EXTRUDING CHARACTERISTICS
OF FUTO FABRICATED
EXTRUDER

By

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CERTIFICATION

This is to certify that the project on "Extruding Characteristics of FUTO Fabricated extruder" was carried out by AHARANWA, BIBIANA CHIMEZIE in the Department of Polymer and Textile Engineering, Federal University of Technology, Owerri.

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DEDICATION

This research work is dedicated to Almighty God, the God of knowledge and wisdom

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The successful completion of a work of this nature cannot be the product of my endeavour alone. I am greatly obliged to acknowledge my indebtedness to the contributive role played by innumerable others, all of whom will not be mentioned by name.

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ABSTRACT

Optimum working condition for the FUTO fabricated extruder was established. The effect of screw speed on the viscoelastic property (die swell), sensory characteristic (hardness) and mechanical properties (modulus, ultimate strength and %elongation at break) of NNPC Polyolefin blends (HDPE/PP) were investigated. Screw speed had no effect on the mechanical properties of the unblended samples. Lower speed was found to favour co-blending of HDPE and PP. Maximization of tensile modulus and ultimate strength in blends containing approx. 75% PP was observed. Mean residence time below 1.6min was found to be unfavourable for the blending of HDPE and PP.

CHAPTER ONE

1.0 INTRODUCTION

Processing of polymers is a way of treating, preserving and converting polymeric raw materials into useful forms which may be intermediates or end – products. Polymers are processed because they exhibit such properties as high strength, flexibility, elasticity, lightness, stability, moldability and / or ease of handling[1]. These properties have led to the rapid growth of the polymer industry. Blending of polypropylene and polyethylene to synergistically combine the properties of these two low-cost polymer families is an attractive option for a variety of applications in films and engineering thermoplastics[2,3]

The processing of polymers is determined largely by the rheological properties of the macromolecules. Thermoplastic materials flow at elevated temperatures, which allow the use of a wide variety of molding processes. In contrast, thermoset polymers undergo cross-linking reaction under processing conditions and so lose the ability to reflow if processed. Processing methods for thermosets include compression molding, reaction injection molding (RIM), transfer molding, injection molding, thermoforming and blow molding.

Thermoplastic polymers are supplied as pellets, granules, flakes and powders. Most molding processes involve the melting of the polymer, followed by the application of pressure to force the molten material into a mould cavity or through a die. The molten plastic is subsequently cooled below its Tg, to harden it. Heat and pressure are also used in thermoset processing.

Polymer processing operations may be classified as follows:

i. Extrusion
ii. Molding
iii. Spinning
iv. Coating
v. Lamination and
vi. Calendering

Extrusion involves continuous production of plastic pipes, films, sheets and rods. The two principal components of an extrusion machine are the screw and the die. The screw helps in the compacting, homogenization, melting, conveying and pumping of the material through the die, which gives the shape of the product.

Molding includes compression molding, transfer molding, injection molding, reaction injection molding, blow molding, thermoforming and rotational molding. Molding generally involves the filling of mold cavity. It is normally a batch process.

Compression molding is mainly used for thermosets such as phenolic resins, alkyds and unsaturated polyesters. It employs either a hydraulically operated press or a press utilizing hydraulically actuated toggles[4].

The nature of the material to be processed and the shape of the product required determine the method of polymer processing to be used.

1.1 AIM

To determine the extruding characteristics of FUTO fabricated extruder using PP/HDPE blends.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 EXTRUDER

The extruder performs more than a simple pumping function. They are sometimes fed with a mixture of pellets of two or more polymers, or with a polymer and a second phase (filler, pigment, lubricating agent etc), with the expectation that the output of the extruder will be homogeneous. This expectation is met to varying degrees depending upon design and operating variables.

2.2 TYPES OF EXTRUDERS

Extruders can be classified based on the methods of operating pressure. Pressure is commonly applied to a paste or molten material in one of the three general ways in industrial processing equipment;

i. By forcing together of two surfaces, normally as rotary cylinders,
ii. By placing the material (paste) in a cylinder and pressing on it with a ram, and
iii. By the use of rotating screws[5].

(a) ROTARY EXTRUDERS

This class of machine is often employed when the precise control of extrudate length is not important and such equipment is used for intermediate products or for those final products in which close tolerances are unnecessary.

In rotary extruder, the melt is fed into the nip between two counter – rotating cylinders, rotation of the cylinders forces the paste (melt) down into the nip and the pressure so generated causes flow through the perforations into the hollow centre of the perforated cylinder. The pieces of extrudate pass along the axis of the perforated cylinder and are removed from one end. It is also possible to have a very similar design in which both cylinders are hollow and perforated, with product being removed from one end of each. As in calendaring, the extrusion process is controlled by the shear imparted by the rotation of the cylinders to the paste (melt) held in the nip between the cylinders.

(b) RAM EXTRUDERS

Ram extruders are widely used to form intricately shaped components. In ram extruder, paste is fed in batches from a purging screw into the barrel. The ram or piston is then used to force material through the die entry into the die land. The ram is either driven by a hydraulic or mechanical system. A given pressure may be applied to the paste or alternatively a fixed ram speed may be obtained independent of paste properties. Advantageous features of ram extruders are that they permit accurate control of flow rate and high pressures can be developed.

(c) SCREW EXTRUDERS

The screw extruder is particularly convenient for making large batches and for processing continuously, unlike ram extrusion of pastes which is often semi batch but can also be continuous. Screw extruders are most suitable for relatively soft pastes, whereas a ram extruder is better when stiff materials make high extrusion pressures necessary. Screw extruder consists essentially of an Archimedean screw rotating in a closely fitting heated cylindrical barrel. The screw mixes, melts, homogenizes and moves the solid polymer feedstock to the end of the barrel where it is forced through a shaped die by means of pressure. The design of the die controls the configuration of the extrudate. On emerging from the die, the extrudate is cooled to reharden and then hauled off. Screw extrusion forms the basis of many other processing methods such as blow molding where it is used to form parison, injection molding where it plasticizes the feed material, extrusion coating where it provides melt from a slit die to coat a thin layer of plastic on a wide variety of substrates, and wire coating where a wire or cable is drawn through the core of a circular die, melt flowing through the annular space covers it.

Screw extruders can be single – screw or twin – screw. Use of twin screw is now becoming increasingly widespread. The two screws in twin extruder can rotate in opposite directions, this equipment being known as counter – rotating screw extruder. However, rotation in the same direction is also used; in this case the equipment is then known as a co – rotating extruder.

Knowledge of twin screw extruders is not as much as that of single screws, since there are more design and operating variables. The twin – screw design pushes the material through the extruder using positive displacement whereas in a single screw the motion is entirely dependent on frictional forces developed between the screw and the material, and between the barrel and the material. For conveying, material properties are thus less significant in a twin – screw machine. The transport of material along the extruder is similar in co – rotating and counter – rotating screw machines, the main differences lying in the degree of mixing in the regions where the screws intermesh. If the device is co – rotating, there is shear of the paste in the space between the screws which will promote homogenization and breakdown of agglomerates. The counter – rotating will transfer material from top to bottom thereby giving a more gentle bulk mixing action.

Both single and twin screws operate most commonly with the axis or axes lying in a horizontal plane. The single – screw extruder behaves like a nut and belt in which the extruder screw is a rotating bolt and the nut is a helical column of material. If there is no friction between the paste and the inner wall of the barrel, the melt rotates with the screw and no forward motion is developed. Conversely, if the melt adheres to the barrel wall too well, this will restrict axial movement. In practice, the combined action of four frictional forces can cause the column of material to move forward at an angle to the axis. These forces are axial and circumferential shear stresses acting at the inner wall of the barrel and stresses exerted on the material by the three faces of screw channel that again have axial and circumferential components. The action of the forces produces a rise of pressure in the material and this is then used to overcome the resistance to flow through the die. The single screw is of simpler mechanical construction and is less costly than a twin – screw machine.

Single screw extruders generally have poor dispersive mixing capability. The dispersive mixing capability can be improved by adding mixing sections to the screw. In comparing the mixing mechanism in single screw extruders to twin screw extruders, there are two important differences6. In single screw extruder, the flow in the high stress region (HSR) of most mixers is predominantly shear flow and the fluid elements passing through the HSR only. In twin screw extruders, the fluid pass through the HSR several times[7.]

2.3 MAIN ELEMENTS OF THE SINGLE – SCREW EXTRUDER

The main elements of a single – screw extruder are an Archimedean screw fitted into a long barrel with a hopper at the input end and a die at the output end[8]. The barrel and die are heated electrically, and the screw is turned by a variable – speed drive. In continuous operation, as in profile extrusion, equipment downstream of the die consists of a cooling tank that may be equipped with post – extrusion sizing or shaping features, and a mechanical puller to drag extrudate through the tank, followed by a coiler, cutter, or other take up equipment. Other auxilaries, such as printers, dryers, and colour concentrate feeders, are needed for most operations.

Non continuous extrusion, as in reciprocating injection moulding or blow moulding, involves starting and stopping screw rotation during each cycle of operation. Principles of screw design are unchanged but mechanics of the drives and controls are different in these cases. Sometimes, when the extruder is to be used primarily as a mixer, extra zones are included. These zones are mixing zone and decompression (or degassing or venting) zone and they improve the quality of the extrudate. The mixing zone consists of screw flights of reduced or reversed pitch or of some other design. It is sited at the end of the metering zone and its function is to ensure a uniform melt of constant properties. This it does by inducing turbulence to ensure intensive mixing action. Normally, it is followed by a second metering zone to even out temperature and pressure before extrusion. A neater arrangement is the use of a screw having a varying – pitch flighted mixing head. A variant of this is to fit a smear head to the end of the screw. It reduces the clearance in the region of the die, retards the melt from moving forward and increases shear thus improving shear mixing.

Rubber and Plastics Research Association have developed a device called Cavity Transfer Mixer (CTM), which is claimed to greatly improve the mixing efficiency of extruders. There is also the union carbide fluted mixing zone, barrier type, used for polyolefins[9].

i. **THE SCREW: -** The screw receives polymer as pellets or as granules (powder) from the hopper, to dispersively mix incoming solids (virgin resin, recycled resin, fillers and colour concentrate). It completely melts the material (except for the fillers), it raises melt pressure sufficiently to overcome fluid friction resistance of the die, and the screw also pumps a distributively mixed melt through the die at a stable pressure and temperature. In order to carry out these functions, almost all single screws have three separate sections: feed, compression or transition, and metering or melt pumping.

Quantitative analysis of polymer flow in a particular screw involves complicated consideration of screw geometry, rheological and thermal properties of the polymer in its solid and melt forms, and the polymer frictional properties.

The feed section is usually the deepest section of the screw. In this zone, resin granules or pellets are compressed sufficiently to force trapped air back to the hopper. Lumps of agglomerated pellets are broken up, so that melting can be effective. Ideally, dispersive mixing of the individual physical components of the incoming material is completed in the feed zone i.e. the different ingredients in the hopper are uniformly dispersed before softening. The solids – conveying zone is the first few flights of the screw, and it continues until frictional or external barrel heating creates a thin film of melt on the barrel. In the delay zone that may follow, the solid plug continues to heat up and advance, but melt film build – up is delayed for a few more flights.

In the transition zone, channel depth is tapered uniformly. Heating and friction are most intense; ideally, plastic leaving this zone should be completely melted, homogenized and raised to the temperature required at the die. The ratio of flight depth in the feed section to that in the metering section is the conventional compression ratio (CR) of the screw. It ranges roughly from 2:1 to 6:1, depending primarily on the type of plastic.

The final stage in a single screw is a constant flight depth metering zone. Melt pressure generally rises in this zone, and the melt is further homogenized and stabilized in pressure and temperature. Temperature can be raised or lowered in this zone and any variations in temperature across the flow stream are reduced or eliminated by distributive mixing within the melt, i.e. mixing in which previously dispersed material interchanges energies and emerges with uniform physical properties. The distance between corresponding points on two adjacent flights is the lead or pitch. A pitch or helix angle $\Theta = 17.66^\circ$. [Pitch = $\pi D \tan \Theta$, so $\Theta = \tan^{-1}(1/\pi)$ for a square pitch screw].

ii. **THE BARREL: -** The barrel housings are generally aluminium alloys for good thermal conductivity from the cast – in electric heating elements (and cooling liquid channels or air – cooling fans). The barrel is divided into four to six zones, which are controlled separately by individual thermocouple sensors and digital temperature contollers. Thermocouple tips should be 3 – 5mm from the inside of the barrel.

