EFFECTS OF MATERIAL SELECTION ON INJECTION MOULDING PARAMETERS USING MOLDFLOW SIMULATION SOFTWARE

MOHD NAZRI BIN ISMAIL

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2009

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled “effects of material selection on injection moulding parameters using Moldflow simulation software “is written by Mohd Nazri Bin Ismail. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

Examiner	Signature
Dr. Daw Thet Thet Mon	....

Universiti Malaysia PAHANG

FACULTY OF MECHANICAL ENGINEERING

THESIS SUBMISSION

REMINDER: Please submit **THREE copies of hard bound thesis** together with **THREE CDs** to the main office of Faculty of Mechanical Engineering.

STUDENT NAME	**: MOHD NAZRI BIN ISMAIL**
ID NO.	**:ME 07003**
PROGRAMME	**: BACHELOR OF MECHANICAL ENGINEERING WITH MANUFACTURING ENGINEERING**
PROJECT TITLE	**: EFFECTS OF MATERIAL SELECTION ON INJECTION MOULDING PARAMETERS USING MOLDFLOW SIMULATION SOFTWARE**
STUDENT SIGNATURE	:
DATE	**: 4 DECEMBER 2009**
SUPERVISOR SIGNATURE	**:**
DATE	**: 4 DECEMBER 2009**

FOR OFFICIAL USE (To be completed by FKM office's staff)

Received Approval (Name & Signature) :

Date :

Stamp :

REMARKS

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

Signature	:	
Name of Supervisor	:	Mohamed Reza Zalani Bin Mohamed Suffian
Position	:	Head of Programme (Industry)
Date	:	20 November 2009

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature	:
Name	: Mohd Nazri Bin Ismail
ID Number	: ME 07003
Date	: 20 November 2009

Dedicated to my beloved parents

Mr. Ismail Bin Derasid

Mrs. Siti Fatimah Binti Yusuff

And

All my sisters and brothers

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Mr. Mohamed Reza Zalani Bin Mohamed Suffian for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, and his strong conviction for science. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for his progressive vision about my training in science, his tolerance of my naive mistakes, and his commitment to my future career. I also would like to express very special thanks to Mr Mohamad Zairi bin Baharom for his suggestions and co-operation throughout the study. And also thanks to Dean Faculty of Mechanical Engineering, Associate Prof. Dr. Rosli Bin Abu Bakar for his advice and suggestion. I also sincerely thanks for the time spent proofreading and correcting my many mistakes.

I would also like to acknowledge with much appreciation the crucial role of the staff in Mechanical Laboratory, who gave a permission to use the computer laboratory to design and run the analysis and also the plastic laboratory to make mould measurement and to use all the necessary tools in the laboratory. Special thanks too goes to Mr. Azizuddin Bin Abd Aziz against as the Final Year Coordinator, who has give some advice and share his knowledge on this final year project.

Many thanks go to the assistant instructor engineer (PJP) especially to Mr. Khairul Azha B A Jalal, and to all the supervisors who have given their full effort in guiding the through on the project progress. I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this project.

ABSTRACT

This dissertation deals with the effects of material selection on injection moulding parameters using Moldflow simulation software. The objective of this dissertation is to define suitable material in producing plastic product (book tray) in term of Profit. The dissertation also describes the finite element analysis techniques to know the effect of cycle time to production cost and reduce the cost in define the material selection using manual method. Eight plastic materials were studied in this dissertation which commonly used in industrial. The three-dimensional solid modelling of plastic product (book tray) was developed using the computer-aided drawing software. The dimension of product based on the actual product mould. The three-dimensional solid modelling of plastic product will import to the computer aided engineering software. The computer aided engineering software was then performed is using Moldflow (MPI) simulation software. The computer aided engineering model of product was analyzed using injection flow analysis. The analysis need to repeat three time for each eight material. Finally, the average value of cooling time (s), filling time (s), and initial injection time (s) obtained from the analysis. From those parameters, the cycle time of product producing can be calculated for each eight material. The cycle time can relate to the production capacity, product cost and profit. From that comparison, the best material for plastic product (book tray) can be selected and also can know the effect of cycle time only on processing cost. By using this analysis method also can reduce the cost in define the material selection for plastic product using manual method.

ABSTRAK

Tesis ini menbentangkan kesan pemilihan bahan plastik ke atas parameter pembentukan acuan suntikan menggunakan perisian simulasi Moldflow. Objektif tesis ini ialah untuk mencari bahan plastik yang sesuai untuk barangan plastik (rak buku) dalam aspek keuntungan. Tesis ini juga menguraikan teknik analisis unsur terhingga untuk mengetahui kesan kitaran masa kepada kos pembuatan dan juga bagi mengurangkan kos untuk memilih bahan plastik untuk barangan plastik menggunakan mesin pembentukan acuan suntikan. Dalam pembelajaran ini, lapan bahan plastik yg biasa digunakan di industri dipilih. Permodelan struktur pejal tiga-dimensi bagi barangan plastik (rak buku) telah dibangunkan menggunakan perisian lukisan bantuan komputer. Ukuran saiz barangan plaktik itu berdasarkan ukuran yang terdapat pada acuan. Permodelan struktur pejal tiga-dimensi untuk barangan plastik itu dimasukan kedalam perisian kejuruteraan bantuan komputer. Perisian kejuruteraan bantuan komputer yang digunakan ialah perisian simulasi Moldflow (MPI). Permodelan kejuruteraan bantuan komputer menjalankan analisis suntikan aliran. Analisis Moldflow bagi setiap lapan bahan plastik itu hendaklah iulangi sebanyak tiga kali dan purata nilai masa menyejuk, masa mengisi dan masa permulaan suntikan di ambil. Kitaran masa dapat dikira berdasarkan tiga parameter yang diperolehi daripada analisis itu. Kitaran masa juga dapat di kaitkan dengan kepadatan pembuatan, kos barangan dan keuntungan. Bahan plastik yang terbaik untuk barangan plastik(rak buku) akan dipilih berdasarkan perbandingan antara lapan bahan plastik dari segi kepadatan pembuatan, kos barangan dan keuntungan. Daripada perbandingan itu juga dapat mengetahui kesan kitaran masa adalah kepada kos perlaksanaan sahaja. Dengan menggunakan analisis ini dapat mengurangkan kos untuk memilih bahan plastik untuk barangan plastik menggunakan mesin pembentukan acuan suntikan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

