INJECTION MOULDING AND THERMAL PROPERTIES OF POLYPROPYLENE HINGES

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ABSTRACT

Studies about polypropylene thermal properties have been carried out towards 2-cavities test mould of an integral hinge and tension band sample. This mould was fitted with pressure /temperature transducer and adapted with a data acquisition system. By using both injection moulding practical work and MoldFlow Plastic Insight (MPI) simulation, the predictions and accuracy of in-mould temperature have been carried out with different settings of processing parameters such as screw speed, shot size, mould temperature and barrel temperature profile. These thermal properties analysis were very important in order to produce optimum processing parameters and a better quality with longer life span of hinges and tension band which are widely applied to product packaging. The analysis of results showed that the measured in-mould temperature during injection moulding practical produced the correct trend as referred to the rheological theories of polypropylene. Through simulation process, MPI has predicted the same trend and slightly similar in-mould temperatures as compared with data acquisition from injection moulding practical work. For additional findings, the shot size of sample can be minimised, with the elimination of second screw speed during packing time. This reduction may helps to accelerate injection cycle time and reduced material consumption. Finally, the optimum process parameter settings for hinge and tension band sample have been rectified and verified by both simulation and practical work. It is proven that simulation prediction able to produce beneficial results which may contribute to make improvements in terms of numbers of trials and procedures, times / power / energy consumption and type of materials which have been used during hinge and tension band design and production.

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CHAPTER 1
INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

This project is about attempts that will be made to manufacture polypropylene artefacts by injection moulding in a 2-cavity test mould which was fitted with pressure / temperature transducers. These artefacts have an integral part or life hinges which is very important in this study. Measurements will be made and compared against those measurement predicted by Moldflow Plastic Insight (MPI) software [1] and through calculation, in order to evaluate accurate thermal properties data, mainly heat transfer coefficient. These findings should help to generate additional accuracy in processing thermoplastics by injection moulding, which is merely important to improve process quality and dimensional stability of manufactured product. Other variables such as filler addition in polypropylene may also be explored. This project is sponsored by Unilever UK Ltd.

1.2 OBJECTIVES

The objectives of this project are listed as below:

1.2.1 To measure in-mould temperature and pressure of artefacts during injection moulding processing.

1.2.2 To predict temperature and pressure of artefacts -by MoldFlow MPI software.

1.2.3 To compare and analyse results from both actual injection moulding process and predicted software simulation.

1.2.4 To estimate the thermal (mainly heat transfer coefficient) and flow properties of Polypropylene plastics by using results from both actual injection moulding process and predicted software simulation.

1.2.5 To explore other variables such as filler addition for Polypropylene and their effects towards final results.

CHAPTER 2
LITERATURE REVIEWS

2.1 POLYPROPYLENE THERMO RHEOLOGICAL PROPERTIES

2.1.1. Mechanical and thermal properties of polypropylene.

Almost all plastic have a high heat capacity (specific heat). At their normal moulding temperatures the total heat content of plastics compare with the heat content let say 20^0C, can be greater than zinc or brass at their melting points. This heat content always referred as enthalpy. This heat content can be put into the plastic as well as being taken out and the former process takes places at cylinder and later in mould. **Figure 2.1** plots the enthalpy of some plastics, including polypropylene, against temperature. In this figure, it is shown that crystalline materials such as polypropylene and polyethylene have heat content exceed 50cal/g (209 J/g) [2].

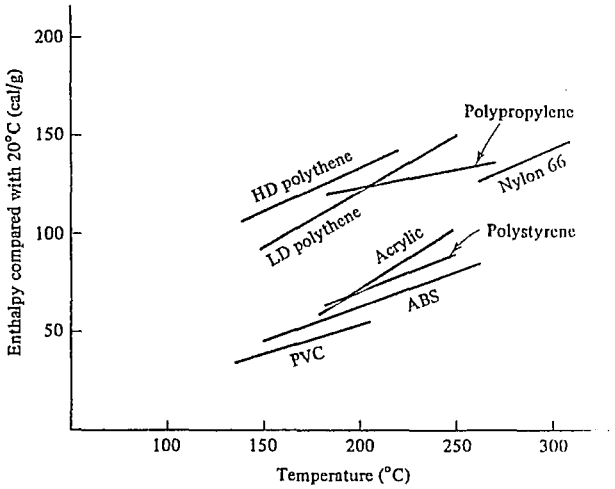

Figure 2.1: Enthalpy of some plastics against temperature [2]