Barrel cooling requirements vary with the type of polymer extruded. High viscosity and / or heat sensitive polymers may require liquid cooling systems. To prevent corrosion and scaling, distilled water (the recommended cooling fluid) is circulated through a closed – loop heat exchanger system built into the extruder base, with the heat ultimately rejected to the plant cooling water system. This adds appreciably to equipment cost. In many cases, air cooling by means of fans located below the barrel is sufficient and much lower in cost than liquid cooling. The fans blow room air over the finned surfaces of the barrel when signaled by the temperature controllers. It is much quicker to heat up an extruder than to cool it down so operations should approach final temperatures slowly during startup to minimize startup time. The overall objective is to heat the polymer to extrusion temperature, cooling represents efficiency loss.

In continuous extrusion, the target is to provide 70% - 80% of the energy requirement from internal viscous friction and the balance from the external electric barrel heaters. The poor thermal conductivity of polymers thereby becomes an advantage by helping to distribute the internal viscous heat uniformly throughout the mass. External conductive heating is inherently non uniform. However, some cooling must be provided to accommodate local or temporary fluctuations. Extruders can be supplied in a range of barrel inside diameters (L.D.) from 10 to 300mm or larger, and in L/D ratios from 5 to 40. L/D ratios commonly used for thermoplastics range from 20:1 to 30:1.

iii. **FEED HOPPER: -** The hopper and its feeder should maintain constant level and pressure of feed material on the screw feed zone. Excessive fluctuations in level can be reflected as fluctuations in extruder flow rate or pressures. The hopper must not allow agglomeration of particles, material bridging, and hang-ups. Simple gravity feed with a conical hopper must be greater than the angle of repose of the plastic particles.

There are many different systems for drawing resin pellets or powder out of storage tanks, cartons, or drums and for delivering feedstock to one or more extruders in the plant.

To avoid bridging and hang-ups, vibrators are sometimes mounted on the hopper walls. For feeding twin – screw, compounding extruders with two different steams, rates of feed can be controlled using vibrators on horizontal feeding trays so that gravity and friction forces do not play a major role and feed composition can be accurately controlled. High capacity machines maybe fed by positive displacement auger feed screws discharging vertically into the extruder hopper. Attachments for the controlled addition of color concentrates and other additives are needed in most cases. If palletized color concentrates are used, the colorant feed control may use a combination of weight sensing and vibration forces. Another technique employs a small auger screw to feed pellets or granules, into the hopper, controlling the auger by on – off timer adjustments.

The feed control may also be arranged to starve feed the screw i.e. to meter in less than the amount required to keep the metering zone 100% filled. Metered starved feeding has the potential of enhancing venting from the feed zone back into the hopper because the screw channel is partly open from the hopper to the melt zone. Under proper operating conditions, starved feeding improves energy efficiency (i.e. it increases kg / hr output per KW consumed) and reduces unwanted surging. It is sometimes suggested as a last resort for extrusion of very high viscosity resins where the available machine and screw do not provide sufficient torque.

iv. **EXTRUSION DIE:** - The shape of the extrudate depends on the die hence the die is an important component of the extrusion process. Poor die design is a veritable source of flow defects. Die design is difficult and complicated because polymer melts are non – Newtonian as well as viscoelastic fluids. Modern computers have greatly facilitated the numerical solution of flow problems in dies. But experience and art still play a role in die design. For a start, the polymer to be extruded, output and dimensions of the shear rates, viscosity, modulus and the tensile component are unknown.

The simplest die has a uniform circular cross – section throughout its length. Circular dies maybe of zero length (short capillary) or of long capillary. Unfortunately these dies lead to non – laminar flow defects.

There is an abrupt change in flow channel diameter from that of the bore of the extruder barrel to that of these dies. The melt on approaching the die entry will immediately assume a natural angle of convergent for streamline flow. A consequence of this convergent flow pattern is that dead spots or recirculating zones where materials are held up are bound to occur in the corners resulting in extrudates of different thermal and stress history. Tensile stresses will also be set up in addition to shear stresses. If these tensile stresses exceed the tensile strength of the melt, the streamlines become discontinuous and disorganized.

The melt ruptures and the extrudate ceases to be smooth in appearance but becomes grossly distorted and even fractured in extreme cases. This phenomenon is known as melt fracture, non – laminar flow defects dies are usually tapered, which may be with or without extended parallel section at the exit called die land. Tapering the die causes a gradual change in flow channel diameter all the way to the die exit.

The three basic forms of tapered dies are coni – cylindrical (circular cross – section), annular with double convergence and wedge slot cross – section. Long die land extends the process time or residence (dwell) time so that there is ample opportunity to erase the memory of earlier processing. The die of the FUTO mini extruder was designed in a coni – cylindrical form.

2.4.0 EXTRUDER DRIVE SYSTEMS

The extruder drive system are perhaps the most important element of a properly engineered extrusion system after the extruder screw[10] Yet, this most critical element is often compromised with a resulting loss of performance in the extrusion process. The extruder drive determine and regulate screw rotation speed/extruder output. It also delivers power and torque to the extruder screw for processing.

2.4.1 DC MOTORS:

This is a type of extruder drive motor which provides two very important characteristics for extruder applications: They are capable of delivering very high starting (break-away) torque (often up to 150%). They are also capable of operating smoothly at very low speed at very high torque[11]. These advantages lead to the changing of the AC induction constant speed operation motor that was installed to the FUTO mini extruder before the onset of this project.

DC motors unfortunately have an inherent disadvantage; they require sliding carbon brushes which can become maintenance problems.

2.4.2 AC VARIABLE FREQUENCY INVERTER REGULATOR:

This varies motor speed by adjusting voltage level and voltage frequency, normally by maintaining the motor's design volts/hertz relationship. AC variable frequency inverters are not generally suited to the extended range of constant torque operation with high break-away requirements of extruder applications. Speed regulator is quite poor especially at low speeds where motor slip can be highest and break-away torque is very limited due to the difficulty in generating a voltage sine wave at zero hertz[10].

2.5 THE FUTO FABRICATED EXTRUDER[12-17]

The FUTO fabricated extruder, designed and constructed by Prof. Enyiegbulam M. E. is one of the first locally made equipment in the Federal University of Technology, Owerri. Prof. Enyiegbulam with the help of his research students[12-17] fabricated the extruder which consists of the following components:

i. The drive system, which consists of the electric motor, the sprocket and the chain system of pulley
ii. The barrel and screw
iii. The electrical component
iv. The die head system
v. The feed hopper
vi. The cooling section, and
vii. The haul – off system

The electric motor installed was an AC motor. This supplies the power needed to rotate the screw. The speed of the motor determines the speed of the extrusion process. The sprocket works with the chain to transfer motion from the drive to the driver. The barrel covers the screw of the extruder, and has the following specifications;

Material	-	Stainless steel
Length of barrel	-	460mm
External diameter	-	57mm
Internal diameter	-	31mm
Thickness	-	26mm

The screw, which does the job of moving the resins through the barrel chamber in a steady and predictable manner, has the following specification:

Material – stainless steel

Screw diameter (D)	–	30mm
Screw length (L)	–	460mm

Length of feed zone (L_f) - 115mm

Length of compression zone (L_c) - 184mm

Length of metering zone (L_m) - 161mm

Flight tip / barrel clearance - 0.55mm

Flight angle (Φ) - 17.67˚

Flight width (e) - 3.0mm

Channel width (T) = (D – e).cosΦ = (30 – 3)cos 17.67˚

= 25.73mm

Number of parallel flights = 12

Channel depth in feed zone (Hf) = 7.5mm

Screw pitch = πD.tanΦ

= π30.tan17.67˚

= 30mm

Flight channel depth (H_m) = 3.6mm

External diameter of Die = 10mm

Diameter Mandrel = 9mm

Die gap = (10-9)mm

= 1mm

The electric components are the heating bands, the thermocouple, the control panel, temperature controller, the switches and indicator bulbs.

The heater bands were used to convert electrical energy to heat energy. The heat energy is transferred to the barrel by conduction. The heater bands installed were six in number, each rating 500watts and 220V. Each zone contains two heating bands.

The FUTO laboratory size extruder is of immense help for students' demonstration. Moreover, its fabrication has been a challenge to both staff and students in the university at large, thereby encouraging and improving their technological development.

2.6 EXTRUSION

Extrusion is derived from the latin word "extrudere": "ex"–out and "trudere": to push. Extrusion therefore involves the softening or melting and forcing out of material under pressure through an orifice (die) which shapes the extrudate to desired profile or cross-section. Softening of a rubber or melting of a rubber or melting of a thermoplastic within a cylindrical tube (barrel) is due to external heating combined with viscous friction created by a rotating screw. The screw also generates the pressure necessary to overcome fluid friction resistance of the die. The extrudate can be thermoplastic polymer, unvulcanized rubber, lead, aluminum, or other metal or even foodstuff, such as spaghetti. Extrusion occurs in food industries and metallurgical industries. Extrusion is a continuous process, shapes like pipe, rod channel and sheet can be extruded.[18,19,20]

2.6.1 EXTRUSION PRODUCTS

Because extrusion includes so many types, it is useful to break extrusion down into major types of products. These include profiles, pipes, sheets, films, blown films, filaments, coating and wire coverings[21].

(a) PROFILE EXTRUSION

The term profile extrusion applies to most extruded products other than pipe, film, sheet and filaments. Products from profile extrusion are generally extruded horizontally. Achieving a desired shape requires equipment to support and shape the extrudate during cooling. The cooling comes from air jets, water troughs, water sprays, and cooling sleeves.

Controlling the size or shape of such profiles can be difficult, because when a material exits an extruder die, it changes shape due to die swell. In the extruder or die, the melted plastic is under compression. The release of elastic energy in the compression causes the extrudate to expand in cross-section. When the extrudate does not have uniform cross-section, the shrinkage upon cooling will also not be uniform. To produce exact cross-sectional dimensions after the extrudate has cooled, allowances must be made in the orifice design. To reduce problems caused by complex geometry of profile dies, postforming of simple shapes are chosen. A flat – tape shape maybe postformed into a corrugated form. Round rods may be postformed into oval or other new shapes while the extrudate is still hot.

(b) PIPE EXTRUSION

Pipe is a tube through which liquids and gases can flow. Pipes hold second place to film with regard to quantity in the extrusion of thermoplastics. Pipes are shaped by the exterior dimensions of the orifice and by the mandrel (sometimes called pin), which shapes inside dimensions. The mandrel is held in place by thin pieces of metal called spiders. The diameter of the pipe or tube is also controlled by the tension of the take – up mechanism. If the tube is pulled faster than speed of the extrudate melt, the product will be smaller and thinner than the die. To prevent the tube from collapsing before cooling, it is pinched shut on the end and air is forced in through the die. This air pressure expands the pipe slightly. The hot tube maybe pulled through a sizing ring or vacuum ring to hold the outside diameter to a close tolerance. The thickness of the pipe wall is controlled by the mandrel and die size. The production of pipe can be broken down into the following products:

i. Conduit pipes
ii. Pressure pipes
iii. Cables – and electro conduit pipes
iv. Drainage pipes
v. Industrial pipes
vi. House drainage pipes
vii. Gutter and drainage pipes
viii. Gas pipes
ix. Pipes for domestic drinking water installation

The range of products is completed by semi-finished products for industrial processing, such as pipes made from other thermoplastic materials, e.g.

polyamide pipes for automobile industry, pipes and hoses from unplasticized PVC for the medical sector, with polyamide or polyester webbing for agriculture, biaxially stretched tubes for shotgun cartridges etc[20].

Pipes made from thermoplastics are continuously extruded. Single screw extruders are used for polyolefins and other thermoplastic materials. Rigid pipes are cut to length and flexible pipes are wound.

(c) SHEET EXTRUSION

The American Society for Testing and Materials (ASTM) has defined film as plastics sheeting 0.25mm [0.01 in] or less in thickness. Sheet extrusion produces stock for use in most thermoforming operations.

Most sheet forms involve extruding molten thermoplastic materials through dies with a long horizontal slot. These dies come in two major styles, the T – shape, and the coat hanger – shape. In both styles, the molten material is fed to the canter of the die. It is then formed by the die lands and adjustable jaw. The width may be controlled by the external deckle bars or by the actual die width. The extruded sheet goes over or through a set of rollers to provide desired surface finish or texture and to accurately size the thickness.