^{0}C	Degree Celsius
^{0} F	Degrees Fahrenheit
%	Percent
∑	Sum
€	Euro

LIST OF ABBREVIATIONS

3D	Three-dimensional
ABS	Acrylonitrile-butadiene-styrene
CAD	Computer aided drawing
CAE	Computer aided engineering
FYP	Final year project
HDPE	High density polyethylene
LDPE	Low density polyethylene
MPA	Moldflow plastics advisers
MPI	Moldflow plastics insight
PBT	Polybutylene terephthalate
PC	Polycarbonate
PE	Polyethylene
PEEK	Polyetheretherketone
PET	Polyethylene terephthalate
POM	Acatel
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl chloride
SAN	Styrene acrylonitrile copolymer
SG	Specific gravity
UV	Ultraviolet

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The injection moulding process is ideally suited to manufacture mass produced parts of complex shapes that require precise dimensions. One of the precise dimensions needs to consider is material selection. Depending on which data bank is consulted, there were between 17,000 and 18,000 different plastic materials available to choose. Because of the wide range of properties and cost associated with these materials, it is imperative that the material selection process be conducted with appropriate care and attention relative to finished product’s appearance and function. The important item need to consider was the effect of material selection on processing.

Based on that case, the project title was proposed in studying the effects of material selection. The project is the effects of material selection on injection moulding parameters using Moldflow simulation software. This project involves the designing process and analysis process. Design process using computer aided design (CAD) software and analysis process using computer aided engineering (CAE) software. All the process method will combine to study and investigate the effect of material selection on injection moulding processing. The project purpose of this project is to define a good material selection on producing plastic product. At the end of the project, the material will be selected based on analysis of injection moulding parameter such as filling time, cooling time and cycle time.

1.2 PROBLEM STATEMENT

Injection moulding process is an expensive process especially in mass production. The material selection should be precise, accurate and effective because it of way to reduce the production cost. Below was common problem occurring while in material selection process:

(i) Low profit in production.
(ii) Higher cost in define the material selection by manual setting.

1.3 OBJECTIVE

The objective of this project is:

(i) To define suitable material in producing plastic product in term of Profit.
(ii) To know the effect of cycle time to production cost.
(iii) To reduce the cost in define the material selection using manual method

1.4 SCOPE OF WORK

The project will focus on the analysis the effect of material selection on injection moulding parameter using Moldflow simulation software. During analysis process, a few items should be scope as a guide the project flow. Below are a few project scopes for this project.

(i) The analysis process only run on one product because to prevent the error occur during the analysis process which is each plastic product have own characteristic.
(ii) The number of material that chooses limited to eight materials only. All of eight materials were selected based on product characteristic and suitable to injection moulding process.

(iii) The limitation of injection moulding parameter that considered is three parameters which are filling time, initial injection time and cooling time.

(iv) The limitation of analysis range is among injection moulding production in Malaysia only.

1.5 PROJECT PLAN

Please refer to appendix A for reference to this below description.

The project is begin with receive PSM title from supervisor and supervisor will explain briefly about that PSM title. Schedule management are needed for this project to make sure the project running in progress. Then, discuss with supervisor about the objective, problem statement, and scope of project. After discuss with supervisor, the project progress start with gather the information by research and literature review via internet, journal, reference books, supervisor and other relevant academic material that related to this project. To understand more about the project, need to study more about material related to the project topic and spend more than two week to make a literature review. Every week, improvement of knowledge is needed to make sure this project will be performing very well.

After few week, all the literature review that related to the project need to collect. The literature review must have material about injection moulding parameters, thermoplastic characteristic, types of plastic materials, cycle time, and Moldflow simulation software (MPI). The progress will continue with working on the design. In this project, need to redraw the plastic product using CAD software. Before draw, the dimension of that plastic product must be measure at that product mould. After drawing process was done, the project progress will continue with learn how to use the Moldflow software simulation. This step will take a few weeks to master that software. After that, task is preparation of progress presentation and report writing chapter one until chapter three. These tasks take two week to be finish. On that particular week, preparation needed to make a FYP one presentation.

The next task will be continuing on second semester with FYP two. The first task on second semester is discussed with supervisor about current progress and continuing the project progress. After that, project progress will be continuing with analysis the product CAD model using Moldflow simulation software. The simulation process begins with find the name of manufacturer for each eight plastic material. The names of manufacturer for each plastic material need to find because in Moldflow analysis need to define the name of manufacturer before run the analysis. The other parameters such as gate location, cooling system, injection pressure and runner are following the design of actual mould. The analysis should be repeated by change the type of material. This process will take a few weeks to done it. Then, the project will continue with collect the data such as filling time, cooling time and others. The data will be analyze by calculate the cycle time for each plastic material and select the best plastic material to be as the material in producing Book Tray product.

Lastly, the final report writing and prepare the presentation. This takes about one week to arrange and accomplish. A report is guided by FKM thesis format and also guidance from supervisor. All task scheduled is take around two semesters to complete.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Injection moulding is a process of forming a product by forcing molten plastic material under pressure into a mould where it is cooled, solidified and subsequently released by opening the two or three halves of the mould. Bryce.M.D (1996) has stated that the injection moulding is used for the formation of intricate plastic parts with excellent dimensional accuracy. A large number of items associated with our daily life are produced by way of injection moulding. Typical product categories include housewares, toys, automotive parts, furniture, rigid packaging items, appliances and medical disposable syringes.

Plastic injection moulding is one of the most important polymer processing operations in the plastic industry today. Ashby.M.F (2009) has stated that the plastic industry that is injection moulding and involving manufacturing has high growth potential caused by the products are made nowadays is from the polymer material. The most establish method for producing plastic or polymer parts in mass production is plastic injection moulding. This is a highly cost-effective, precise and competent manufacturing method, which can be automated. However, it is very costly tooling and machinery are needed this manufacturing process. The design of a polymer or plastic injection mould is an integral part of plastic injection moulding as the quantity of the final plastics part is greatly reliant on the injection mould. A plastic injection mould is a high precision tooling used to mass produce plastic parts and it by itself an assembly of cavities, mould base and standard components and more.