In injection moulding which is highly capital intensive process, the duration of the cycle time is primary importance in costing. The dilemma is the heat required for full plasticisation is very high and the rate at which is can be put into plastic is limited by thermal conductivity and thermal stability of the material. When melting, most metals are feasible to apply a very hot flame to the solid. With plastics, which have very low thermal conductivities, this is not possible because the high temperature on outside will burn and

decomposition before enough heat could penetrate to melt the mass of material [2]. Therefore the understanding of material's thermal properties is necessary selection appropriate process of manufacturing. The thermal properties of polypropylene is stated as **Table 2.1** below [2, 3, 4, 7]

Thermal properties of Polypropylene	**Values**
Thermal conductivity ($Wm^{-1}K^{-1}$)	0.1382
Processing temperatures (^0C)	200-250
Onset decomposition temperatures (^0C)	280
Thermal diffusion constants (m^2 sec^{-1})	0.9×10^{-7}
Specific heat	0.46
Mould temperature (^0C)	30-80
Thermal diffusivity (m^2 $^0C^{-1}sec^{-1}$)	6.5×10^{-9}
Typical moulding temperature: Cylinder (^0C) Mould (^0C) Heat distortion (^0C) Factor * Moulding set up time (seconds) =factor x max thickness (m)	 250 60 120 338

Table 2.1: Thermal properties of polypropylene [2, 3, 4 and 7]

To quote an example, a research about thermo mechanical environment and the microstructure of an injection moulded polypropylene copolymer has been carried out by J.C. Viana, A.M Cunha and N. Billon [6]. This experiment is valid through systematic changes on the processing condition, which are melt temperature, mould temperature and injection flow rate. The skin core structure is characterised by several experimental techniques. The skin ratio is assessed by polarised light microscopy. The morphological features of the skin later, which consist of level of crystalline phase orientation, degree of crystallinity, β-phase content and double texture, are evaluated by wide angle X-ray diffraction. The core features, which are degree of crystallinity and lamella thickness, are then evaluated by mould filling simulations. The thermal and shear stress levels are assessed by a cooling index and the wall shear stress [6].

The result of this research showed the microstructure development is interpreted by considering the constriction imposed during processing, and this is being assessed by thermo mechanical indices. Furthermore, the direct connection between these indices, with the degree of crystallinity of the core and the level of orientation is verified by using this technique. As for moulding process, the thermal and shear stress levels are strongly coupled, whereby the former increases as the latter decreases. For the mouldings and processing window used, some of the following relationships are established [6]:

- The skin ratio increases with the stress level and decreases with thermal one.
- The level of orientation of the skin increases with stress level and decreases with thermal one. The influence of the former is more accentuated
- The degree of crystallinity of the skin increases with both thermal one and stress level.
- The double texture index of the skin is mainly dependent on stress level, decreasing with it and mainly for lover stress value.
- In general a thicker skin is simultaneously more oriented and crystalline. At the same time the core is less crystalline with thin lamellae. This is reflex of the strong thermo mechanical coupling.

Furthermore the development of the skin layer has been interpreted in the light of two main factors which are the time allowed for relaxation until crystallisation temperature is reach, t_r and the relaxation time of material, λ. If t_r is smaller than λ, a highly oriented crystalline structure is developed. The final degree of crystallisation of the core is related to competition between the grow rate and the cooling rate [6].

2.1.2. Polypropylene morphology.

By the use of Ziegler-Natta catalysts, polypropylene (PP) has been produced from monomer of propylene. The usefulness properties of polypropylene and its copolymers make this polymer become an excellent choice for injection moulding products such as house wares, automobile parts, packaging products, laboratory ware, hospital ware, toys, sports and others [5]. With a nominal as-moulded density 902 kgm^{-3}, this material is lighter than polyethylene and non polyolefin plastics. This results more products can be produced per volume than other materials. In addition, this material is very stiff and easy

to be processed, allowing the moulded part manufactured with very thin layer or parts and these parts are very flexible, which has been manipulated to form integral hinge or also known as living hinges [2, 3, 5 and 7]. For more than 40 years, creative design engineers used living hinges in thousands of applications ranging from dispensing closures with hinged caps to automobile gas pedals and carrying cases. The current trend for parts consolidation and assembly minimization has created a renewed interest in integrally moulded hinges [43]. Other PP characteristics which are very beneficial to be used as products such as [2, 5]:

Light weight	Ability to from integral hinge
Heat resistance	Stress-crack resistance
Hardness	Dimensional stability
Surface gloss	Chemical resistance
Stiffness	Process ability

Table 2.2 provide certain ranges of condition for polypropylene artefacts base on various thicknesses. After a mould is constructed, quantity and quality matters shall plays major roles and the cost of mould should be determined carefully to ensure the return of investment is achievable. With regard of quality matters, variables such as injection speed, pressure, clamping pressure , melt temperature , mould temperature and cycle time need to be monitored [2,3 and 5].