(d) FILM EXTRUSION

Film extrusion and calendaring produce finished products that are rather similar. Although calendaring is not technically an extrusion process, it logically deserves treatment along with film extrusion. Film extrusion is similar to sheet extrusion. Beside the difference in thickness, film – extrusion dies are lighter than sheeting dies and possess shorter die lands than sheet dies.

Film extrusion is costlier than blown film and consequently, is used only when the film quality must be higher than blown film. Some plastics such as PVC are heat sensitive and tend to decompose or degrade due to high temperature. So, to make PVC film, slot extrusion or blown film techniques are generally not used. PVC film generally requires calendaring.

(e) BLOWN – FILM EXTRUSION

In blown – film extrusion, the film is produced by forcing molten material through a die and around a mandrel. It emerges from the orifice in tube form. This process is like that used to make pipes or tubes. Blowing air through the centre of the mandrel until the desired film thickness is reached expands this tube, or bubble. The tube is usually cooled by air from a cooling ring around the die. The size and thickness of the finished film is controlled by several factors including extrusion speed, take – off speed, die (orifice) opening, material temperature and the air pressure inside the bubble or tube. Blow – up ratio is the ratio of the die diameter to the bubble diameter.

Blown – extruded film is sold as seamless tubing, as flat film, or as film folded in a number of ways. Blown films are semi – oriented, that is, they have less orientation of molecules in a single direction than film from slot dies. Blown films are stretched as the tube is expanded by air pressure. Such stretching results in a more balanced molecular orientation in two directions. Products are biaxially oriented, one in the direction of length and one across the diameter of the bubble. Improved physical properties are an asset of blown film. However, clarity, surface defects and film thickness are harder to regulate than with slot extrusion.

(f) FILAMENT EXTRUSION

A filament is a single, long, slender strand of plastics. This single filament of plastics may be made in any desired length. Yarns maybe composed of either mono-filament or multifilament strands of plastics. The term fibre is used to describe all types of filaments, natural or plastics, monofilament or multifilament. Monofilaments are produced much as are profile shapes, except that a multi-orifice die is used. These dies contain many small openings from which the molten material emerges. Such dies are used to produce granular pellets, monofilaments and multifilament strands.

Filament shapes are made by forcing plastics through small orifices in a process referred to as spinning. The plastic is shaped by the opening in the die or spinneret. Because these openings are very fine (small), spinnerets are often made of such metals as platinum, which will resist acids and orifice wear. To be extruded out of these small openings, the plastics must be made fluid.

(g) EXTRUSION COATING AND WIRE COVERING

Paper, fabric, cardboard, plastics, and metal foils are common substrates for extrusion coating. In extrusion coating, a thin film of molten plastic is applied to the substrate without the use of adhesives and pressed between rollers. For special applications, adhesives may be needed to ensure proper bonding. Some substrates are pre-heated and primed with adhesion promoters using slot – extruder dies. In wire and cable coverings, the substrate for extrusion coating is a wire. During this process, a molten plastic is forced around the wire or cable as it passes through the die. Wires and cables are usually heated before coating to remove moisture and ensure adhesion.

2.6.2 EXTRUSION DEFECTS

(a) **DIE SWELL:-** This is a common experience that when a polymer is extruded from a die, provided there is no drawing down, the cross-section of the extrudate is greater than that of the die. Swelling ratio, X, that is ratio of the extrudate diameter (D_e) to die diameter (d), using a circular die. It is generally between two to three.

$$\text{Swelling ratio} = De/d \qquad \text{------} \qquad 2.1$$

The amount of die swell is related to the amount of elastic deformation of the material at the inlet of the die[22]. The degree of die swell is dependent on the length of the die when material is extruded at constant throughput. Die swell can result in the swelling of wall thickness, B_{st} and diameters B_{sw} of the parison (extrudate). The swelling ratios have a relationship

$$B_{st} = B^2_{sw} \qquad \text{-----} \quad 2.2$$

$$B_{st} = T_e/T \qquad \text{-----} \quad 2.3$$

where T_e = thickness of extrudate and T = die gap

The basic idea is to think of die swell as a problem in elastic recovery. Tanner[23] in his model related die swell with shear rate. The theory due to Tanner may be written in the form

$$X = (1 + \tfrac{1}{2} S^2_R)^{1/6} \qquad \text{--------} \quad 2.4$$

where X = die swell, S_R = Shear rate.

He suggested replacing X with (X – 0.1) as a means of compensating for the viscous contribution to die swell.

The parameters which affect die swell may be listed as flow rate (shear rate), temperature, capillary length – to radius ratio (L/R), residence time, shear strain/ shear stress, molar mass and molar mass distribution, die design and chemical nature of the polymer. Fujiyama and Kawasaki[24] in their work found that die swell of HDPE and PP blends are always greater than that of the unblended samples

(b) MELT FRACTURE

If a polymer is extruded at low output rates (or low shear rates), a regular shaped extrudate with a smooth and glossy surface is usually obtained, however, above the critical flow rate (or critical shear rate or critical shear stress) the extrudate is no longer smooth but becomes uneven and may even be grossly distorted. The form of distortion varies widely and may be described as spiral, bamboo and ripple where the distortions are fairly regular or as random fracture where there is a full break-up of the melt[9]. To avoid this problem, this research was carried out at low screw speeds.

(c) SHARKSKIN

Sharkskin is a surface defect on an extrudate and shows itself as a series of ridges perpendicular from melt fracture in that the distortion is perpendicular to the flow direction rather than having helical or irregular pattern. Temperature has a strong effect on sharkskin being considerably delayed when the temperature is raised. Extrusion at high temperatures and slow speeds reduces Sharkskin considerably[9].

(d) FROZEN – IN ORIENTATION

The long chain molecules of polymers are usually coiled and entangled at random. On application of stress these molecules tend to disentangle and align themselves in the stress direction. This is referred to as orientation. On releasing the stress the molecules strive to coil up again. The rate of coiling is given by relaxation time and for many polymer melts, it is about 0.1 – 0.5 sec. Orientation invariably occurs during normal processing as polymer melts are forced to flow along channels and into mould cavities. The greater the shear rates the higher the degree of orientation. Unless this orientation is first relaxed by releasing the shearing force in the melt and thus allowing the molecules to recoil, some of the orientation may be ‘frozen – in’ in the solid polymer. The extent of orientation depends on the processing conditions such as shear rate, melt temperature and mould temperature, and on material properties such as specific heat and geometry of molding.

2.7 MATERIALS

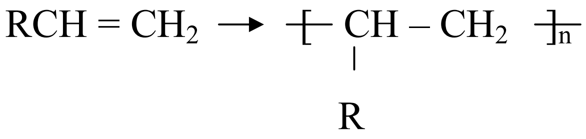
2.7.1 POLYOLEFINS

Polyolefins is a term used to indicate a family of polymers produced from hydrocarbons with double carbon – to – carbon bonds (olefins). The word olefin means oil forming. It was originally given to ethylene because oil was formed when ethylene was treated with chlorine. Some of the olefin monomers are ethylene, propylene and methyl pentene. These monomers are polymerized to get polyethylene, polypropylene and polymethyl pentene respectively[25]. All are break–resistant, non-toxic, and non-contaminating. These are the only plastics lighter than water. They easily withstand exposure to nearly all chemicals at room temperature for up to 24 hours. Strong oxidizing agents eventually cause embrittlement. All polyolefins can be damaged by long exposure to light.

The polyolefins derive their physical properties from the arrangement or entanglement of the atoms in the chain molecules. Branching caused by radical transfer influences the physical properties as well as molecular distribution.

Polyolefins are the volume leaders in industrial polymers. They are based on low – cost petrochemicals, or natural gas and the required monomers are produced by cracking or refining crude oil. The outstanding growth rate of the four major polyolefins, polyethylene, polypropylene, polyvinyl chloride (PVC), and polystyrene is based strictly on economics. They are by far the least expensive industrial polymers in the market[26].

Polymerization of olefins is a general reaction, and in addition to the four major products a wide variety of other polyolefins are commercially available. In all polyolefins the repeating unit in the macromolecule is identical with the monomer.



$$RCH = CH_2 \rightarrow \left[\underset{\displaystyle R}{\underset{|}{CH}} - CH_2 \right]_n$$

R depends on the monomer or polymer in question. Four types of polymerization processes for polyolefins are known:-

i. Free radical initiated chain polymerization,

ii. Cationic polymerization

iii. Anionic polymerization, and

iv. Organo – metallic intiation (Ziegler – Natta catalyst). By far the most extensively used process is the free radical initiated chain polymerization.

(a) POLYETHYLENE: - The polymerization of ethylene results in an essentially straight chain, high molecular weight hydrocarbon. The polyethylenes are classified according to the relative degree of branching (side chain formation) in their molecular structures, which can be controlled with selective catalysts. Like other polyolefins, the polyethylenes are chemically inert. Strong oxidizing agent will eventually cause oxidation and embrittlement. Aggressive solvents will cause softening or swelling, but these effects are normally reversible.[27]

Polyethylene is partially amorphous and partially crystalline. Side – chain branching is the key factor in controlling the degree of crystallinity. High density polyethylene (HDPE) has up to 90% crystallinity, while low density polyethylene (LDPE), exhibits crystallinities as low as 50%. Increasing the density, increases stiffness, tensile strength, hardness, and heat and chemical resistance, opacity and barrier properties but reduces impact strength and stress – crack resistance. There are different types of polyethylene;

i. **Low density polyethylene (LDPE): -** This is manufactured under high pressure (15,000 – 50,000 psi and temperature to 350˚C), using peroxide initiators. The amorphous and branched product has a melting range of 107 – 120˚C. LDPE has more extensive branching, resulting in a less compact molecular structure.

ii. **High Density Polyethylene (HDPE): -** This type of polyethylene uses Zeigler – Natta or Philips catalysts (Chromium oxide) in a low – pressure process. The melting range of the more linear HDPE is 130 – 138˚C. This has minimal branching, which makes it more rigid and less permeable than LDPE.

iii. **Linear Low Density Polyethylene (LLDPE): -** LLDPE polymers are linear but have a significant number of branches. The linearity provides toughness. It combines the toughness of low – density polyethylene with the rigidity of high – density polyethylene. They exhibit good flex life, low war page and improved stress-crack resistance

iv. **Very low Density Polyethylene (VLDPE)**

This linear, non-polar polyethylene is produced by copolymerization of ethylene and others alpha olefins. Densities range from 0.890 to 0.915. VLDPE is easily processed into disposable gloves, shrink packages, vacuum cleaners hoses, tubing, squeeze tubes, bottles, diaper film linear and other heath care products.

v. **Ultrahigh Molecular Weight Polyethylene (UHMWPE):**

Ultrahigh molecular weight polyethylenes have molecular weights from 3 to 6 million. This accounts for their high wear resistance, chemical inertness, and low coefficient of friction. These materials do not melt or flow like other polyethylenes.

vi. **Cross linked High Density Polyethylene (XLPE):** - This is a form of high – density polyethylene, wherein the individual molecular chains are bonded to each other (using heat, plus chemicals or radiation) to form a three –

dimensional polymer of extremely high molecular weight. This structure provides superior stress crack resistance and improves the toughness, stiffness and chemical resistance of HDPE. This is a superior material for molding very large storage tanks, as well as tanks that will be used in high performance applications.

(b) POLYPROPYLENE (PP):- PP is made by low – pressure processes, using Zeigler – Natta catalysts (aluminum alkyls and titanium halides). Usually 90% of the polymer produced is in the isotactic form. The isotactic polypropylene cannot crystallize in the same fashion as polyethylene (planar zig zag), since steric hindrance by the methyl groups prohibits this conformation. Isotactic polypropylene crystallizes in a helical form in which there are three monomer units per turn of the helix. PP is similar to polyethylene, but each unit of the chain has a methyl group attached. It is translucent, autoclavable, and has no known solvent at room temperature. It is slightly more susceptible than polyethylene to strong oxidizing agents. It offers the best stress – crack resistance of the polyolefins. Products made of polypropylene are brittle at 0˚C and may crack or break if dropped from bench top height.

(c) POLYVINYL CHLORIDE (PVC): - Is similar in structure to polyethylene, but each unit contains a chlorine atom. PVC is produced mainly by free radical initiated suspension. Emulsion polymerization processes are also employed to some extent. The chlorine atom in PVC renders it vulnerable to some solvents, but also makes it more resistant in many applications. It has extremely good resistance to oils (except essential oils) and very low permeability to most gases. It is transparent and has a slight bluish tint. Narrow - mouth bottles made of this material are relatively thin – walled and can be flexed slightly. When blended with phthalate ester plasticizers, useful tubing to be found in every well – equipped laboratory.