2.2 MOULD AND PRODUCT

2.2.1 Mould

Mould is one of important part in injection moulding process. Mould is consists of two types, two plate and three plate mould. This project needs to simulate the products that have produce by three plate mould. This mould produce plastic product known as ‘Book Tray’. Below is characteristic of that mould.

(i) Three plate mould
(ii) Have six (6) gates, type of gate is pin point gate.
(iii) Have thirty (30) ejector pin.
(iv) Mould size is 500 mm x 500 mm x 440 mm
(v) Coolant system is horizontal type and the mould should be cooled by hot water controller (40 ^{o}C– 100 ^{o}C)
(vi) Cavity size is 249 cm^{3}

Figure 2.1: Three plate mould (book tray)

Source: FKM laboratory

2.2.2 Product

The product for this project is book tray. The product usually used at the office or education place. The function of this product is as storage for the papers, books, and paper work. This product need to design looked attractive because the product usually located on the table. Below is showing the picture of the product.

Figure 2.2: Book tray

Source: Solidwork (2006) 3D drawing

2.3 PROCESSING PARAMETER

Injection moulding process have a few processing parameter. The processing parameter such as:

(i) Melt Temperatures

Melt temperature is the temperature at which the plastic material is maintained throughout the flow path. Bryce.M.D (1996) has proposed that the temperature of the melt must be control along the path, starting with the heating cylinder. Below is suggested melt temperature for various plastic should be setting while injection moulding process.

Table 2.1: Suggested melt temperature for various plastics

Plastic material	**Temperature (^{o} C)**
Acrylonitrile Butadiene Styrene (ABS)	216
Polycarbonate (PC)	288
Polyethylene (PE)	210
Polypropylene (PP)	177
Polystyrene (PS)	199
Polyethylene terephthalate (PET)	280
Acetal (POM,Polyacetal)	218
Polybutylene terephthalate (PBT)	230
Acrylic	218
Cellulose acetate	196
Cellulose acetate propionate	177
Ethylene vinyl acetate	177
Liquid crystal polymer	260
Nylon	260
Polyallomer	252
Polyamide-imide	343
Polyarylate	371
Polybutylene	246
Polyetheretherketone (PEEK)	382
PVC	163

Source: Bryce.M.D, 1996, pp 31-32

(ii) Mould Temperature

The mould temperature is measured directly on the moulding surface of the tool with a solid probe on the pyrometer device. Bryce.M.D (1996) has proposed that the mould temperature each product, depending on its design and plastic material, demand specific cooling rate and mould temperature. Below is suggested mould temperature for various plastic should be setting while injection moulding process.

Table 2.2: Suggested mould temperature for various plastics

Plastic material	**Temperature (^{o} C)**
Acrylonitrile Butadiene Styrene (ABS)	85
Polycarbonate (PC)	104
Polyethylene (PE)	43
Polypropylene (PP)	49
Polysulfone (PS)	82
Polyethylene terephthalate (PET)	100
Acetal (POM,Polyacetal)	99
Polybutylene terephthalate (PBT)	50
Acrylic	82
Cellulose acetate	66
Cellulose acetate propionate	49
Ethylene vinyl acetate	49
Liquid crystal polymer	121
Nylon	93
Polyallomer	93
Polyamide-imide	204
Polyarylate	135
Polybutylene	93
Polyetheretherketone (PEEK)	193
PVC	60

Source: Bryce.M.D, 1996, pp 33-34

2.4 PLASTIC MATERIALS

Plastic can be defined as any complex, organic, polymerized compound capable of being shaped or formed. Usually, the terms plastic and polymer are used interchangeably, although strictly speaking, a polymer is a plastic, but a plastic does not have to be a polymer as been carried out by Biron.M (2007). Another distinction that the different between thermoplastic and thermosets. Campo.E.A (2006) has stated that the thermoplastic is a plastic material that, when heated, undergoes a physical change. It can be reheated and reformed over and over again. But, a thermoset is a plastic material that, when heated, undergoes a chemical change and cure. It cannot be reformed, and reheating only degrades it. Plastic consist to two categories, amorphous and crystalline.

Amorphous

Amorphous materials are those in which the molecular structure is random and becomes mobile over a wide temperature range. Biron.M (2007) has stated that simply means that these materials do not literally melt, but rather soften, and it begins soften as soon as heat is applied to them. It simply gets softer and softer as more heat is absorbed, until it degrade as a result of absorbing excessive heat. However, it is common and acceptable to refer to amorphous material as melting.

Crystalline

Crystalline materials are those in which the molecular structure is well ordered, and become mobile only after being heated to its melting point. That means these materials do not go through a softening stage but stay rigid until they are heated to the specific point at which they melt. It immediately melts and will degrade if excessive heat is absorbed as has been carried out by Bryce.M.D (1996).

2.5 TYPES OF PLASTIC MATERIALS

Plastic or thermoplastic resin classifications divide the polymers into four family groups based on their application performance as stated by Campo.E.A (2006). The first is the commodity resins, which have a large consumption volume, extensive application end uses, low material cost, and limited property performances. The commodity resins include polystyrene (PS), polyethylene (PE), and styrene acrylonitrile copolymer (SAN).

The second group is classified as intermediate resins. These resins have mechanical, thermal, chemical, and electrical properties generally that are higher than the commodity resins. The intermediate categories of resins include acrylics, thermoplastic olefin (TPO), polyphenyleneoxide (PPO), polypropylene (PP), and acrylonitrile-butadiene-styrene (ABS).

The third group is classified as engineering resins. Campo.E.A (2006) has stated that the level of mechanical properties that qualify as engineering grade is somewhat arbitrary a tensile strength that not lower than 7000 psi with a minimum modulus of elasticity. Engineering resin are fundamentally unmodified resins, whose properties are improved by compounding. A compounded resin is defined as a material containing a matrix, additives, a reinforcing ingredient, such as fiber glass or minerals, heat and ultraviolet stabilizers, flame retardants, and other additives. The engineering resins are acetal, polyamide (nylon,PA), polycarbonate (PC), polybutylene terephthalate (PBT), and polyethylene terephthalate (PET).