More often than not, depends on the cavities that being filled, high injection speed is used for this material because fast filling speed will produce a uniform temperature as it fills into the cavity. If the filling rate is slow, it may cause defects at certain thin part due to rapid cooling when the first material enters the cavity. Incomplete fill, lamination and warpage are the examples of defects due to slow speed of injection, especially for polypropylene and its copolymers because it has a relatively high crystallinity melting temperature and solidify quickly in cavity. It may necessary to reduce the speed in injection process to control [3, 5]. Cycle time is largely dependent on section thickness, machine conditions, heating capacity and injection capacity. The overall cycle time can vary from approximately 5 sec for thin articles to 60 sec or more for thick articles [5]. As for injection moulding hinges, it is important that the flow front cross the thin section at one instant. Gate location must also provide balanced fill. Substantial pressure drop

occurs when the flow front crosses the hinge, resulting in an increase of shrinkage rate. This may require adjustment of cavity dimensions to ensure proper fit of mating halves. The flow through the hinge will generate additional shear heating requiring additional local cooling. If the mating halves require two gates for fill and packing, they must be designed and developed to locate the weld line away from the hinge [39].

Moulding Conditions	Thickness of sections		
	1.6 mm	3.2 mm	6.4 mm
Temperatures (^{0}C)			
• Rear cylinder	193-216	193-204	193-204
• Middle cylinder	204-232	193-216	193-216
• Forward cylinder	216-249	204-232	204-216
• Nozzle	193-216	193-216	193-216
• Melt	204-249	204-232	193-216
• Mould coolant	10-27	10-27	10-27
Hydraulic injection pressure (MPa)	4-10	4-10	4-10
Typical cycle time (s)			
Plunger forward	5-10	10-15	15-20
Total cycle	15-25	25-35	35-60
Shrinkage (%)	1-2	1-2	1-2

Table 2.2: Certain ranges of condition for polypropylene artefacts base on various thicknesses [5]

D.G.M. Wright et all [9] have extended Katti and Schultz findings to examine the crystalline structures and mechanical properties of injection moulded semi crystalline thermoplastic test pieces. These test specimens are prepared by using 'normal' moulding conditions. They also studied about the effect of annealing on crystalline structure and mechanical properties. The crystalline structure is characterized by optical microscopy, differential scanning calorimetry and X-ray diffraction and the mechanical testing included a tensile, impact and torsion of pendulum. In their conclusion, they found that for these semi crystalline materials, a consistent quality of moulded item can only be achieved by establishing and maintaining adequate controls over the moulding process

parameters. The moulding process needs to be controlled both during the injection and cooling phases of the production of a moulding if consistent levels of crystallinity, structure and hence performance are to be achieved [9]

Another research about the morphology of polypropylene plaques containing a weld line has been investigated by x-ray wide and small angle scattering, light scattering and polarization microscopy [26]. Werner Wenig et all [26] have found results which are correlated to mechanical values which has been obtained from tensile tests. While the lamellar morphology is from the neglectable influence, it is found that the mechanical properties of the samples are strongly influenced by the spherulitic structure. Clustering of β-type spherulitic and strong morphological in homogeneities in the vicinity of the weld line are the primary reason of the mechanical weakening of the plaques. The temperature of the mould has a strong effect on the spherulitic structure and also on the tensile properties of the samples [26]

The flow of polypropylene, nylon 6, 6, and 33-percent glass-fibre-filled nylon 6, 6 into a tensile bar mould have been investigated by Howard W. Cox, et all [31]. Pressures needed to fill the cavity and runner system are measured as a function of fill time and melt temperature. The experimental results are compared with pressures predicted by using the MoldFlow flow-analysis programs [1]. Correlation between experimental and predicted pressures is good provided that accurate input data to the computer programs are used. The choice of runner diameter in the approximation of the irregular shaped runner of this tensile bar mould is found to be important, since the runner length is approximately 40 percent of the total flow length. The important material properties are thermal conductivity, viscosity, and no-flow temperature. Viscosity/shear rate/temperature data are needed for the computer programs and two methods of obtaining the data are examined which are Instron capillary rheometer and capillary nozzle on an injection-moulding machine. Good agreement between these two methods is found for polypropylene over a shear rate range of 100 to 10,000s^{-1} [31].

