $^{\circ}\text{C}/\text{min}$, it is found that PE has a melting point decreased to 131.26 $^{\circ}\text{C}$, melting enthalpy decreased also to 30.34 (J/g) and the crystallization

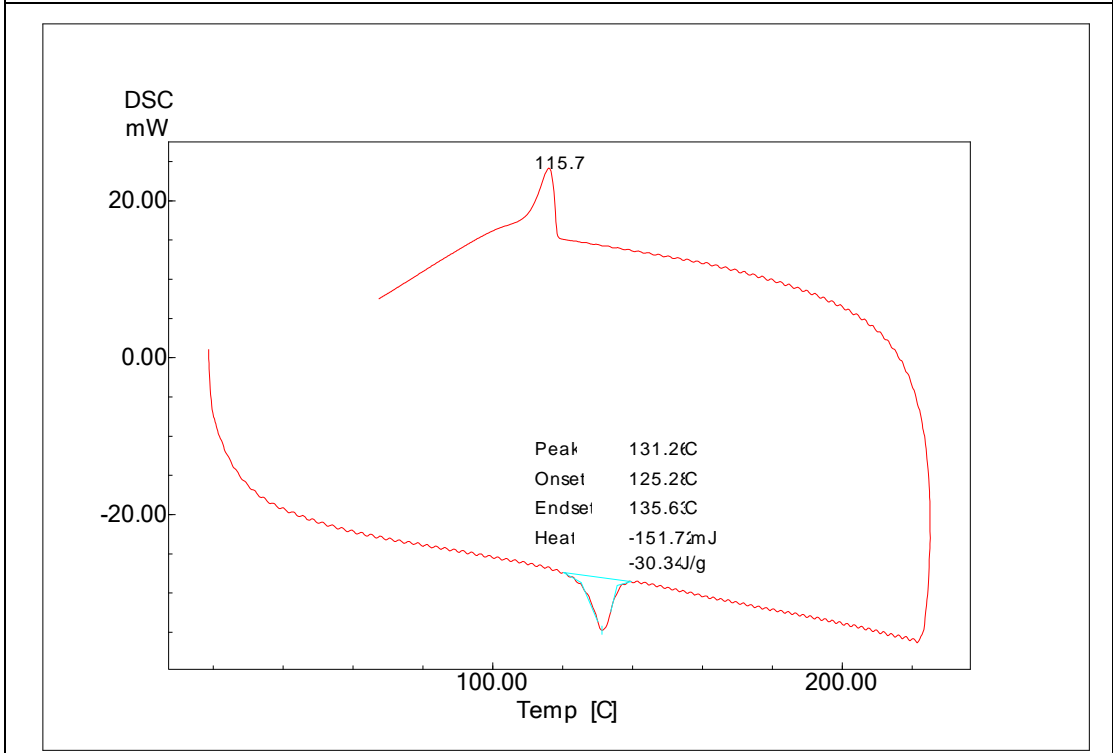
temperature increased to 115.7 C°. For PP, it is found that the melting temperature is slightly increased to 164.53 C°, melting enthalpy decreased to 36.9 J/g and the crystallization temperature decreased to 110.8 C°. For PVC, it is found that the glass transition temperature decreased to 126.46 C°, also both melting temperature is 284.93 C°, and melting enthalpy 15.8 J/g were decreased. Table (3-1) shows the thermal properties of PE, PP, and PVC at different heating rates (10, 20 C°/min).

Table (3-1): DSC data for PE, PP, and PVC at different heating rates.