The fourth group is the high performance engineering resins. These resins in this category have the highest resistance retaining a high percentage of their useful mechanical properties at high temperatures, providing a longer service life of the product as has been carried out by Bryce.M.D (1996). Its also maintain properties at higher electrical frequencies without sacrificing their chemical resistance properties when exposed to corrosive elements. The high performance engineering resins include high temperature nylon (PA), liquid crystal polymers (LCP), polysulfone (PSU), fluoropolymers, and polyetherimide (PEI).

Acrylonitrile-Butadiene-Styrene (ABS)

The ABS resin has a well balanced set of properties for molding close dimensional control articles with an outstanding surface finishing, good impact resistance, and metal plating characteristics as has been carried out by Biron.M (2007). ABS resins belong to a very versatile family of thermoplastic polymers. They are produced by combining three monomers; Acrylonitrile, Butadiene and Styrene. Biron.M (2007) also has stated that the chemical structure of these monomers requires each monomer to be important component of ABS resins. Acrylonitrile contributes heat resistance, chemical resistance, and surface harness to the system. The butadiene contributes toughness and impact resistance, while the styrene component contributes processibility, rigidity, and strength.

(Please refer to Appendix B1 for detail ABS material characteristic)

Acatel (POM,Polyacetal)

Acatel resin provides a well balanced set of properties including a hard self-lubricated surface, excellent chemical resistant, strength, stiffnes, and toughness over a broad temperature range. Ashby.M.F (2009) carried out that the acetal homopolymer was first introduced in 1960 as semi-crystalline form of polymerized formaldehyde forming in a liner chain of molecules of oxymethylene. In the homopolymer process, the formaldehyde is separated form the water and purified to CH_2O gas, which is then polymerized to the polyoxymethylene molecule. In this case, the molecule is stabilized by a reaction with acetic anhydride to give acetate end groups. The acetate capped homopolymer is less resistant to attack by base, but it has higher melting point and mechanical advantages in strength, stiffness, toughness, hardness, creep, and fatigue than the copolymer acetal as has been stated by Bryce.M.D (1996).

(Please refer to Appendix B2 for detail POM material characteristic)

Polycarbonate (PC)

Polycarbonate was introduced in 1985. This material is an amorphous engineering thermoplastic material with exceptionally high impact strength, transparency, high temperature resistance, and dimensional stability. Biron.M (2007) has stated that the melt flow rate is one of most important properties of polycarbonate. It is produced by reacting bisphenol A and carbonyl chloride in an interfial process. This reaction is carried out under basic condition in the presence of an aqueous and an organic phase. Molecular weight is controlled by phenolic chain stopper. Polycarbonate does not have a true melting point as other crystalline polymers. It have a high glass transition temperature of 300 ^{0}F.

(Please refer to Appendix B3 for detail PC material characteristic)

Polybutylene Terephthalate (PBT)

Polybutylene terephthalene is high performance, semi-crystalline resin, one of the toughest and most versatile of all engineering thermoplastics. Bryce.M.D (1996) carried out that the strong and lightweight of this polyester is characterized by low moisture absorption, excellent electrical properties, broad chemical resistance, lubricity, durability, mechanical strength, and heat resistance. These properties are stable over a broad range temperature and humidity conditions. The resin is commonly supplied with fiber glass and mineral reinforcements. Polybutylene terephthalene is produced by the transesterification of dimethyl terephthalene with butanediol. This reaction takes place by a catalyzed melt poly-condensation, resulting in repetition of the molecular unit as has been carried out by Campo.E.A (2006).

(Please refer to Appendix B4 for detail PBT material characteristic)

Polyethylene Terephthalate (PET)

Polyethylene terephthalate (PET) is a versertile polymer widely used in synthetic fibers, industrial and packaging films, injection molding, blow molding, and thermoforming. Campo.E.A (2006) has proposed that high strength products are possible because of the ability of the material to be oriented and crystallized. Unoriented PET melt crystallizes or hardens slowly during its production. Molten PET is subject to hydrolytic degradation and must be rigorously dried before melt processing.

(Please refer to Appendix B5 for detail PET material characteristic)

Polyethylene (PE)

The development and testing of polyethylene polymers in the 1930s for use as high frequency insulation for radar cables during World War II gave impetus to its commercial production as stated by Campo.E.A (2006). Polyethylene is available in a range of flexibilities, depending on the production process. High density polyethylene (HDPE) is most rigid of the three basic types of PE resins (HDPE, low density polyethylene (LDPE) and linear low density polyethylene (LLDPE). HDPE can be formed by a wide variety of thermoplastic processing methods and is particularly useful where moisture resistance and low cost are required. Bill fry (1999) also carried out that the polyethylene is limited by low end use temperature characteristics.

(Please refer to Appendix B6 for detail PE material characteristic)

Polypropylene (PP)

Polypropylene was introduced in the late 1950s and is the fastest growing commodity thermoplastic in the world as has been carried out by Campo.E.A (2006). Ashby.M.F (2009) has stated that the polypropylene continues to displace other material, such as fiber glass, mineral reinforced thermoplastics and metals, in a variety of application. Polypropylene is manufactured by polymerizing propylene monomer with a titanium based catalyst; a second co-catalyst is added to initiate the polymerization reaction and hydrogen is used in the reactor to control polymer molecular weight. This reaction is produced using a slurry or gas phase type of process. There are three polypropylene structure; isotactic, syndiotactic, and atactic.

(Please refer to Appendix B7 for detail PP material characteristic)

Polystyrene (PS)

Polystyrene (PS) has been known for well over 100years, but its molecular nature was not clarified until about 1920, when the work of Staudinger described the material molecular structure. Polystyrene has been commercially produced since the late 1930s. Polystyrene is most popular commodity amorphous thermoplastic resin; it has a broad range of balanced properties and an attractive price as stated by Ashby.M.F (2009). Polystyrene is divided into semi-crystalline polystyrene (GPPS), rubber modified medium and high impact polystyrene (MIPS and HIPS), and expandable polystyrene (EPS)

(Please refer to Appendix B8 for detail PS material characteristic)

2.6 PLASTICS RAW MATERIAL COST

Polymeric materials are intrinsically expansive, but their uses become appealing if one take into account the processing costs, the new technical possibilities that they permit and the total at the end their lifetime.