(d) POLYMETHYL PENTENE (PMP): - This is similar to polypropylene, but it has an isobutyl group instead of a methyl group attached to each monomer group of the chain. Its chemical resistance is close to that of PP. It is produced by Zeigler type catalyst at atmospheric pressure. It is more easily softened by some hydrocarbons and chlorinated solvents. PMP is slightly more susceptible than PP to attack by oxidizing agents. Its excellent transparency, rigidity and resistance to chemicals and high temperatures make PMP a superior material for lab ware. PMP withstands repeated autoclaving, even at 150˚C. It can withstand intermittent exposure to temperatures as high as 175˚C. Products made of PMP are brittle at ambient temperature and may crack or break if dropped from bench top height.

(e) POLYSTYRENE (PS): - Polystyrene is made by bulk or suspension polymerization of styrene. It is commonly available in crystal, high impact and expandable grades. It has excellent dimensional stability and good chemical resistance to aqueous solutions, but limited resistance to solvents. This glass – clear material is used for disposable laboratory products, electronics appliances, furniture and construction (insulation). Products of PS are brittle at ambient temperature and may crack or break if dropped from bench top height.

(f) POLYKETONE: - This is a new and unique family of aliphatic polymers composed of carbon monoxide, ethylene and minor amounts of other alpha olefins. This family of semi – crystalline resins exhibits many of the properties of engineering resins with processing similar to polyolefins. The resins exhibit excellent creep resistance and stiffness coupled with broad chemical resistance to acids, bases and aliphatic and aromatic hydrocarbons.

(g) ELPENE AND ELPROP[29,30]: - Elpene is the trade name of the linear polyethylene resin produced by Eleme Petrochemical Company Ltd (A subsidiary of NNPC) using the SLAIRTEC linear polyethylene process. Its main properties include:

i. A wide range of densities (0.915 – 0.960)
ii. Excellent chemical resistance
iii. Excellent heat – sealing performance
iv. Outstanding mechanical strength, manifested in high tensile strength
v. Attractive surface gloss
vi. Resins with narrow through medium to broad molecular weight distribution
vii. Outstanding capability to draw down to thinner grades
viii. High impact strength

Elpene has the ability to meet plastics market demands for the following: film, injection moulding, blow moulding, extrusion coating, pipes, oriented structures and rotational moulding.

Elprop is the trade name of the polypropylene resin using the MONTELL polypropylene process technology. Its main properties include;

i. High hardness and rigidity
ii. Good heat and abrasive resistance
iii. Good impact strength
iv. Excellent processability
v. Excellent chemical resistance

Elprop can be used in a wide spectrum of applications, which include extruded films and sheets, injection moulding items, paper and cardboard / laminations, electrical, automobile and domestic appliances, pipes (rigid and flexible, pressure pipes, corrugated pipes) cable coating.

2.8 BLENDING

Mixing together of two or more different polymers is known as blending. In a polymer blend, the constituent polymers are usually present in significant weight or volume proportions with respect to each other, but seldom all in equal proportions. The objective of blending is to develop and produce new uniform materials having ranges of properties far different from those of the constituents.

2.8.1 COMPATIBILITY OF POLYMERS

The question of compatibility between polymers is a very important consideration in making blends from them. In a general manner it may be said that polymer – polymer incompatibility is more a rule than the exception. Even if two different polymers are by and large compatible under a specified condition, they slowly develop incompatibility as they are put to use under a different set of conditions. It is at the same time questionable if complete miscibility or compatibility between the component polymers in a blend is at all the most desired feature. A useful blend has the characteristics of a uniform dispersion – fine discrete particles of one component being uniformly dispersed through the medium or matrix of the other component.

2.8.2 TECHNIQUE OF POLYBLENDS

There are different techniques of polymer blend (polyblend)

i. Mechanical polyblends
ii. Chemical polyblends
iii. Mechano – chemical polyblends
iv. Solution cast polyblends and
v. Latex polyblends

2.8.3 MECHANICAL POLYBLENDS: - This is made by melt blending of the constituent polymers. In the cases of binary blends from two different amorphous polymers, the processing temperature must at least be well above the T_g of both the constituting polymers, and for blends of semi crystalline polymers, it must be higher than the melting points (MP) of the two constituent polymers. Because of the high heat input necessary to maintain a low melt viscosity and also because of the high shearing rates needed for thorough mixing or blending, some degree of chain branching or chain extension leading to formation of block and graft copolymer structures, chain scission and even cross – linking may occur in the polymers making the blend. (Melt mixing is used for systems in which thermal degradation does not ordinarily occur. This is the type of blend carried out in this research work).

2.8.4 CHEMICAL POLYBLENDS AND MECHANOCHEMICAL POLYBLENDS: - A chemical polyblend is given by polymeric systems in which long monomeric sequences of one kind are chemically linked to similar long monomeric sequences of a different kind in either the axial direction giving block copolymer or graft copolymer structures, respectively. Selective or random cross linking of mechanical blends may ultimately lead to mutual grafting, co cross linking or inter cross linking resulting in the formation of what may be termed as mechano – chemical polyblends.

2.8.5 SOLUTION CAST POLYBLENDS: - In solution blending, selected diluents are used to dissolve the component polymers; the diluents also lower the temperature and shear force necessary for satisfactory and uniform mixing without having any degradative effect in the bulk properties of the blend prepared.

2.8.6 LATEX POLYBLENDS: - In latex polyblend, polymers are present as suspended, stabilized microphores of a specific size and size distribution. The mixture contains a random suspension of dissimilar kinds of particles, each unaffected by the presence of the others of like or unlike kinds. As the flocculation is entirely contingent upon the emulsifier concentration and not on the polymer characteristics, the coagulation is manifested as a random process. Blends obtained on coagulation appear as relatively intimate mixtures of the constituent polymers.

2.9 TYPES OF POLYBLENDS

Commercial polyblends are commonly of three types: -

i. Elastomer – elastomer blends
ii. Plastomer – plastomer blends, and
iii. Elastomer – plastomer blends

2.9.1 ELASTOMER – ELASTOMER BLENDS: - Single elastomer often fails to offer the desired balance of properties and overall cost advantage, as a result, elastomer – elastomer blends are widely made. Natural rubber is selectively blended with synthetic rubbers to improve a range of properties such as tack, resilience, tear strength, heat – build – up and sometimes fatigue resistance. Likewise, selected synthetic rubbers are blended with primarily natural rubber based compound to obtain advantages with respect to wear or cracking resistance, bounce and cost – effectiveness. Synthetic rubbers are sometimes blended with themselves.

2.9.2 PLASTOMER - PLASTOMER BLENDS: -

In the thermoplastic range, commercial polyblends include combination of poly(methyl methacrylate), polystyrene (PS), polycarbonates (PC), nylons, polyethylene (PE), polypropylene (PP), polyethylene teraphthalate (PET), Polyimides, thermoplastic polyurethanes, ionomers etc. They are combined to enhance the quality of the blends such as to reduce the flammability, brittleness etc. It can also be blended to increase the stability and reduce cost. (With FUTO laboratory size extruder, HDPE and PP were blended to get compositions with good balance of stiffness and toughness).

2.9.3 ELASTOMER PLASTOMER BLENDS:

- Blending of an elastomer with a selected plastomer provides a convenient means of making thermoplastic elastomers (TPE) of diverse nature. Polyolefin thermoplastics are blended with such elastomer as natural rubber. To be widely useful, the elastomer component should have a $T_g < -50^\circ C$ and the thermoplastic polymer used must have a $T_m \gg$ the service temperature of the blend.

2.10 MECHANICAL PROPERTIES OF POLYMER

The mechanical properties of a material describe how it responds to the application of a force or load[25,26]. There are only three types of mechanical force that can affect materials namely: - compression, tension and shear. The mechanical tests consider these forces separately and in combinations. Tensile, compression and shear tests measure only one force, while flexural, impact and hardness tests involve two or more simultaneous forces. So many factors affects the mechanical properties of polymers such as incorporation of additives blending and copolymersation[33] Lovinger[34] et al and Noel, F.C[35] in their work found that maximization of some mechanical properties (such as modulus and ultimate strength) and minimization of the % elongation occur at higher PP composition of HDPE and PP blends.

2.11 TENSILE TEST

A common mechanical test for plastics is the tensile test. Tensile properties are important indicators of the material's behaviour under loading in tension. A specimen is stretched at a constant speed, and the force recorded. Measurement of induced force or stress, elongation or strain is done simultaneously, manually, mechanically or with the help of computer microprocessor[35].

A stress – strain curve can then be derived. This curve characterizes the behaviour of the material tested. Engineering stress, σ_E and strain, ε_E measures are distinguished by the use of fixed reference qualities, typically the original cross – sectional area or original length. More precisely, in engineering applications, these definitions are accurate enough, because the cross – sectional area and length of the specimen do not change substantially while loads are applied in other situation (such as the tensile test), the cross – sectional area and the length of the specimen can change substantially. In such cases, the engineering stress calculated using the definition (as the ratio of the applied load to the undeformed cross – sectional area) ceases to be an accurate measure. To overcome this issue alternative stress and strain measures are available known as true stress and true strain. Engineering stress and strain are converted to true stress and strain with the equation below:

$$\varepsilon_T = \ln(1 + \varepsilon_E) \quad - \quad - \quad - \quad - \quad - \quad 2.4$$

$$\sigma_T = \sigma_E(1 + \varepsilon_E) \quad - \quad - \quad - \quad - \quad - \quad 2.5$$

where σ_T and ε_T, are true stress and true strain respectively. σ_E and ε_E are engineering stress and strain.

2.12 TOUGHNESS:

TOUGHNESS: The toughness of a material is the area under a stress-strain curve. It is the work (energy) required to break the sample. The toughness is a measure of the energy a sample can absorb before it breaks.

$$\text{Toughness} = (Y_s + U_s)/2 \times S_f \quad \text{----------------}2.6$$

where Y_s = Yield stress

U_s = Ultimate Stress

S_f = Strain at fracture

2.13 ELONGATION:

ELONGATION: This is the ratio of change in length to original length.

$$\text{Elongation} = (L_f - L_o)/L_o \quad \text{---------------}\ 2.7$$

where L_f = Final length

L_o = Initial length.

2.14 IMPACT STRENGTH:

IMPACT STRENGTH: Impact tests measure the energy expended up to failure under conditions of rapid loading. There are a number of different types of impact tests. These include the widely used izod and charpy tests in which a hammer like weight strikes a specimen and the energy-to-break is determined from the loss in the kinetic energy of the hammes.[37] Other variations include the falling –ball or dart test, whereby the energy-to-break is determined from the weight of the ball and the height from which it is dropped. Values of impact test may also be calculated from the area under the stress-strain curve in high – speed tensile tests.

2.15 HARDNESS: This is a complex property and is related to such mechanical properties of materials as modulus, strength, elasticity, resilience and plasticity. Hardness of a material refers to its resistance to deformation or indentation by a rigid body of a specified dimension under specified condition[19].

CHAPTER THREE

3.0 EXPERIMENT

3.1 MATERIALS & EQUIPMENTS

The materials used in this study were;

1. High density polyethylene (HDPE), P5B grade supplied by Eleme Petrochemical Company Ltd., a subsidiary of NNPC.
2. Polypropylene (PP), P130GP grade, also supplied by Eleme Petrochemical Company.
3. FUTO Fabricated Extruder
4. Instron
5. Venier caliper
6. Micrometer Screw Gauge
7. Digital Tachometer (DT – 2235B $^{+}$)
8. Pressure Gauge (Wika) – 10 bar approx. 150psi
9. Variable Speed Motor
10. COMACD Rubber Tester for Hardness.
11. Electronic Weighing Balance.
12. Stop Watch

3.2 CLEANING OF THE EXTRUDER AND REPLACEMENT OF PARTS

The extruder was switched on. It was allowed to heat above 137˚C, which is the melting temperature of polyethylene. During the heating process, it was observed that the two heater bands at the compression zone were not functioning. The spoilt bands were replaced prior to cleaning of the machine.

At 150˚C, the old materials in the barrel melted, and then the extruder parts dismantled and thoroughly cleaned.