Samples	10 C°/min.				20 C°/min.			
	Tg	Tm	ΔH	Tc	Tg	Tm	ΔH	Tc
PE	---	137.57	88.45	114.2	---	131.26	30.34	115.7
PP	---	163.39	107.10	111.64	---	164.53	36.9	110.8
PVC	142.21	291.26	95.43	---	126.46	284.93	15.8	---

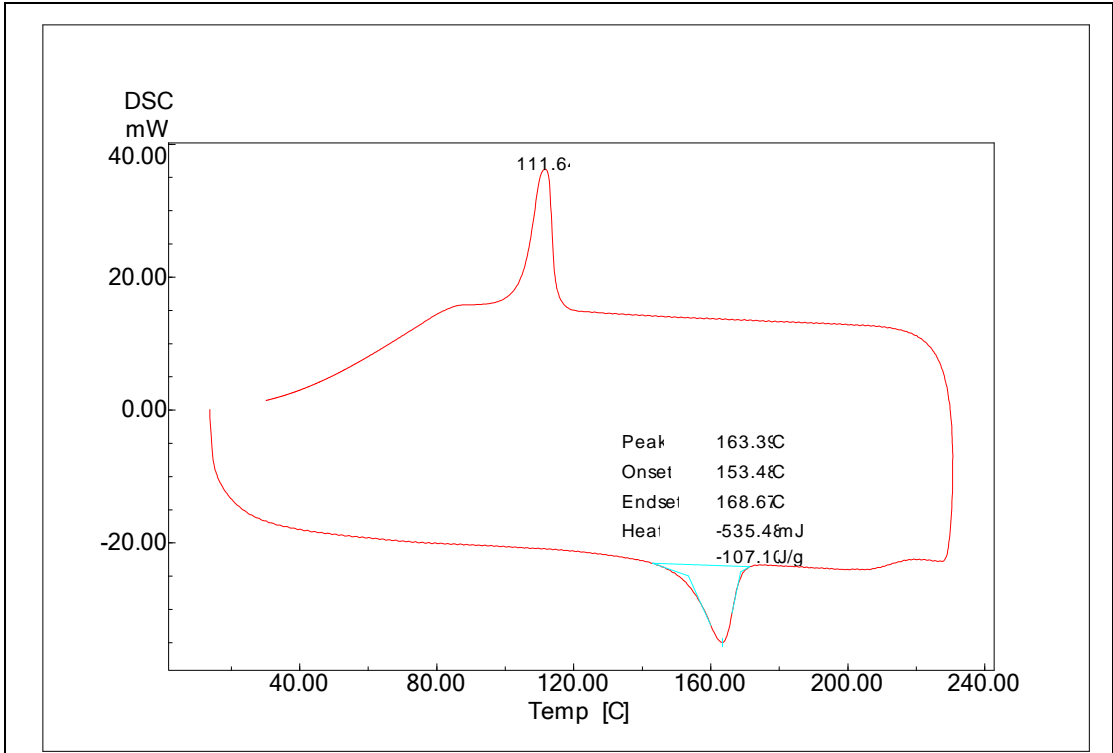


HDPE 10 C°/min.