Biron.M (2007) has stated that most significantly, the price per litre varies from about euro *(€)* 1 more than euro *(€)* 100 according to the nature of the polymer itself, the formulation of the grades and the inclusion of high cost reinforcements include carbon fibre and so on. The highest price relate to the polymer with highest performances. Below is show the figure of current common plastics material price in euro (€).

Table 2.3: Average cost for plastic raw material (€/ litre)

Thermoplastic	Minimum	Maximum
PE, PVC, PS, PP	0.8	4
ABS, SAN, SMA	3	5
PMMA, PC, PA, POM, PET, PBT, PPE	3	8
Speciality PA	7	12
PPS, PSU	7	30
PEI,PAI	20	40
PTFE	25	50
PEEK, LCP	20	120
ETFE, ECTFE, FEP, PFA	60	220

Source: Biron.M. 2009. PP 12

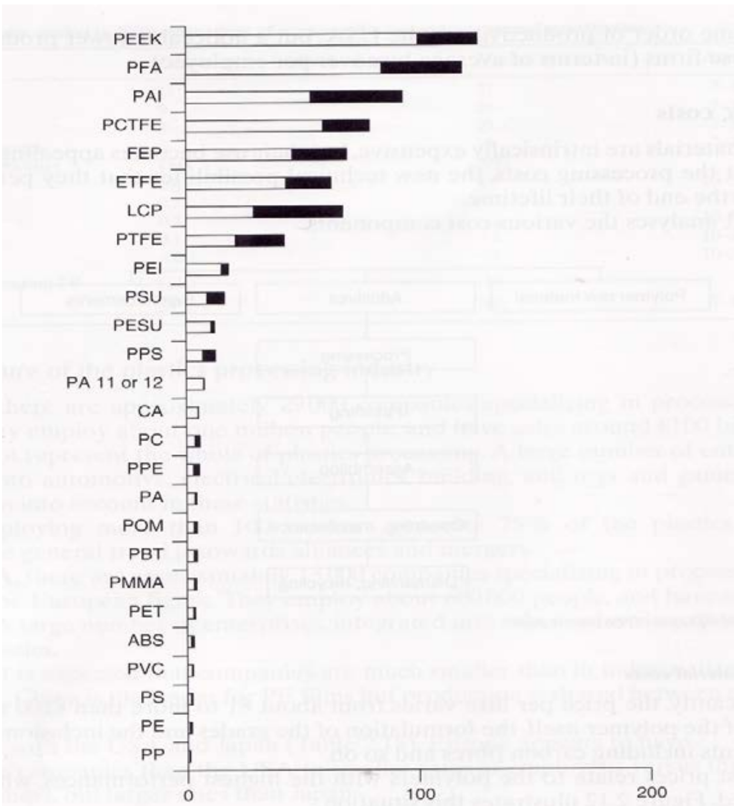

Figure 2.3: Plastic raw materials cost € per litre

Source: Biron.M. 2009. pp 48

2.7 PRODUCTION CYCLE TIME

Injection moulding is an industrial technology first used in the 1920’s. From this date, many companies have adopted this technology using it from daily life product to industry items such as a plastic fork. Henderson.J et al. (2006) carried out their study, the companies that use injection moulding machines will have a need for optimizing the machine to decrease cycle time and increase profits. Having a process that is efficient is necessary in this world market to compete with world class companies. Cutting down the cycle time for each part is a major concern with the injection moulding machine. Manipulate cooling time, back pressure, and plasticizing limit on the injection moulding machine to reduce the cycle time and keep the quality of the part that deal with problems such as shrinkage, flash, and other abnormalities.

Cooling Related to Cycle Times

The most important influence on cycle time is the cooling portion of the cycle. Bryce.D.M (1996) has stated that the amount of time required for this cooling portion is determined primarily by average wall thickness of the part and the temperature at which the mould is maintained. In general mould temperature should be set to the values recommended by supplier of plastic material. The cooling time can reduce by reduce the wall thickness. This is demonstrating the important to minimize the wall thickness of any part being moulded in order to reduce the cycle time.

Table 2.4: Average time for cycle activities

Parameter or cycle time activity	Average value
Gate closing time	1 second
Mould closing time	4 seconds
Initial injection time	3 seconds
Injection hold time	5 seconds
Cooling time	12 seconds
Screw return time	8 seconds
Mold open time	4 seconds
Ejection time	1 second
Part removal time	2 seconds
Mold inspection, clean, spray time	2 seconds

Source: Bryce.D.M. 1996

2.8 MOLDFLOW SIMULATION SOFTWARE

The plastics injection moulding process is integral to many of today's mainstream manufacturing processes. The industries such as telecommunications, consumer electronics, medical devices, computers and automotive all have large, constantly increasing demands for injection moulded plastic parts. The production of injection moulded parts is a complex process where, without the right combination of material, part and mould design and processing parameters, a multitude of manufacturing defects can occur and thus can incurring high costs as carried out by Direct industry (2002).

The plastic flow simulation (Moldflow software) is Computer Aided Engineering (CAE) tools are used to simulate the manufacture of plastic parts and the results help the engineer's correct defects on the final design, before mould tool manufacture is completed. The above factors bring a level of complexity to injection molding that makes it necessary to use Moldflow software as CAE tools to predict and solve potential problems before they occur. Additionally, the cost of tooling for injection molds can be very high and subsequent rework increases these already high costs. These entire factors combine to make injection molding an ideal application for CAE simulation using Moldflow software as has been carried out by Menges et al (2001).