3.3 INSTALLATION OF A DC VARIABLE SPEED MOTOR

The AC motor installed previously, extrudes at a fixed screw speed. To obtain variable screw speed needed for this research work, a DC variable speed motor with specification shown below was installed.

Voltage of motor = 0 – 90V DC
Current rating = 1 Amp
Speed of motor = 1725rpm
Gear ratio = 1: 20
Phase = Single phase

3.4 INSTALLATION OF THE PRESSURE GAUGE

In order to get the output – pressure relationship, effort was made to install the pressure gauge on the extruder. A drill of diameter 13mm was made at the barrel 10mm away from the breaker plate. Pressure gauge of 10 bar (150psi) was incorporated and sample test-run. This was done three times, the gauge was later removed and drilled hole filled.

3.5 PRELIMINARY EXPERIMENTS

When feed rate swings higher or lower, more or less material enters the extruder barrel and products may randomly fail to meet specification. As a result, processing parameters such as feed rate and temperature were varied at constant screw speed of 30rpm.

i. 5g/min of resin (HDPE) was fed into the extruder at the barrel temperature of 180˚C, 200˚C and 200˚C for feed, compression and metering zones respectively.
ii. 5g/min of resin (HDPE) was fed into the extruder at the barrel temperature of 210˚C, 250˚C and 250˚C for feed, compression and metering zones respectively.

iii. 20g/min of sample was fed at barrel temperature of 180˚C, 200˚C and 200˚C.
iv. 25g/min of sample fed at barrel temperature of 180˚C, 200˚C and 200˚C.
v. 20g/min of sample fed into the extruder at barrel temperature of 210˚C, 250˚C and 250˚C for feed, compression and metering respectively.

3.6 PREPARATION OF MATERIAL

The polymer resins (PE and PP), were thoroughly manually mixed at composition ratio of PE/PP of 100/0, 83.3/16.7, 80/20, 66.3/33.7, 50/50, 33.7/66.3, 25/75, 20/80, 16.7/83.3 and 0/100 by weight. The mixtures were extruded at four different screw speeds – 20rpm, 33rpm, 45rpm and 60rpm at the temperature of 180˚C, 200˚C and 200˚C for feed, compression and metering zones respectively. The extruder was cleaned intermittently after extruding a particular composition.

Four samples of each composition were prepared to eliminate variations that may arise from non – uniformity of the extrudates.

EFFECT OF SCREW SPEED ON THE WEIGHT OF THE OUTPUT AT SCREW SPEEDS OF 20rpm, 33rpm, 45rpm, and 60rpm

The output of each PE/PP composition at a particular screw speed was cut off from the die head at known time intervals of 60, 120, 180, 240 and 300sec. The output was allowed to cool to room temperature and weight recorded.

3.7 EFFECT OF SCREW SPEED ON DIAMETER / THICKNESS OF THE EXTRUDATE

Length of 10m of each of the PE / PP compositions was extruded and cooled. The extrudate was cut into ten pieces and the internal and external diameters measured with micrometer screw gauge and vernier caliper.

3.8 THE HARDNESS OF THE EXTRUDATES

The hardness was measured with COMACD Rubber tester. The pointed tip was pressed on the sample material at four different positions and the resistance to indentation taken.

3.9 MECHANICAL PROPERTIES OF THE BLEND

The outputs were cut into dumb bell shape, and the tensile properties measured according to ASTM D638 standard of measurement using Instron machine.

3.11 STATISTICAL ANALYSIS: The statistical parameters such as the mean and standard deviations were calculated from the data obtained. From the mean value, x, the standard deviation[38] and standard error of mean, SEM, were computed.

Standard deviation, SD, $\sqrt{[\sum(x - x)^2]/(n - 1)}$ ---------------- 3.1

where; $(x - x)$ = the difference between the observed values and the mean of the observation

n = total number of observed values.

$n - 1$ = degree of freedom

SEM = $SD/\sqrt{n}$ ------------------ 3.2

3.12 MEAN RESIDENCE TIME[23]

Calculation of the mean residence time, R, of the FUTO mini extruder at extruder speed; 20, 33, 45 and 60 rpm, was carried out with equation 3.3

Mean Residence Time, R, = $(2L)/(\pi DN\sin\theta)$ ------------- 3.3

Where;

L = Length of screw,

D = Diameter of screw

N = Screw speed in rpm

θ = helix angle of screw

Table 3.1: *Mean Residence Time at 20, 33, 45 and 60 rpm of FUTO extruder*

Screw speed (rpm)	20	33	45	60
Mean Residence Time (R), min	1.607	0.974	0.714	0.536

3.13 ESTIMATED SHEAR RATE OF THE SCREW SPEEDS

The mean shear rate produced by the screw rotation in the extruder barrel were estimated by[39],

$$\gamma = \pi N D \cos\theta / (60 \times \Omega) \qquad \text{----------------} \quad 3.4$$

where;

N = Screw speed

D = Screw diameter

Ω = Flight channel depth

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 INSTALLATION OF PRESSURE GAUGE

The pressure gauge installed was inefficient for the laboratory size extruder. As a result of the back pressure built by the breaker – plate, the molten material was forced to enter into the pressure gauge through the orifice (opening) at its base. The material blocked the opening rendering it useless for further investigation. As a result, the gauge was removed and the drilled hole filled.

4.2 INSTALLATION OF THE GEARED DC MOTOR.

The DC motor with speed 1725rpm and gear ratio of 1:20 gave output speed of 86.25rpm. The maximum screw speed of the extruder obtained was 86.6rpm (confirmed with the tachometer). The motor, therefore gave a variable speed range of 0 – 86.6rpm. With this range, the effect of screw – speed on the extrudates was monitored.

4.3 RESULTS OF THE PRELIMINARY EXPERIMENTS

5g/min of resin fed into the extruder, at the temperature of 180^{o}C , 200^{o}C and 200^{o}C for feed, compression and metering zones, respectively, gave a non – uniform pipe (extrudate) which may be attributed to the quantity of the material fed into the hopper. The quantity is small compared with the time interval of one minute. It can therefore be concluded that the degree of fill in the barrel is small. Within the stipulated time interval (60sec.), little or no material was left in the barrel thereby leading to extrudate with irregular dimension.

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5g/min and 20g/min of resin fed into the extruder at the temperature of 210°C, 250°C, and 250° C for feed, compression and metering zones, respectively gave similar result. The extrudates shrinked on cooling. This implies that the temperature used was above the required processing temperature.

20g/min and 25g/min of resin, fed at the temperature of 180°C, 200°C and 200°C for feed, compression and metering zones, respectively, resulted in uniform pipes, without shrinkage after cooling. Therefore, feed rate between 20 – 25g/min at the temperature of 180, 200 and 200 for feed, compression and metering zones, respectively ,resulted in better extrudate than that obtained at higher temperature.

4.4 RESULTS OF SAMPLE WEIGHT AGAINST TIME OF EXTRUSION

The weights of the extrudate after an interval of 60, 120, 180, 240 and 300s, were obtained from the 100% and blended samples at the screw speed of 20, 33, 45 and 60rpm. As a result of extruding the samples at different time intervals and screw speeds; the effect of these variables on the quantity of the extrudate was determined. Results are shown in table 4.1

Table 4.1: *Weight of sample against extrusion time*

Screw speed	**Time (Sec)**	**Weight. x 10^{-2} g (% PP Composition)**									
		0	**16.7**	**20**	**33**	**50**	**66.7**	**75**	**80**	**83.3**	**100**
20 rpm	60	499.8	540.6	547.2	561	582	600	615	621	627.6	749.4
	120	1054.8	1139.4	1155.12	1184.28	1228.56	1266.66	1297.62	1310.94	1324.2	1581.96
	180	1499.4	1627.2	1701.78	1710	1746	1800	1845	1863.06	1882.8	2248.2
	240	1994.4	2178.6	2188.266	2238.36	2322.18	2399.4	2458.86	2483.34	2509.74	2622.9
	300	2598.96	2811.12	2851.2	2917.2	3026.4	3118.8	3150	3174.6	3263.4	3739.68
33 rpm	60	655.8	709.32	718.02	734.88	762.42	779.4	805.62	813.36	822	1020.6
	120	1416.48	1546.26	1565.28	1602	1646.82	1683.48	1756.2	1773.36	1793.16	2173.86
	180	1973.94	2135.04	2161.2	2211.96	2294.88	2338.2	2432.28	2440.44	2474.22	3039.6
	240	2583.84	2815.98	2850.48	2917.44	3026.76	3094.26	3140.16	3156.3	3263.34	4061.94
	300	3344.58	3617.46	3661.86	3821.28	3888.36	3983.46	4100.58	4148.76	4207.8	5092.74
45 rpm	60	806.4	903.12	921.18	939.6	958.38	982.32	1011.78	1052.22	1073.28	1200
	120	1611.96	1805.28	1841.4	1878.24	1915.8	1963.62	2022.54	2103.48	2145.48	2398.8
	180	2507.88	2808.66	2864.82	2922.12	2980.56	3126.36	3136.38	3272.4	3348.6	3732.06
	240	3225.66	3612.48	3684.72	3758.4	3833.52	3929.28	4047.12	4208.88	4292.04	4788.06
	300	4023.9	4515.54	4574.46	4594.62	4791.9	4922.4	5058.9	5267.34	5355.66	6014.82
60 rpm	60	959.4	1018.92	1026	1038.48	1059	1112.22	1134.48	1146	1157.28	1379.4
	120	1919.88	2047.8	2055.66	2077.56	2099.94	2224.44	2265	2279.94	2314.86	2896.74
	180	2920.38	3097.5	3119.04	3156.96	3219.36	3381.12	3448.8	3483.84	3518.1	4193.34
	240	3856.74	4096.02	4124.52	4174.68	4257.18	4471.08	4560.96	4606.92	4629.12	5515.68
	300	4883.34	5186.28	5222.34	5285.88	5390.28	5561.1	5763.12	5729.94	5902.08	7034.94

Results in table 4.1 are plotted to show the effect of extrusion time and screw speed on the quantity of the extrudate obtained. Graph of weight in grams against extrusion time in seconds at screw speeds, 20, 33, 45 and 60rpm respectively were therefore plotted as shown in Fig 4.1- 4.4

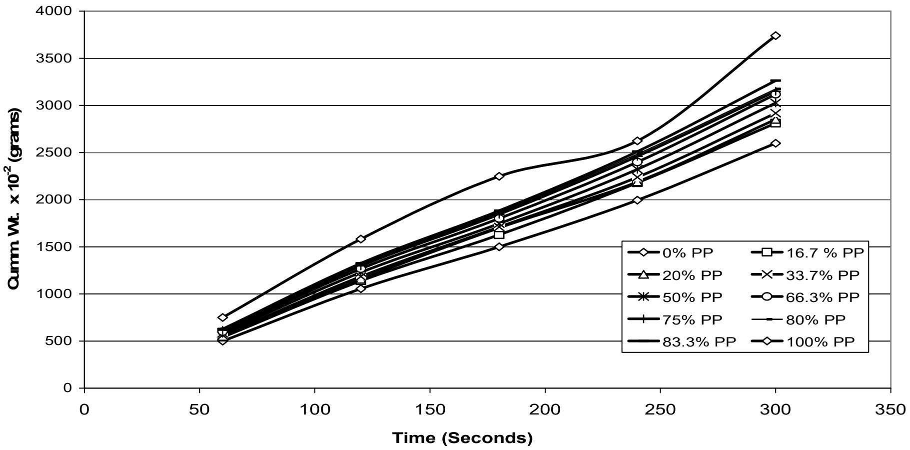

Fig. 1a: Cumm. Wt. vs Time at 20 rpm

r blends.