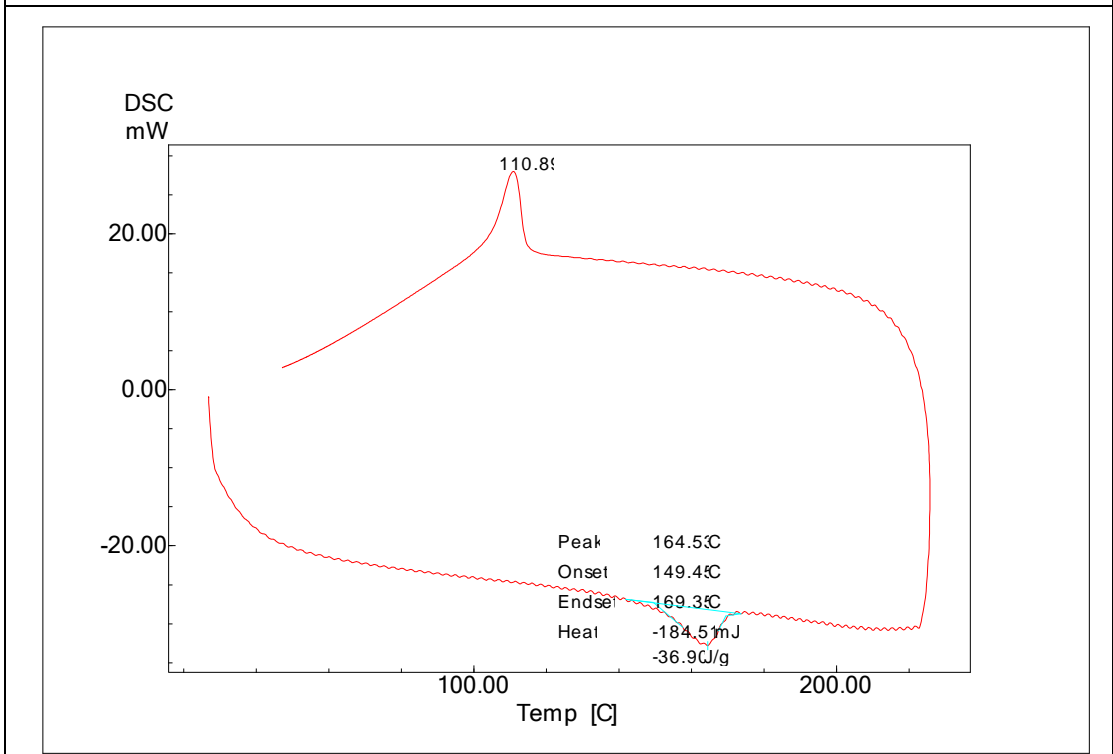


HDPE 20 C°/min.

Figure (3-4): DSC heating and cooling Curves for HDPE at different heating rate.

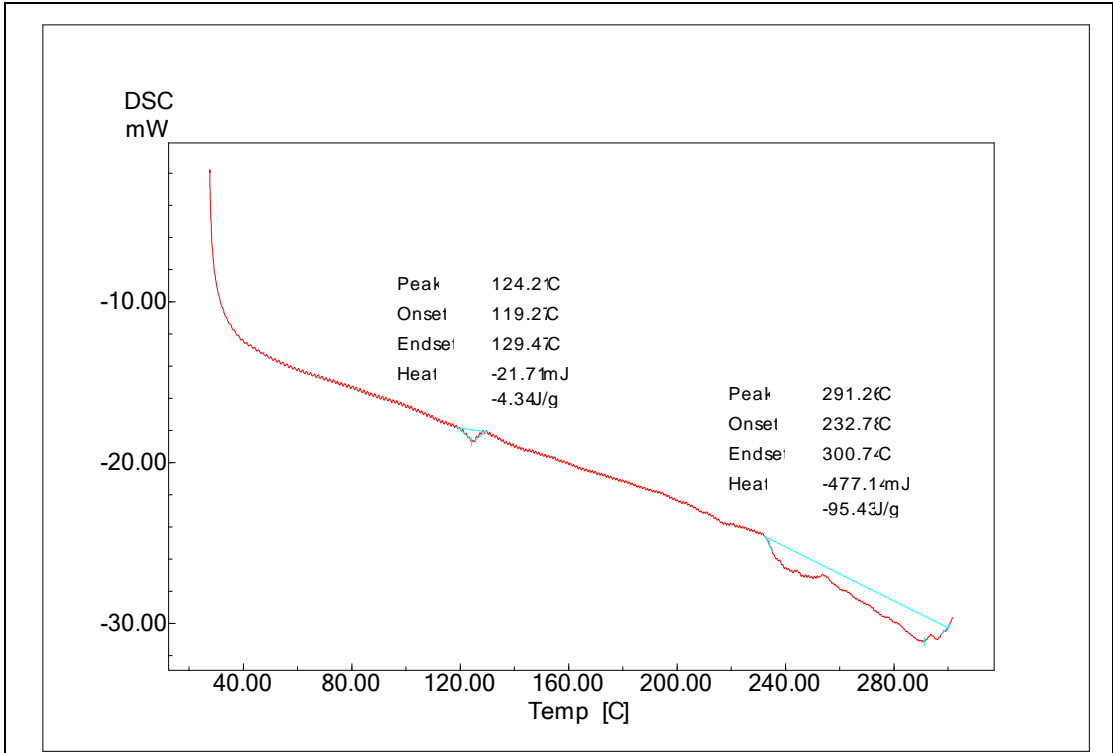


PP 10 C°/min.