The mold flow consists of two types, Mold flow Plastics Insight (MPI) and Mold flow Plastics Advisor (MPA). To simulate more accurate and get the meshing analysis, usually using Mold flow Plastics Insight (MPI) as simulator to simulate the plastic. The Mold flow Plastics Insight (MPI) suite of software is the world's leading product for the in-depth simulations to validate part and mold design. In a research on the plastic producing, Imtech technology (2005) carried out that the most companies around the world have chosen Mold flow's solutions because the software allows the user to analyze CAD solid models of thin-walled parts directly, resulting in a significant decrease in model preparation time. The time savings allow the user to analyze more design iterations as well as perform more in-depth analyses. Based on the previous analysis, proven that the solutions for all types of applications Mold flow's analysis products can simulate plastics flow and packing, mold cooling, and part shrinkage and war page for thermoplastic injection molding and injection compression molding processes. Imtech technology (2005) also carried out that the mold flow software also can create solution technique based on a solid finite element volume mesh, MPI/3D allows you to perform true three dimensional flow simulations on parts that tend to be very thick and solid in nature as well as those that has extreme changes from thin to thick. Below is some of benefit of Mold flow simulation in injection molding process.

(i) Efficient process conditions
(ii) Optimum cooling for cycle time savings.
(iii) Optimum gate position for minimum machine size

(iv) Position weld line where you want them

(v) Runner balancing for minimum scrap

(vi) Eliminate gas traps, sink marks & burning

(vii) Minimize clamp force requirements

(viii) Control fiber orientation

(ix) Reduced part shrinkage

(x) Gas injection simulation

(xi) Reduced war page at fast cycles

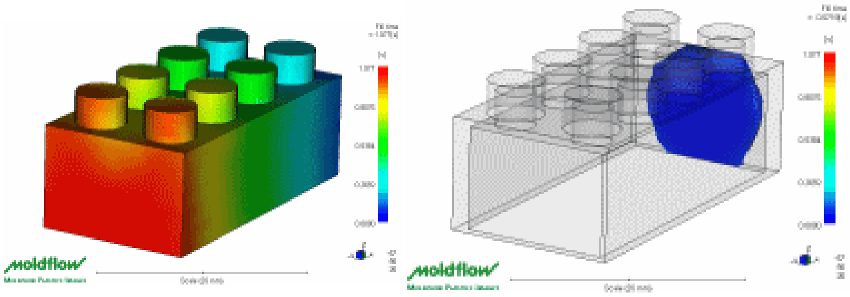

Figure 2.4: 3D filling simulation in Moldflow

Source: Imtech technology. 2005

CHAPTER 3

PROJECT METHODOLOGY

3.1 PROJECT FLOW DIAGRAM

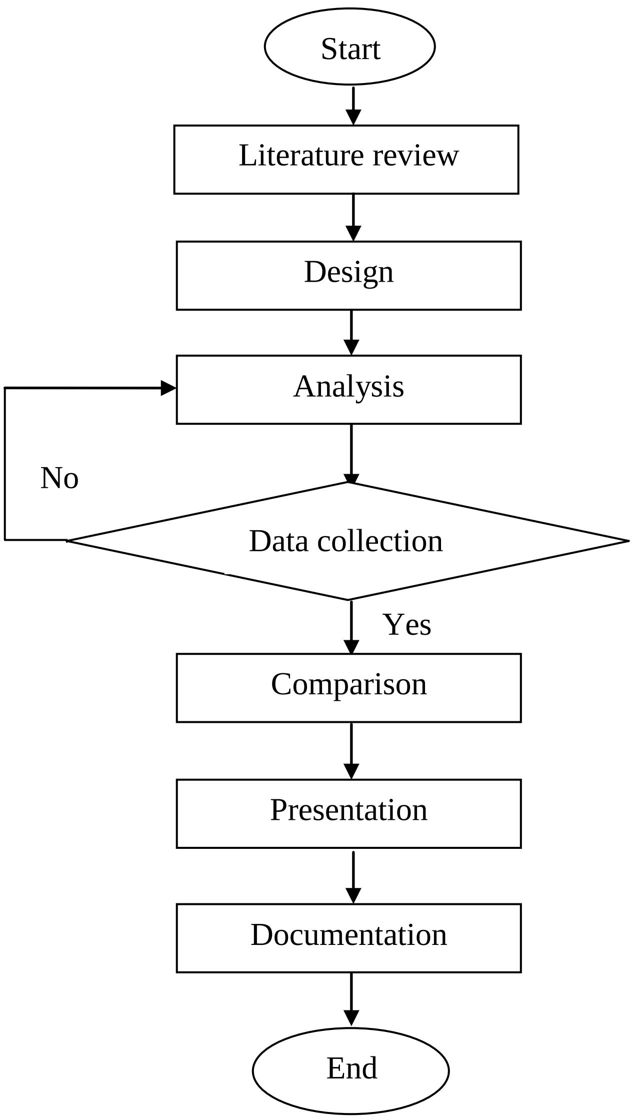

Figure 3.1: Project flow chart

3.2 LITERATURE REVIEW

The progress for this project will start with gather information by research and literature review via internet, journal, reference books, supervisor and other relevant academic material that related to this project. The literature is more about the injection moulding process, thermoplastic characteristic, types of plastic materials, cycle time, and Moldflow plastic insight (MPI) software. The detail literature review can be referring to chapter two.

3.3 DESIGN

In design stage, the product (Book Tray) needs to redraw in 3D drawing by using Computer Aided Design (CAD) software. The Computer Aided Design (CAD) software that used is Solidwork (2008 version) software. It is because this software can create a good 3D drawing. After draw in Solidwork software, the drawing file needs to save as in 'Iges file'. This type of file will be export to the Moldflow plastic insight (MPI) software for simulating process. Below are front view, side view, top view and isometric drawing of product. Please refer to appendix C for technical drawing.