One of the latest research about the analysis of morphology and performance of polypropylene microstructures manufactured by micro injection moulding, is made by K. F. Zhang and Zhen Lu [23].In their research, PP (polypropylene) microstructures are manufactured by micro injection moulding (MIM). The surface topography and internal

defect under different process conditions are studied. An internal defect named ''hollow'' is observed in microstructures made without vacuum so the vacuum is necessary for micro 'blind' cavity. Results of polarized light microscopic observation reveal that these microstructures also represent 'skin-core' morphology, i.e. a highly oriented non-crystalline skin layer, a shear zone with column crystal essentially parallel to the injection direction and a spherulitic core. Nevertheless, the morphology distribution of microstructures is different from the macroscopic structure which are the non-crystalline layer is much thinner, the ratio of skin layer (non-crystalline and column crystal layer) to core thickness is very big; and there is no change of spherulitic dimension from skin to centre. The increasing of relative content of skin layer induces some special mechanical properties is differ from the macroscopic parts .A critical vacuum degree is needed to be found, under which microstructures can be filled wholly without 'hollow' defect whereby this critical value can save the cost and time of vacuumizing and shorten the production cycle [23].

2.1.3. Rheology in injection moulding – Viscous behaviour of simple shear

Polymer melts are viscoelastic in their response to an applied stress. Thus, under certain conditions, they will behave like liquid, and will continually deform while stress is applied. Under other conditions, the material behaves like an elastic solid, and on the removal of the applied stress, there will be some recovery of the deformation. Conversely, if the strain is held constant at the end of an experiment, the stress will not immediately return to zero, but will relax with time. Thus to characterise the rheological behaviour of polymer melts completely it is necessary to measure both elastic and viscous response to the applied stresses. The elastic properties are important in many actual processing operations. Elastic properties also need to be aware in defining this characteristic. As for this project, the viscous behaviour for molten polypropylene is pseudoplastic, whereby these materials, the viscosity increases as shear rate increases. This is the most common response for almost all molten polymers. The viscosity cannot be specified unless by specifying the shear rate [44].

The rheology of a thermoplastic melt is complex, being very dependent on temperature and shear rate. Two key points need to be emphasise about plastic flow are non Newtonian and that viscosities are very high. These characteristics are dictated by the long polymer chain molecular structure of the material. To understand and control melt

processes, it is necessary to define the way in which melt viscosity changes with temperature and shear rate. In terms of principles characteristic of controlled rheology polypropylenes, if the property narrower molecular weight distribution, it gives advantages such as reduced warpage, more uniform shrinkage and improved draw-down performance. The disadvantages are reduced melt strength and stiffness, and less reduction in viscosity at high shear rates. As for shorter polymer chains, the advantage is reduced melt viscosity [34].

Richard Schertzer, Alfred Rudin, and Henry P. Schreiber [24] have conducted research about shear and thermal history effects in polypropylene melts. Fibre grade polypropylenes with melt flow indices of 3 and 12 are studied in the as polymerized (powder) state and after pelletisation. Palletising operations caused very little change in the molecular weight distributions of these polymers. The lower melt flow index material exhibited much greater apparent viscosity and melt elasticity in the powder than in the pellet from during screw extrusion at 190°C. These results are consistent with the existence of a higher entanglement density in the powder version. Instron rheometer data showed no difference between the two polymer forms because of the possibility for entanglement in the rheometer reservoir during rheological experiments. The effects of sample history noted with the 3 melt flow polymer are less pronounced with the lower molecular weight 12 melt flow material. The differences in flow curves of powder and palletized forms of the latter polymer are negligible at 175 and 190°C. However, differences in die swell are more noticeable. The effects observed are attributable to reversible shear-induced decreases in entanglement density. The results reported here have implications in quality control procedures for thermoplastics and in the production of polymers with desired property balances [24].