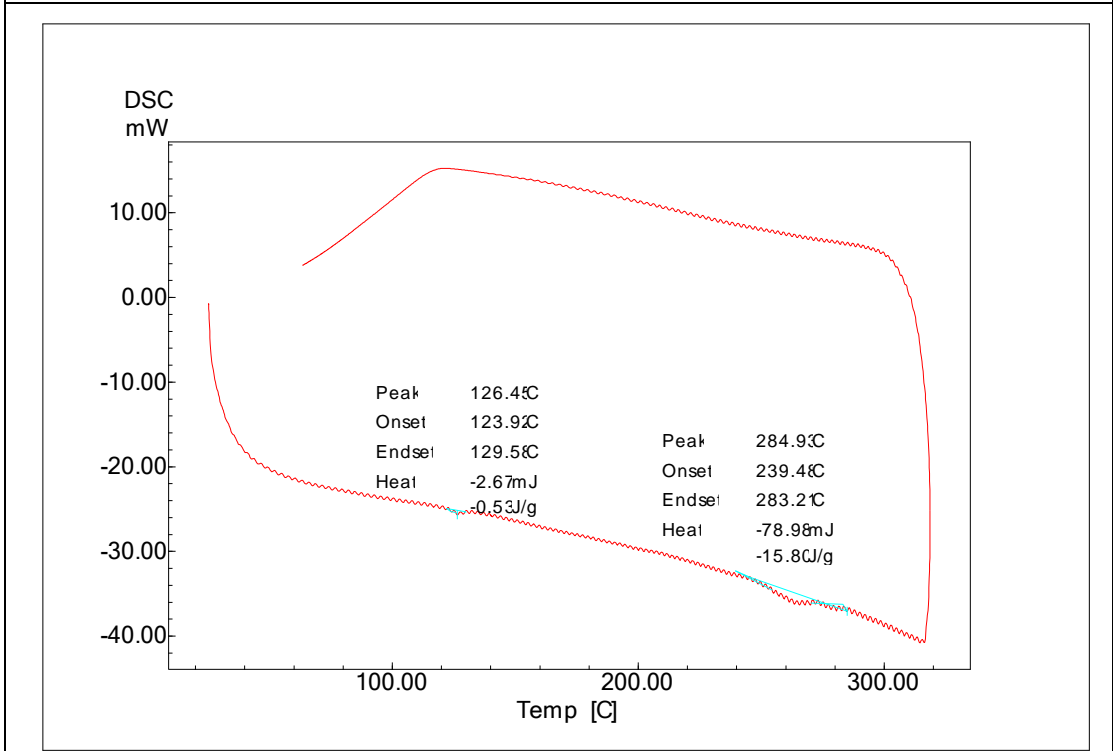


PP 20 C°/min.

Figure (3-5): DSC heating and cooling Curves for PP at different heating rate.