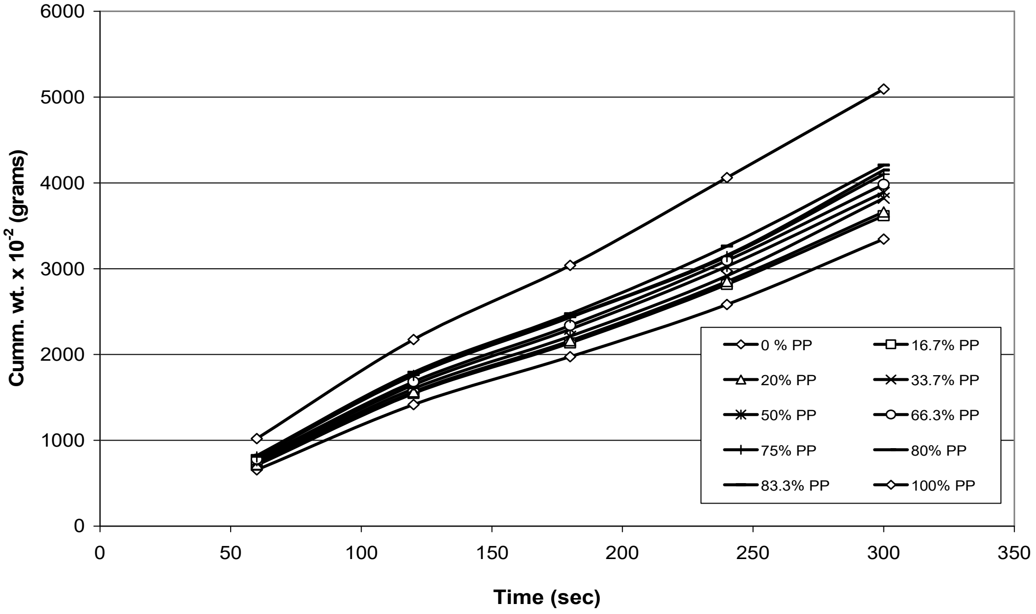

Fig. 1b: Plot of Cumm. wt vs time for 30 rpm

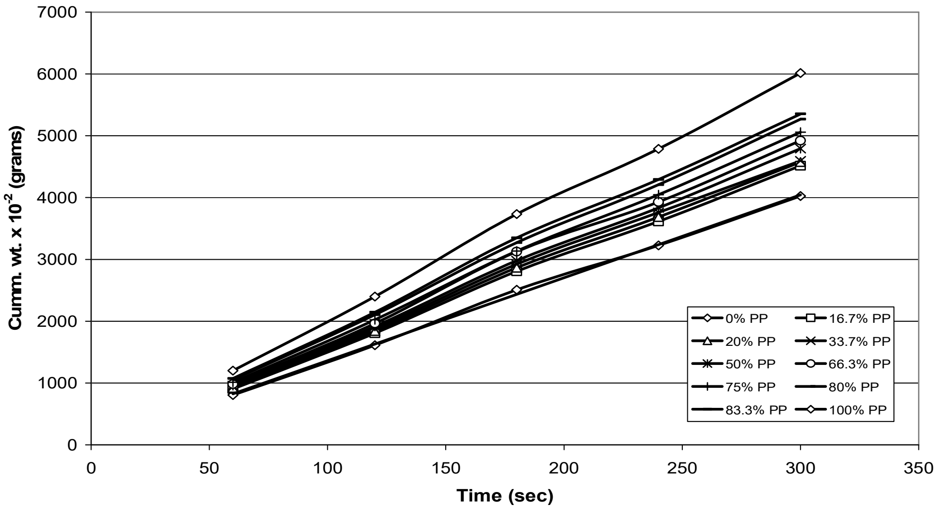

Fig. 1c: Plot of Cumm. wt. vs Time for 45rpm

ends

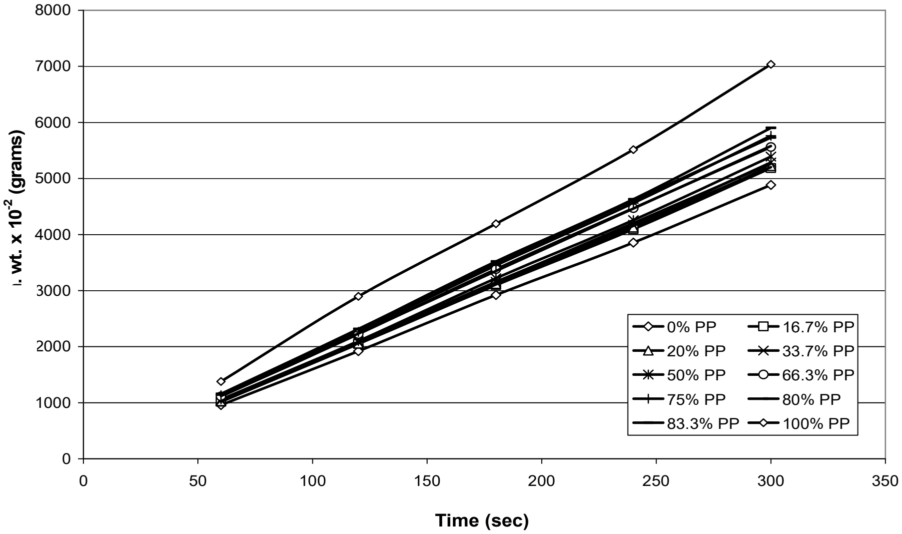

Fig. 4.4: Sample wt vs Time at 60rpm for PP, HDPE and their blends

The weight (g) increases with time of extrusion (seconds) as expected. As the time of extrusion increases, the quantity of extrudate also increases. Secondly, the variation in the slope of the l plots, which shows the quantity extruded per second (Q_{max}) shown in table 4.2, shows that increase in screw speed, has positive effect on production. This is as a result of increase in shear rate, which increases the frictional force between the melt and the barrel, thereby pushing the extrudate forward.

Table 4.2: Q_{max} at Different Screw Speeds

Screw speed (rpm)	Q_{max} (g/s) x 10^{-2} for % PP composition									
	0	**16.7**	**20**	**33.7**	**50**	**66.3**	**75**	**80**	**83.3**	**100**
20	8.56	9.3	9.4019	9.6108	9.9707	10.284	10.385	10.466	10.762	11.703
33	10.908	11.81	11.955	12.48	12.72	13.032	13.29	13.423	13.736	16.72
45	13.415	15.053	15.25	15.317	15.975	16.41	16.865	17.559	17.852	20.032
60	16.308	17.436	17.536	17.653	18.033	18.574	18.905	19.158	19.255	23.217

The slope of 100% PP under the same condition was higher than the others. More `quantity of PP was extruded than PE and the blends. PP melts flow more rapidly, than HDPE. Addition of 16.7% of PP, increased the flow ability by 1.101 ± 0.24g/s. Within the screw speed measured and under the same condition, production of PP was found to be approximately 5.62 ± 0.86 g higher than that of HDPE. In other words, one can set the time, set the speed of the FUTO mini extruder for steady known output.

At the time interval of 300sec, the rate of increase on the quantity of HDPE extruded as the PP composition increases is shown in Fig 4.5. This plot shows how the addition of PP affects the flow ability of HDPE.

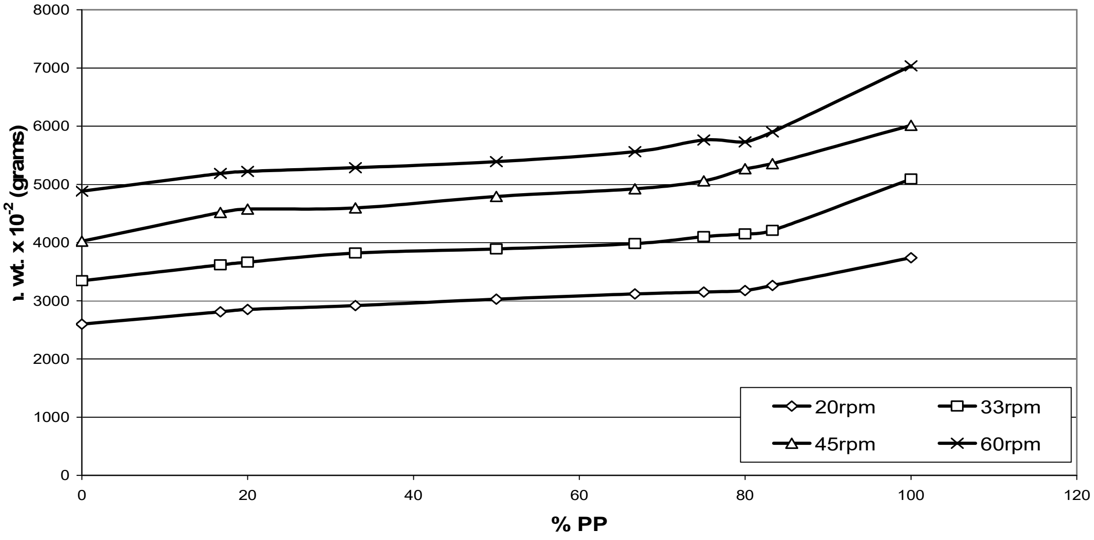

Fig. 4.5 Plot of Sample wt. at 300 seconds against blending ratio

The weight of the samples at 300sec for the four screw speed investigated followed the same order. As the speed increases the weight also increases as expected.

4.5 EFFECT OF SCREW SPEED ON THE DIAMETER AND THICKNESS OF THE EXTRUDATE

Die swell in this work was calculated in terms of change in thickness of extrudate with respect to the die gap. This is to take into account the effect of die swell on both the internal and external diameter of the extrudate. The effect of screw speed on the diameter and thickness of the extrudate is shown in table 4.3 was calculated with equation 2.3

Table 4.3: Effect of Screw Speed on the diameter / thickness of the extrudate

Sample %PP	Screw speed (rpm)	External diameter (mm)	Internal diameter (mm)	Die swell
0%	20	13.85	12.03	1.82
	33	13.472	11.232	2.24
	45	13.57	11.108	2.462
	60	13.642	10.944	2.698
16.70%	20	13.421	11.401	2.02
	33	13.496	11.254	2.242
	45	13.57	11.11	2.46
	60	13.645	10.935	2.71
20%	20	13.424	11.396	2.028
	33	13.5	11.249	2.251
	45	13.562	11.086	2.476
	60	13.648	10.927	2.721
33.70%	20	13.425	11.394	2.031
	33	13.501	11.247	2.254
	45	13.573	11.093	2.48
	60	13.65	10.925	2.725

50%	20	13.426	11.392	2.034
	33	13.502	11.245	2.257
	45	13.575	11.092	2.483
	60	13.652	10.923	2.729
66.30%	20	13.244	11.215	2.029
	33	13.009	10.756	2.253
	45	13.57	11.092	2.478
	60	13.651	10.928	2.723
75%	20	13.424	11.396	2.028
	33	13.51	11.259	2.251
	45	13.642	11.166	2.476
	60	13.649	10.928	2.721
80%	20	13.421	11.397	2.024
	33	13.502	11.244	2.258
	45	13.573	11.098	2.475
	60	13.648	10.927	2.721
83.30%	20	13.421	11.402	2.019
	33	13.497	11.255	2.242
	45	13.569	11.103	2.466
	60	13.642	10.924	2.718
100%	20	13.535	11.703	1.832
	33	13.488	11.274	2.214
	45	13.549	11.15	2.399
	60	13.616	11.004	2.612

Plot of the theoretical die swell and the experimental die swell of the samples against the screw speed shows the extent, die swell of extrudates from FUTO fabricated extruder deviates from theoretical findings. It also helps to show the effect of screw speed on the extrudates.

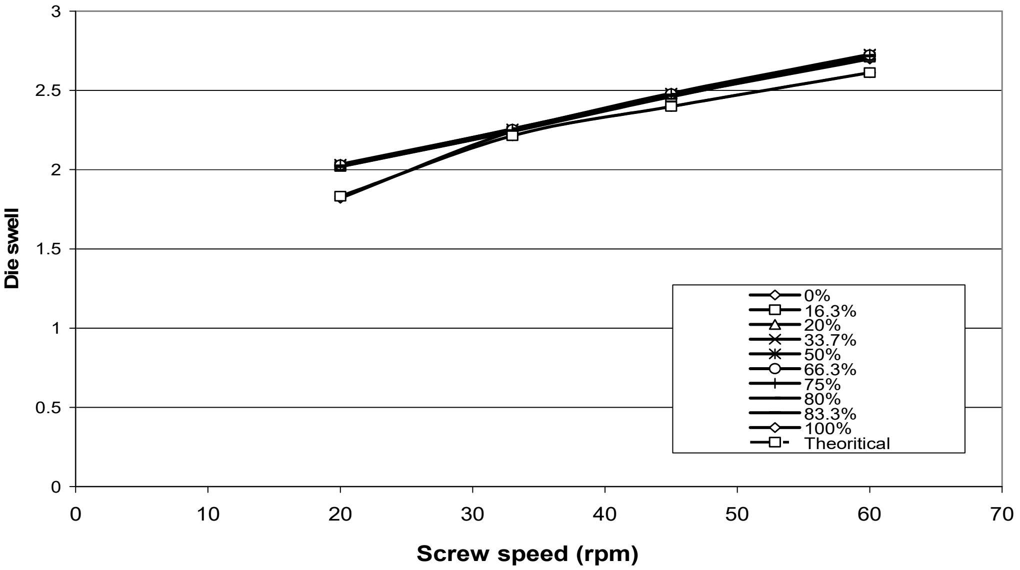

Fig. 4.6 Die swell vs screw speed

From the plot of die swell vs screw speed, it was observed that die swell increases with screw speed in both pure and blended samples. At high speeds, the molecular disruptions of the polymer melt at the orifice are not given enough residence time to relax which leads to expansion of the extrudate. At all speeds, the die swell ratio of the blends were found to be slightly higher than the components. This observation is in agreement with the work of Fujiyama and Kawasaki. This could be as a result of incompatibility of PP and HDPE; as one expects die swell of blends to fall between the values for the two components.