Semi crystalline thermoplastics are used in fabrication of various types of moulded items. It is necessary to understand the behaviour of semi crystalline materials and in particular the effects of processing variables on crystallinity and of crystalline microstructure on mechanical properties. The microstructure of injection moulded semi crystalline polymers has been investigated by Katti and Schultz [11]. They reported that the structure and properties of the materials are dependent on the flow patterns within the mould during filling and packing, and the rate of heat loss to the mould walls [11].

2.1.4. Influence of temperature in shear flow

Flow occurs as a result of polymer chains sliding over each other. The ease of flow will depend on the mobility of the chains and the entanglement forces holding them together. An increase in temperature will increase the mobility and hence reduce the viscosity. The variation of viscosity with temperature depends on the polymer type and varies widely. It is important to design a proper process which relates to fundamental physical properties of material. The measurement of melt viscosity as a function of both shear rate and temperature is a time consuming procedure and there is a need for a generalised method to predict the flow at any temperature [44].

2.2 INJECTION MOULDING PROCESS FOR THERMOPLASTICS /POLYPROPYLENE PRODUCTS.

2.2.1 Injection moulding machine description and principle of operation

In general, injection moulding is a process which involves hot, injection moulded molten polymer which is injected automatically by a screw with the support of hydraulics actuator into cooled mould where the molten polymer will follow the final shape of the mould [16]. A simple schematic diagram of injection moulding machine is shown as **Figure 2.2** below [44]:

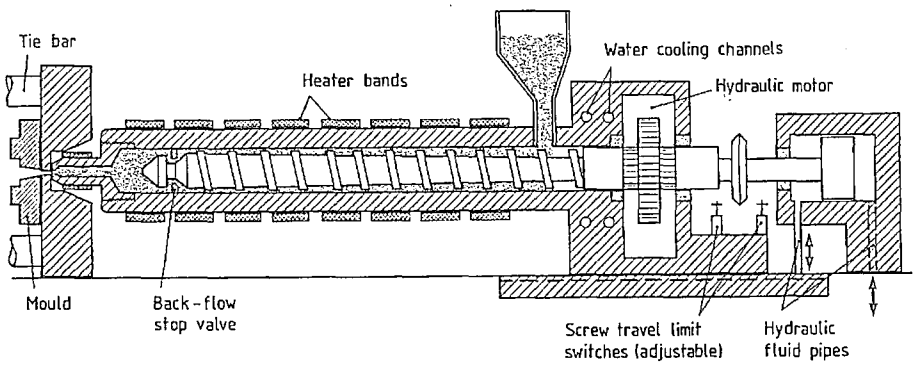

Figure 2.2: Single screw injection moulding: Injection unit [44]

The operating cycles for an injection unit are [44]:

- Considering the cycle from the point where the charge of molten plastic has been injected and is cooling: the screw is powered by a hydraulic motor and as it

rotates, material is drawn from the hopper to be heated and compressed in the extruder screw channel.

- Since the sprue is already occupied by rapidly-cooling melt, the material being pumped forward by rotary shear action of the screw generates a positive pressure in front of screw tip, which forces the screw back down the barrel to a pre-set limit which determines the swept-volume available for the next shot, the stroke. The screw position phase is normally known as screwback.
- Soon after screwback is completed, the mould is opened about its parting line and the solidified injection moulded part is ejected from the machine. The floating mould platen is then moved to close the mould and a high clamping force is applied to maintain mould-face contact, about the plane of the parting-line during subsequent injection.
- Injection of the next shot then occurs, usually at a constant volumetric displacement rate which is pre-set earlier. In this way, the injection time can be controlled to comply with external constraints.
- Further consolidation of the injected melt is achieved during packing phase, immediately following injection. Further material is packed into mould under high pressure, to counterbalance the thermal shrinkage which would otherwise occur as the moulded part cools towards ambient temperature. The packing time is effectively terminated when the flow path to the mould cavity becomes sealed due to material solidification in the gate region.
- Whilst the moulding is cooled, the screwback phase is reinitiated and the moulding cycle repeats.