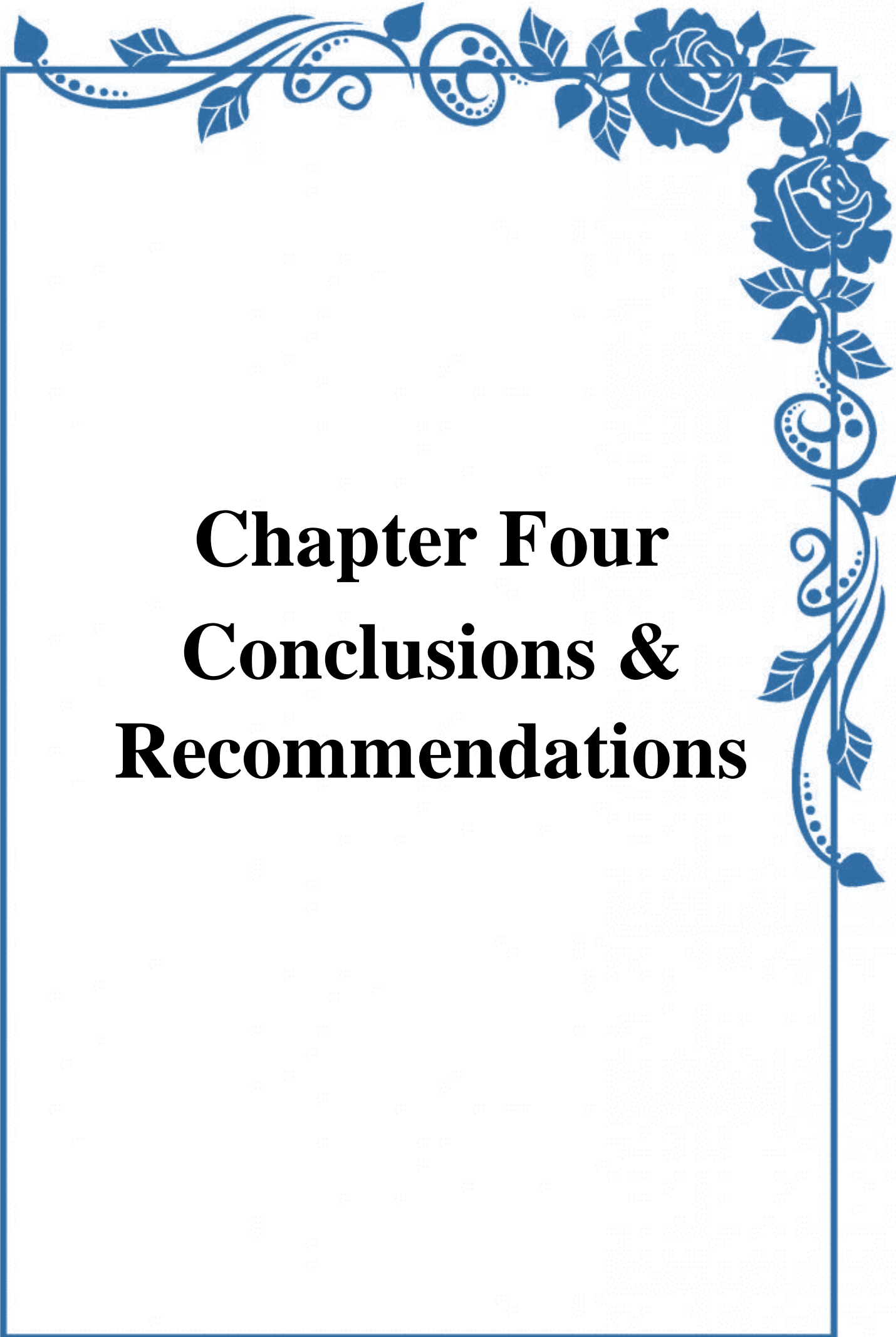


PVC 10 C°/min.



PVC 20 C°/min.

Figure (3-6): DSC heating and cooling Curves for PVC at different heating rate.



Chapter Four
Conclusions &
Recommendations

4.1. Conclusions

From the results discussed in chapter four, the following conclusions can be summarized as shown below:

1. Both tensile strength and the elastic modulus were increased as the strain rate increase, while elongation at break was decreased this is due to the change in material behavior as the strain rate increase.
2. The melting temperature and melting enthalpy were decreased as the heating rate increase; in addition, the crystallization temperature was slightly changed.

4.2. Recommendations

From the present study, the following recommendations can be helpful for further studies:

1. Study the effect of the addition of nanoparticle on the mechanical behavior of the same polymers with different strain rates.
2. Study the effect of the addition of nanoparticle on the thermal properties for the same polymers with changing the heating rates.
3. Preparing a polymer blends from other polymers and Study the effect of the same parameters (strain rate, and heating rate) on mechanical and thermal properties.



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