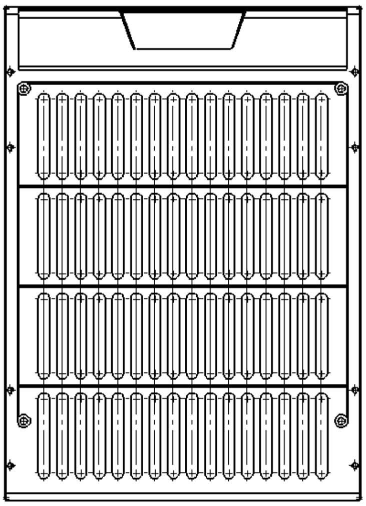

Figure 3.2: Top view

Figure 3.3: Isometric drawing

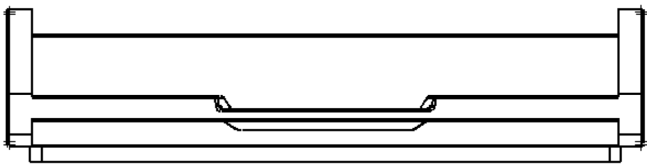

Figure 3.4: Front view

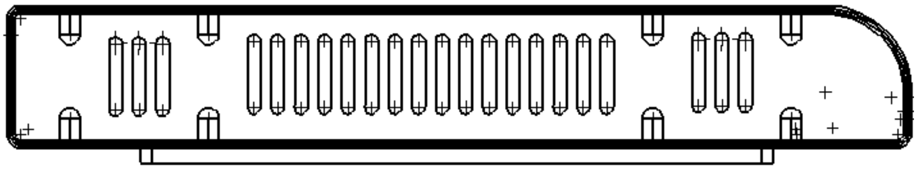

Figure 3.5: Side view

3.4 ANALYSIS

The analysis of project will be perform by simulate the plastic product using Moldflow software. The purpose of the analysis is to know the effect of material selection on injection moulding parameters. In analysis setup, all the mould parameter follows the actual mould such as get location, type of gate, cooling system, and runner system. The others parameters such as melt temperature, clamping force, holding pressure, back pressure and ejection force are constant and certainly based on material characteristic. The analysis need to repeat eight time with different material. Below are a few steps in using the Moldflow software and the constant process parameters.