The estimated shear rate at speed 20, 33, 45 and 60 rpm were therefore calculated to know the relationship between FUTO laboratory extruder die swell and the Tanner's die swell.

Table 4.4: RELATIONSHIP BETWEEN TANNER'S DIE SWELL AND EXPERIMENTAL DIE SWELL

Screw speed (rpm)	Estimated shear rate (s^{-1})	Tanner's die swell	Die swell for 100% HDPE	Die swell for 100% PP
20	8.318	1.9136	1.92	1.832
33	13.725	2.2367	2.24	2.214
45	18.7155	2.4676	2.462	2.399
60	24.954	2.705	2.698	2.612

Fig 4.6 and table 4.4 above, show the relationship between the experimental and the theoretical die swell. It was found that no significant difference exists between them. HDPE deviated from experimental by a value of 2.5×10^{-4} while PP deviated by 2.0×10^{-4} (values obtained from the difference in slope of the theory and experiment) This implies that, the die head of the laboratory extruder was well constructed and can compete favourably with other extruders. It also shows that the ratio of swell of NNPC polyolefin (HDPE and PP) are within the normal range.

4.6 HARDNESS TEST RESULT

The result of the hardness test carried out showed that there was no significant effect of the screw speed on the hardness of the materials tested. Uniform range of results was obtained for different compositions at different speeds. Though 100% PP was found to have values greater than that of 0% PP (100% HDPE) at all screw speeds as shown in table 4.5.

Table 4.5 hardness test results

Screw speed (rpm)	% PP Composition									
	0	16.7	20	33.7	50	66.3	75	80	83.3	100

20	76.2±0.36	83.4±0.4	77.3±0.45	83±0.47	79.5±0.5	84±0.36	89.5±0.4	89.1±0.52	80.7±0.47	84.2±0.38
33	82±0.46	82.1±0.46	82.5±0.6	78.5±0.36	78.25±0.37	80.1±0.4	88.9±0.42	90.2±0.4	81.3±0.51	84.75±0.5
45	77.5±0.62	83.55±0.7	80.25±0.6	85.2±0.36	82.35±0.76	83±0.51	90.25±0.6	88.7±0.7	79.5±0.54	83.9±0.76
60	80±0.44	81.75±0.6	81.5±0.42	76.2±0.36	80.5±0.71	79.95±0.6	87.95±0.7	89.3±0.62	82.05±0.5	83.95±0.8

4.7 RESULTS OF TENSILE TEST

Fig. 4.7 – 4.10 obtained from the tensile strength tests carried out from 0 – 100% PP compositions at different screw speeds. The stress – strain plots were used to know the material properties of the samples analyzed.

From the stress – strain plots, Fig 4.7- 4.16 cold drawing was experienced in all the 0% PP samples. As PP was added one expects gradual reduction in the degree of cold drawing, but abrupt fracture was seen in almost all the blends and pure PP(possibly as a result of incompatibility in blends of HDPE and PP). This implies that there is reduction in the level of ductility of the blends and 100% PP.

4.7.2 EFFECTS OF SCREW SPEED AND BLENDING RATIO ON THE MECHANICAL PROPERTIES OF THE EXTRUDATE:

The effect of screw speeds on the mechanical property of the unblended HDPE and PP samples, showed that no significant relationship exits between them, although there is slight change in modulus as screw speed is increased. The yield stress, the ultimate stress and percent elongation (at break) of pure samples fall within the same range at the four screw speeds monitored.

The modulus, yield stress, ultimate strength, strain at fracture, toughness and % elongation were obtained from the stress - strain plots.

Table 4.6, Mechanical properties of samples

Mechanical Properties of Samples at Screw Speed of 20 rpm

	% PP Composition									
Properties	***0***	***16.7***	***20***	***33.7***	***50***	***66.3***	***75***	***80***	***83.3***	***100***
Modulus (MPa)	444.44	500	520	562.87	611.11	666.67	700	666.67	657.89	500
Yield stress (MPa)	8	8.5	9	9.4	11	12	11.9	12	12.5	12
Ultimate strength (MPa)	22	22	24.5	25.8	26.4	33	40.3	36	31.1	30
Elastics limit (mm)	0.018	0.017	0.0173	0.0167	0.018	0.018	0.017	0.018	0.019	0.024
Strain at Fracture	0.16	0.1339	0.13026	0.1279	0.1072	0.088	0.084	0.0873	0.0918	0.92
% elongation	800	666.92	651.3	639.77	535.75	440.03	420.02	436.5	459.29	460
Toughness	2.4	2.042	2.1818	2.25	2.004	1.98	2.19	2.095	2	1.933

Mechanical Properties of Samples at Screw Speed of 33 rpm

	% PP Composition									
Properties	***0***	***16.7***	***20***	***33.7***	***50***	***66.3***	***75***	***80***	***83.3***	***100***
Modulus (MPa)	430	500	520	557	612.9	666.67	693.33	697.17	634.27	506.96
Yield stress (MPa)	8.6	6	9.4	10.03	9.9	10	10.4	8.3	10.47	11.66
Ultimate strength (MPa)	21.5	21.8	22.4	22.6	23.7	25.6	31.2	28	22.8	30.2
Elastics limit (mm)	0.02	0.012	0.018	0.018	0.0161	0.015	0.015	0.0119	0.0165	0.023
Strain at Fracture	0.16	0.13	0.126	0.108	0.0954	0.07609	0.0716	0.0759	0.08696	0.092
% elongation	800	650	630	540	477	380.45	358	379.5	434.8	460
Toughness	2.408	1.87	2.003	1.72	1.6027	1.354	1.314	1.392	1.445	1.925

Mechanical Properties of Samples at Screw Speed of 45 rpm

	% PP Composition									
Properties	***0***	***16.7***	***20***	***33.7***	***50***	***66.3***	***75***	***80***	***83.3***	***100***
Modulus (MPa)	400	390	412.5	404	289	570	350	596	452	500
Yield stress (MPa)	8	7.8	6.6	9.3	5.5	11.3	7	6.8	7.7	10
Ultimate strength (MPa)	22.3	17.6	17.7	25.2	12.2	25.8	18.5	18.5	17.9	23.3
Elastics limit (mm)	0.02	0.02	0.016	0.023	0.019	0.02	0.02	0.0114	0.017	0.02
Strain at Fracture	0.162	0.132	0.13	0.12	0.074	0.056	0.07	0.056	0.08	0.093
% elongation	810	660	650	589	370	280	350	280	400	465
Toughness	2.3	1.67	1.58	2.07	0.65	1.039	0.892	0.66	1.024	1.548

Mechanical Properties of Samples at Screw Speed of 60 rpm

	% PP Composition									
Properties	***0***	***16.7***	***20***	***33.7***	***50***	***66.3***	***75***	***80***	***83.3***	***100***
Modulus (MPa)	410	350	375	303.84	533.33	466.6	501.8	550	458	550
Yield stress (MPa)	8.2	7	7.5	7.9	8	7	5.6	5.5	11	11
Ultimate strength (MPa)	23.8	24.3	24.8	26	25.8	23	21.65	17	30	28.8
Elastics limit (mm)	0.022	0.02	0.02	0.026	0.015	0.015	0.011	0.1	0.024	0.02
Strain at Fracture	0.16	0.086	0.09	0.148	0.072	0.056	0.063	0.0704	0.08	0.092
% elongation	800	430	450	739	360	280	316	352	400	461
Toughness	2.56	1.346	1.453	2.5	1.216	0.84	0.858	0.792	1.64	1.83

The difference in modulus, ultimate strength and % elongation obtained at the four screw speeds at different PP compositions were plotted, to know the effect of screw speed and blending ratio on modulus, ultimate strength and % elongation.

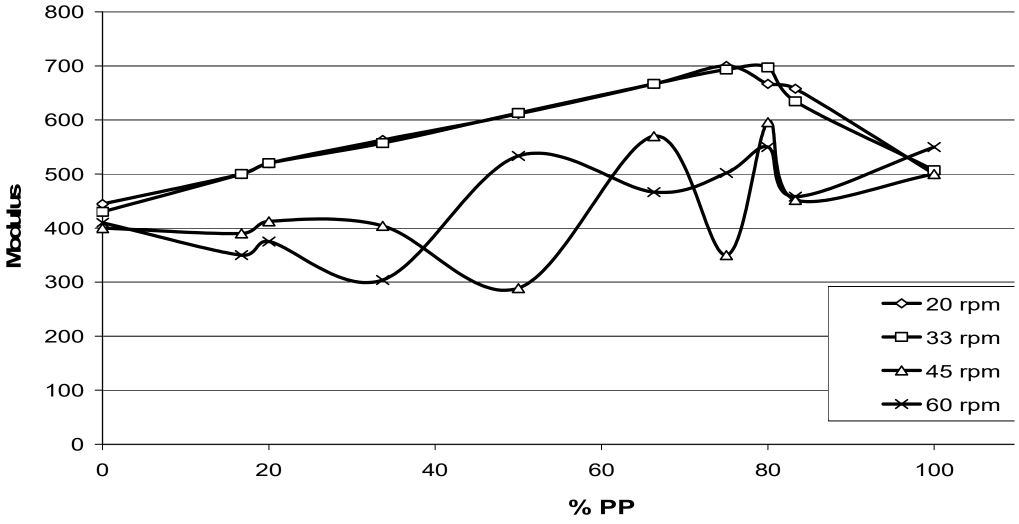

Fig. Fig. 4.17 : of % PP on Modulus

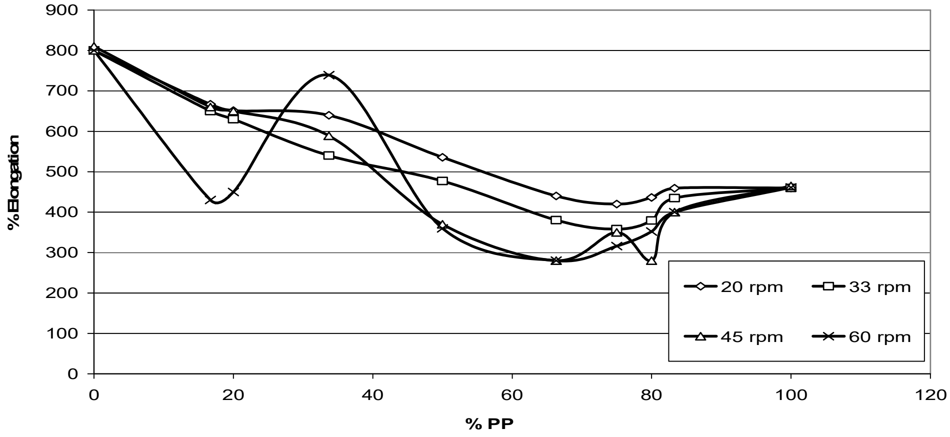

Fig. 14c: % Elongation against % PP

Fig. 4.19: % Elongation against % PP

For the blends both the screw speed and the blending ratio had much effect on the mechanical properties of the extrudate. At lower speeds 20rpm and 33rpm as seen in Fig 4.11 – 4.13 above there does appear maximum in the tensile strength and modulus at 75% PP content and a minimum in the % elongation (at break) at the same composition. This observation is consistent with the observation of others . For speed 45rpm and 60rpm inconsistent results were obtained with some modulus of the blends below the modulus of the neat samples. This is probably because of non-uniformity of mixing.

On varying the extruder speed, two things changed – the residence time of the polymer inside the extruder screw, and the shear rate to which the polymer is subjected. In mixing/blending, the use of heat, either internally generated by shear or externally applied, is needed to obtain compound uniformity. This on the other hand reduces the residence time required for thorough mixing.