For further details, this process started by injecting molten thermoplastic polymer material into a cavity with walls, is defined by at least two separable mould parts, allowing the thermoplastic polymer material to cool and solidify in the cavity in a cooling phase, separating the mould parts and extracting the solidified material characterized in that one of the mould parts, which is capable to move relative to the other mould parts. The process continues to the defines walls of the said cavity, in a direction away from and towards the cavity and in that injection of molten parts of thermoplastic material, until the movable mould part is caused to move a position away from the cavity by pressure created in the cavity by the injection there into the thermoplastic material and

wherein as the thermoplastic material in the cavity undergoes shrinkage on cooling the movable mould part is caused to move towards the cavity thus maintaining contact with the injected material in the cavity [3,14].

Injection moulding is one of the most suitable for certain thermoplastic. The advantages of using this process are [3, 16]:

- Suitable for any size product, from those weighing fraction of a gram to large pellets and containers weighing more than 40 kg.
- Excellent surface definition
- Good accuracy and repetitiveness
- High productivity
- Less finishing after moulding

It is very important to find out what kind of effects that correlates between the properties of polypropylene and injection moulding parameters. J. Billiani and E. Fleichmann [10] have studied about the effects of injection rate and melt temperature on the molecular weight distribution of the polypropylene. Selected layers of the plates produced are analysed to determine changes in the molecular weight averages by gel permeation chromatography. Molecular weight distributions are obtained for surface layer and core. The experiments are performed on plates moulded with very high injection rates and pressures of about 1500 bar. Serious degradation (in the amount of -30% in weight average) is mainly caused by high melt temperatures. The effect of high shear rates and high shear stresses is found to be less. The result of thermal and mechanical measurements is correlated with the polymer degradation especially as measured by changes in the weight average molecular weight, whereby the number average molecular weight does not change within the precision of the measurements. Thus injection moulding without packing causes narrowing of the molecular weight distribution. Hence degradation is caused by oxidative chain scission processes due to the high melt temperatures. The impact strength strongly decreases both with increasing melt temperature and flow front velocity. The surface layer and the spherulitic core cannot be differentiated with respect to molecular weight distribution and melting temperature. Therefore it seems likely that the degradation processes take place in the sprue and plasticising system [10].

2.2.1 Pressure of mould during injection moulding processing.

The injection pressure must be sustained at minimum level which is required to fill in the mould. Shrinkage and sink marks can be reduced by increasing the injection pressure but this may cause in packing material into mould cavity. Packing may results difficulties in ejecting piece from the mould and warpage at thin sections. Usually the stiffness part of polypropylene artefacts increase slightly towards the pressure increments, especially when low melt temperature is applied. Changes in injection pressure may not change the impact strength of the moulded parts [5].

It is often thought that by pressuring the plastic in mould able to make up the reduction of volume as component cools. By doing so, hopefully the sink marks and voids are being avoided. For changes in specific volume which takes place as the plastic is heated or cooled, it is seen that it would nit necessary to compress amorphous plastic by over 7 % and crystalline plastic by double that amount to compensate the reduction of volume as the mould cools [2].

Extreme pressurisation of the mould leads only to localised areas of frozen in stress in the moulding because it is only rarely that the pressures will itself out in a complete filled mould. The viscosity of the melt is generally too great and the rate of cooling of the material too rapid to allow this to happen. It is the best injection moulding to use only the pressure necessary to enable injection to take place at the desired speed and for only the duration of injection. The pressure can then be held at only what is necessary to prevent back flow from the mould until the gate freeze. After this, holding the plunger forward is completely unnecessary. However if very thick walled moulding are being made, it is permissible to inject a slow rate over a long period , in fact flow moulding in which the screw continues to rotate during injection, has met with some success, but the is always a danger of other faults developing [2] .

There is a study about the effects of constant-pressure isothermal crystallisation on polymer structure is conducted in bulk isotactic polypropylene. An investigation to determine the influence of pressure, temperature, and melt history variables on the structure of this bulk polymer has been designed. The results (by using the Clausius-Clapeyron equation) demonstrated that the effects of pressure and crystallisation temperature can be quite adequately combined into one processing parameter, under

cooling which defined as the melting temperature minus the crystallisation temperature. This parameter is demonstrated to be important in determining the kinetics of crystallisation and the resultant structure. From moderate to high under cooling parameters are involved in this study which represent commercial injection-moulding processes, and number of conclusions regarding commercial processing are made based on these laboratory investigations [28].