Results obtained at 20rpm suggest that, at this speed, there is optimum combination of shear rate and residence time which are conducive for an effective stress transfer resulting in strong mechanical integrity. For the blends, results obtained at speed 20rpm and 33rpm are better than those at 45rpm and 60rpm; since inconsistent results were obtained at speed 45rpm and 60rpm. At speed 20rpm, 75%PP gave the toughest output though this was not observed with speed 33rpm. This implies that better blend was obtained at 20rpm than at 30rpm.

Mean residence time of 1.6min was found to be favourable for the blending of HDPE and PP with FUTO mini extruder

CONCLUSION

. The inability to incorporate the pressure gauge to the machine is a handicap as the output–pressure relationship of the machine cannot be calculated directly and the exact condition of the material in the extruder cannot be obtained. Despite this shortcoming, the extruder in this research work has helped to show that

(1) The output does not depend on blending in the extruder.

(2) Within the range monitored screw speed had no effect on the mechanical properties of unblended HDPE and PP.

(3) The L/D ratio of 15.33:1 for FUTO lab extruder is perfectly good for the extrusion of pure PE and PP samples. Blending, operations should be carried out at lower speed.

(4) A PE/PP blend (25/75 ratio) of NNPC polyolefin resulted in a blend with maximum modulus and ultimate strength. Therefore blending at this ratio gives a good balance of toughness and stiffness.

FUTURE WORK

The morphology of the blend of PE/PP from FUTO mini extruder should be found to know the effect of the blend on the structure of the components involved.

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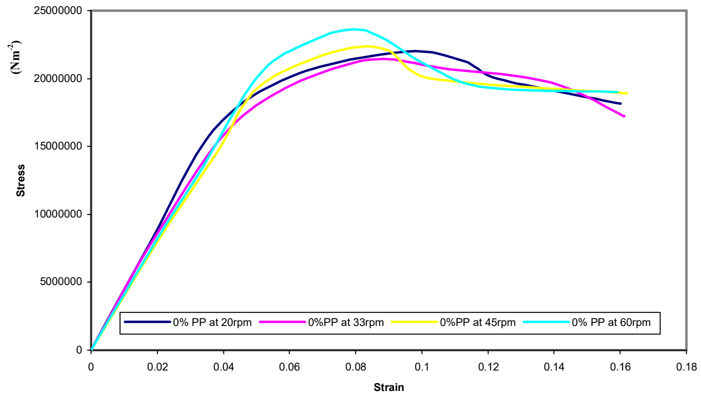


Fig. 4.7:Plot of Stress vs Strain for 0% PP at the Four Screw Speeds

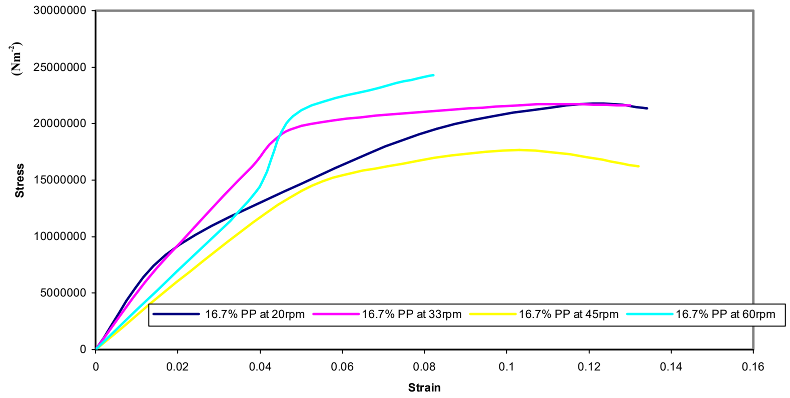
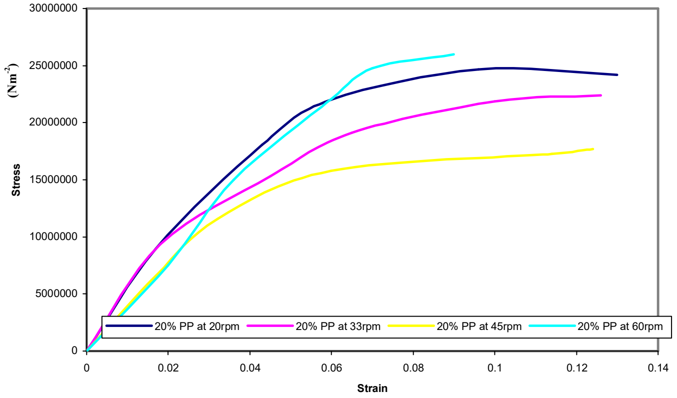


Fig. 4.8: Plot of Strss vs Strain for 16.7% PP at the Four Screw Speeds



Fif. 4.9: 20% PP at the Four Screw Speeds

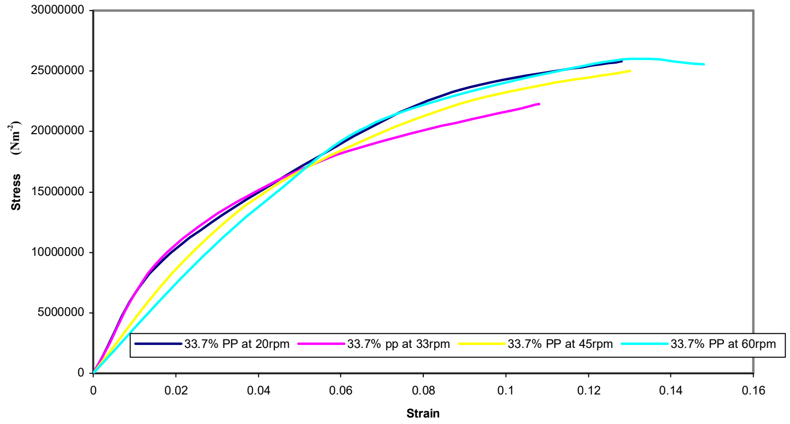


Fig 4.10: Plot of stress vs strain for 33.7% PP at the Four screw speeds

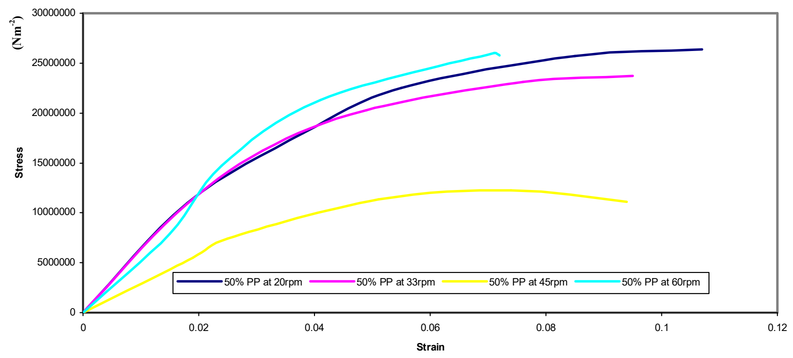


Fig. 4.11: Plot of stress vs strain for 50% PP at the Four screw speeds

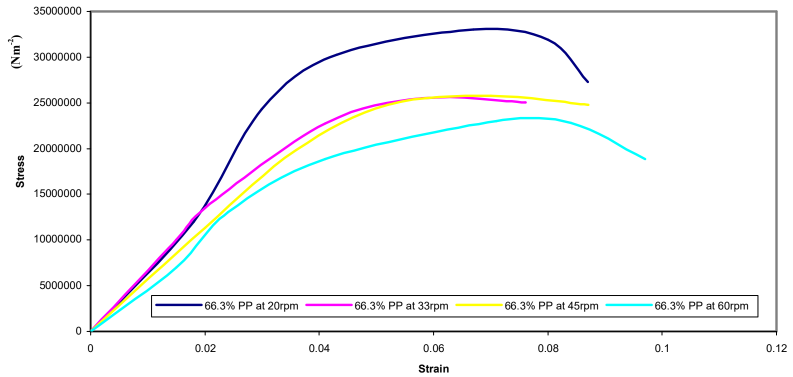


Fig 4.12: Plot of stress vs strain for 66.3% PP at the Four screw speeds

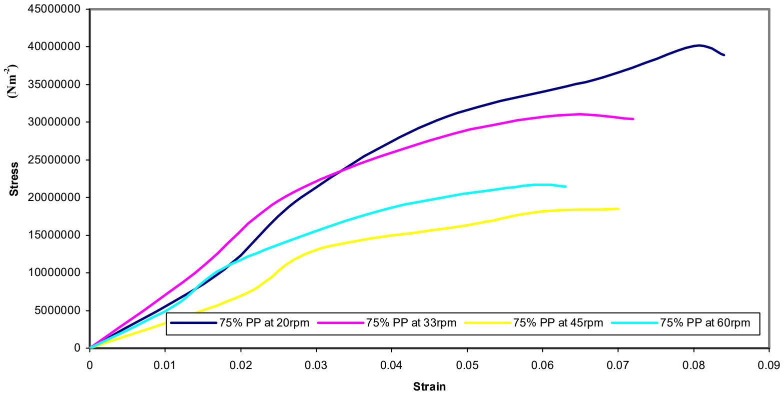


Fig. 4.13: Plot of stress vs Strain for 75% PP at the Four Screw Speeds

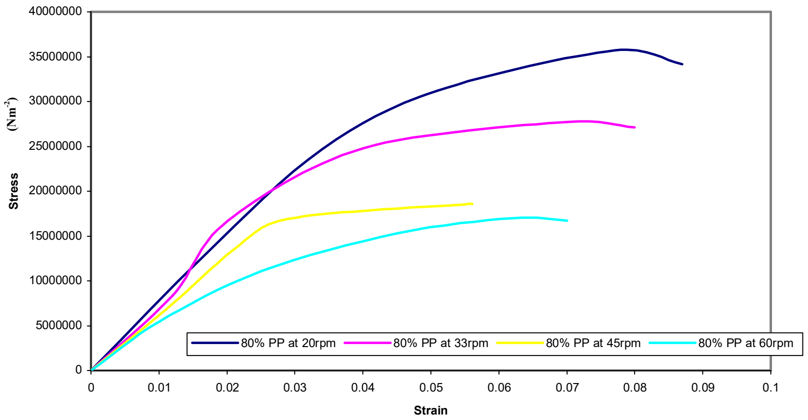


Fig.4.14: Plot of Stress vs Strain for 80% PP at the Four Screw Speeds

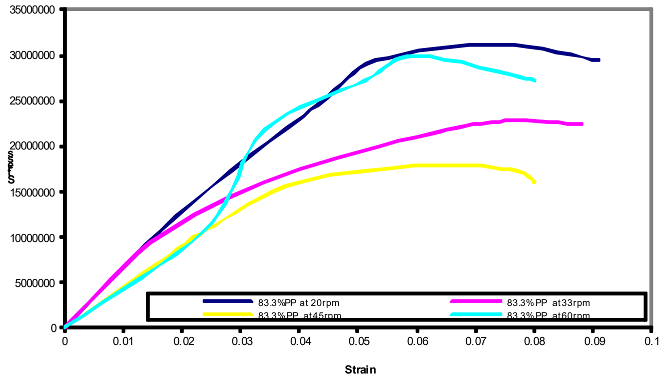


Fig. 4.15: Plot of Stress vs Strain for 83.3% PP at the Four Screw Speeds

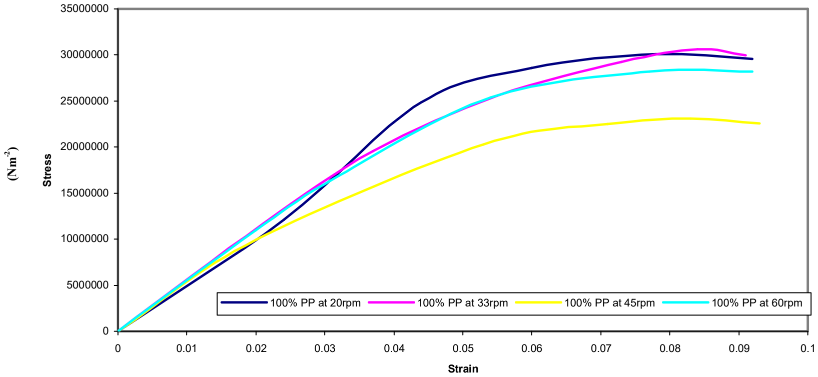


Fig 4.16: Plot of Stress - Strain for 100% PP at the Four Srew Speeds