2.2.2 In-mould processing temperature and heat transfer in injection moulding.

To produce parts which have a correct dimension and tolerance, the cavity temperature must be controlled during moulding process. Computer programs can now analyse a mould temperature control requirements and recommend a cooling circuit layout which provide uniform temperature control for all cavities. To obtain uniform cavity temperature control, the cooling system must be designed to remove heat from the melt as it enters the cavity. It must also provide rapid cooling of part so that repetitive and economical cycle can be obtained. The mould cavities require a balanced temperature gradient across it surfaces so that residual moulded in material stresses are minimised. This occurs when the melt enters the cavity at one temperature and flows into the cavity to meet an increasingly hotter cavity surface. This may cause by the coolant, which initially enters at the mould's cooling channel- the gate area. As the coolant flows around the cavity, it loses cooling capability as the resin heat is transferred into the cooling medium. The temperature differential in the cavity can cause a resin skin effect on the part, which if severe, could lock in differential surfaces stresses. After the part is ejected this could cause the product to bend or wrap. This is often seen with large flat panels, both with or without side walls and ribs to support. Therefore, a well thought out routed cooling system is very important to attain the desired product with a good dimensional stability and of course good quality [35].

Optimum processing temperatures for polypropylene are varied according to processing equipment characteristics and its accessories. In the other hand in any given processing situation, the optimum temperature may differ somewhat with the flow rate of the material. As the melt temperature increases, there is a decrease of stiffness and impact strength of moulded artefacts. This is due to the increment of melt temperature is very high when a high injection pressure is used [5].

Below certain minimum melt temperature, severe stresses in the moulded part can occur with a resistant loss of impact strength. At normal injection temperatures around 232 ^{0}C to 243 ^{0}C there is no major difference in deflection temperature caused by changes in melt temperature. At extremely high temperature 260 ^{0}C to 288 ^{0}C an increment is noted. High melt temperatures along with long residence time at melt temperature can caused an increased flow rate and reduced toughness, which can promote material breakdown. It is desirable that the shot size utilized one half or more of the cylinder capacity to limit melts residence time. Generally an increase in the cylinder temperature makes it possible to use lower injection pressure and produced a better surface finish but it is also tends to increase drooling from nozzle, which may make some flashing problem and increased time of cooling [5].

Close control of mould temperature is important in injection moulding but it is more important for polypropylene and its copolymers because of its highly crystalline nature. Mould temperature shall affects more to copolymer than polypropylene itself. It is usually desirable to obtain maximum impact strength rather than maximum stiffness. Therefore low mould temperature should be used, normally in the range of 0 ^{0}C to 32 ^{0}C. A cold mould cools polypropylene rapidly and caused the formation of crystalline structure. Some moulded parts may require maximum stiffness with impact strength of secondary importance. If this is the case, mould temperatures in the range of 43 ^{0}C to 54 ^{0}C are desirable. [5].

The main heat transfer processes in thermoplastic processing are conduction, convection and viscous heating with radiation only playing a role in thermoforming. In the other words it starts from heat to melt the materials, change shape and finally cool to solidify. Most products are much thinner than they are wide, so only one dimensional heat flow will be considered [8].

V. Brucato and G. Titomanlio [25] in their research found that heat of crystallisation shall slowed down polymer cooling. Therefore, the pressure drop will increase during mould filling with thermoplastic crystalline polymers. If a correction of thermal diffusivity can be calculated for such a cooling slow down at least as far as the effect on pressure drop is concerned, the use of non isothermal crystallisation kinetics

may be avoided in the simulation of mould filling. A procedure to identify such a correction is outlined in their work. Pressure drop values during cavity filling are being calculated favourably compared with literature data taken with polypropylene and polyethylene resins [25].

There is a theoretical mathematical model presented to describe the temperature distribution and the rate of phase change in the injection moulding process of crystalline plastics. Under some assumptions, an exact closed form is solved with the use of an internal technique. This model is tested by measuring the temperature profile in a slab mould instrumented with thermocouples. Measurements of temperature profiles in the centre of the polymer slab compare well to model prediction [27].

2.2.3 Injection moulding instrumentations

Mould temperature control means a systematic approach to fundamental of heat transfer. Enough volume of capacity must be available for a mould temperature controller, to assure the turbulent flow existed in all mould cooling channel. Mould cooling channels must be designed to ensure the temperature distribution is even to all cavities. Piping diagrams are a must. The important consideration in mould temperature control is the ability to monitor the flow of the heat transfer media each line of the mould. Therefore the turbulent flow existence and the flow condition are same from set up to set up [33].

Temperature controller in injection moulding control system usually operate independently of each other. The placement of temperature sensor is extremely important because heat flow in any medium sets up a temperature gradient in pipe establishes a pressure drop and the flow of electricity in wire can cause a voltage drop [5].There are two common types of sensors which are used in injection moulding machines are thermocouple and resistance temperature detector. Thermocouple is very popular, whereby it depends on the fact that every type of metallic conductor has a characteristic electrical barrier potential, and whenever two different metals are joined together, there will be a net electrical potential at the junction. This electrical potential changes with temperature. The resistance temperature detector (RTD) is based on the resistance of some metal changes markedly with temperature, whereby the resistance of platinum, the

most commonly used metal in RTD is extremely stable. Its variation in temperature is both repeatable and predictable to high degree of accuracy. In the past, thermocouple offered a major cost advantages by with the advent of low cost solid state dc amplifiers, the usage of RTD become more reliable. It is because RTD have higher sensitivity than thermocouple, and their amplifier are less expensive and much less sensitive to electrical noise disturbance. Moreover RTD offer better linearity, which is almost twice of thermocouple [5].

A. Bendada et all [32] have analysed the application of the infrared hollow waveguide method for the remote sensing of the temperature decay of polymer streams during injection moulding. The key feature of the infrared procedure employed is its low transmission loss of the thermal energy in the mid and far infrared spectral regions. This particular advantage allows the hollow waveguide device to measure not only the bulk temperature within the polymer, as commercially available full-core optical fiber instruments do, but also the temperature at the polymer surface. Moreover, the hollow waveguide device is able to measure quite low temperatures, which conventional thermometers cannot do either. Experimental trials have been run on a Husky injection moulding press in order to investigate the effect of some process parameters and shrinkage on the bulk and surface temperature decay signals. The results showed a drastic deviation between the kinetic behaviours of the surface and bulk temperature traces throughout the injection cycle. Particularly, it is noticed that the cooling rate of the surface temperature is more affected by part shrinkage than the cooling rate of the bulk temperature. The results showed also that temperatures below 60°C could be reliably measured with reasonable signal-over-noise ratio [32].

S. Johnson et all [22] have made a research about "*Estimation of bulk melt temperature from in-mould sensors: Part 2- Convection*". In this research, they tried to make an estimation of bulk melt temperature in a mould cavity by considering the contact resistance of the mould-melt interface into account by modelling it as a convection boundary condition. The increment of convection coefficient h_c, has simulated a reduced contact resistance and produces higher temperature predictions. Due to a numerical instability at high values of h_c, the predictions from the convection analysis are very low and the predictions from the original conduction analysis are preferable. The accuracy of

both analyses is found to depend heavily on the accuracy of the temperature measurements and the assumed uniform mould temperature [22].

2.3 INJECTION MOULDING SIMULATION

A.H.S Al-Ashaab [12] in his PhD research entitled "*A manufacturing model to capture injection moulding process capabilities to support design for manufacture*" has done an experimental manufacturing model based on the Express representation and related DFM applications which has been implemented in Object-Oriented form by using Loops-Xerox 1988. The manufacturing information to support injection moulding process has been categorized as mould ability features, mould elements and injection moulding machine elements which represent the main entities of the Manufacturing Model. To explore the use of manufacturing model, it has been expand to support the design for manufacturing application where the object-oriented methodology of Boosch has been used. Three DFM applications has been considered, which consist of Design for Mould Ability, Supporting Mould Design and the Selection of Injection Machine [12].

R. Y. Chang and B. D. Tsaur [30] have proposed an integrated theory and computer program to develop a research about simulation of shrinkage, warpage, and sink marks of crystalline polymer injection moulded parts. The basic theory of this research considered the following items [30]:

- Mould cooling analysis;
- Analysis of the polymeric filling, packing, and cooling processes;
- Viscoelastic behaviour of polymeric fluid;
- Influence of thermal and mechanical properties of polymer;
- Pressure-volume-temperature relationship of polymer;
- Crystallisation kinetics of crystalline polymer;
- Solid mechanics analysis.

Other considerations are the origins of defects, e.g. no uniform cooling process, no uniform volume shrinkage, flow-induced residual stress, thermal induced residual stress, and crystallisation behaviour. The boundary element and the finite difference method are applied towards calculating the mould cooling analysis for obtaining the temperature profile at the cavity surface as the boundary conditions in filling and packing analysis. A