3.4.1 Step in Running Moldflow Simulation

a) Create new project

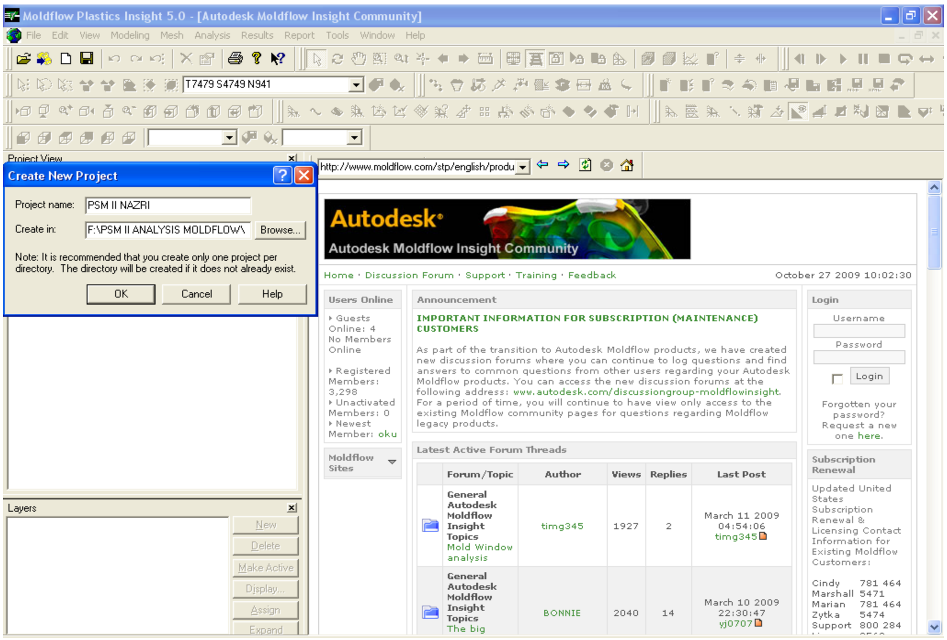

Figure 3.6: Create new project

b) Import 3-D CAD file

i.Import ‘iges’ file

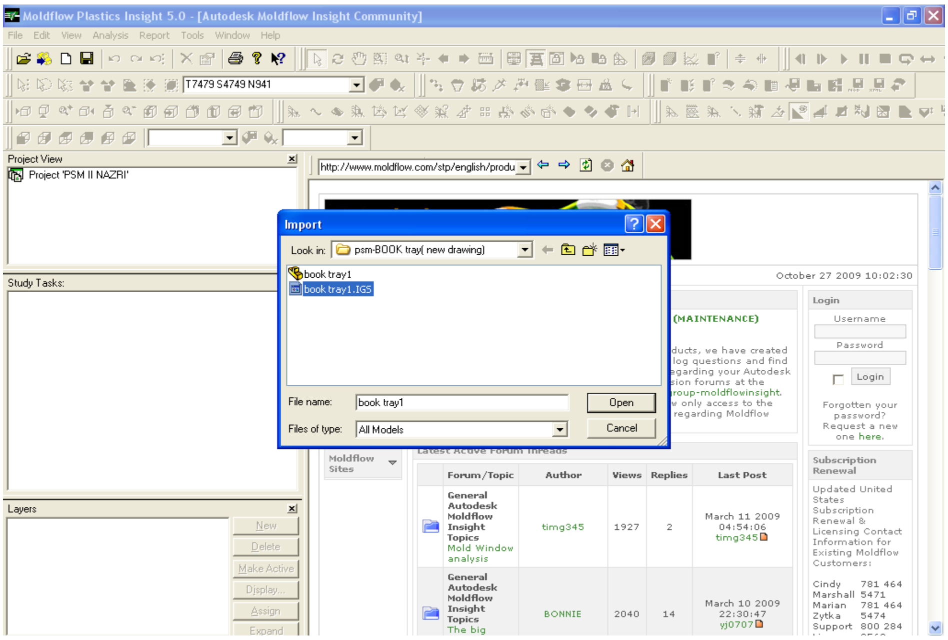

Figure 3.7: Import ‘iges’ file from CAD drawing

ii.Select type of mesh

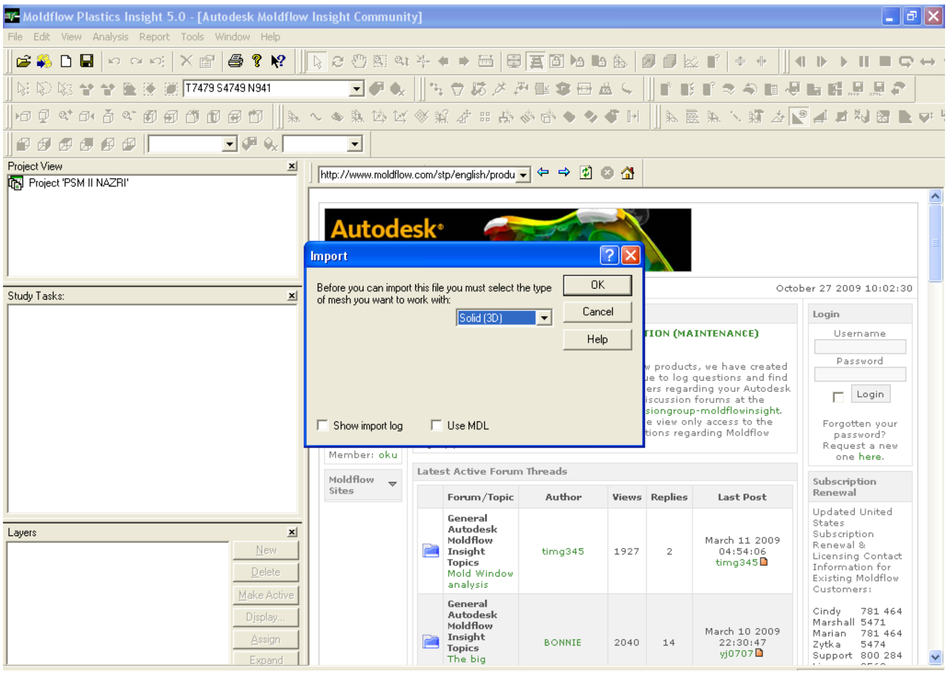

Figure 3.8: Select type of mesh

iii.Product was appeared

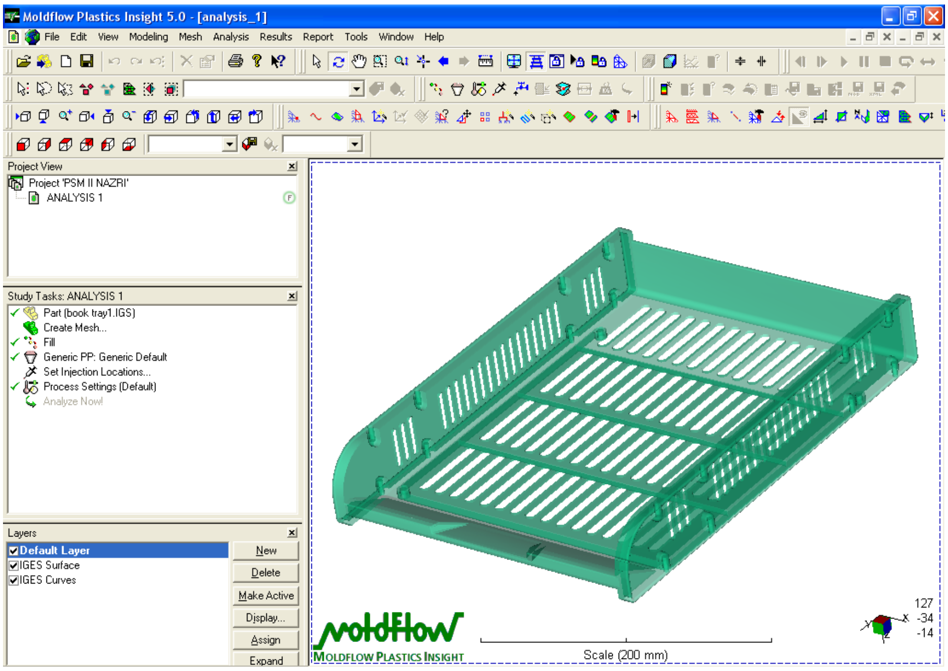

Figure 3.9: Book Tray appeared on Moldflow software

c) Generate mesh

i.Select generate mesh toolbar

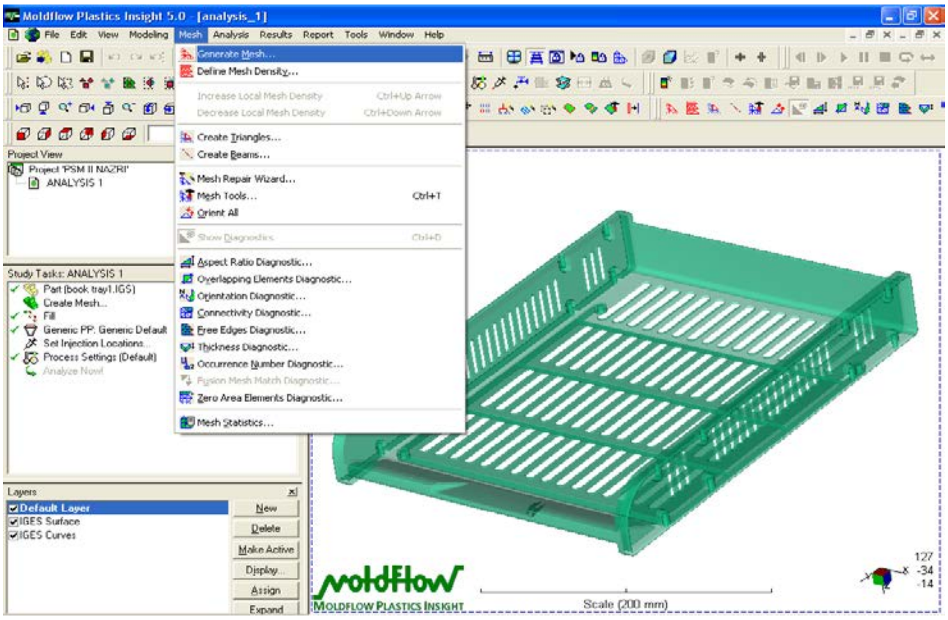

Figure 3.10: Generate mesh toolbar

ii.Start generate mesh

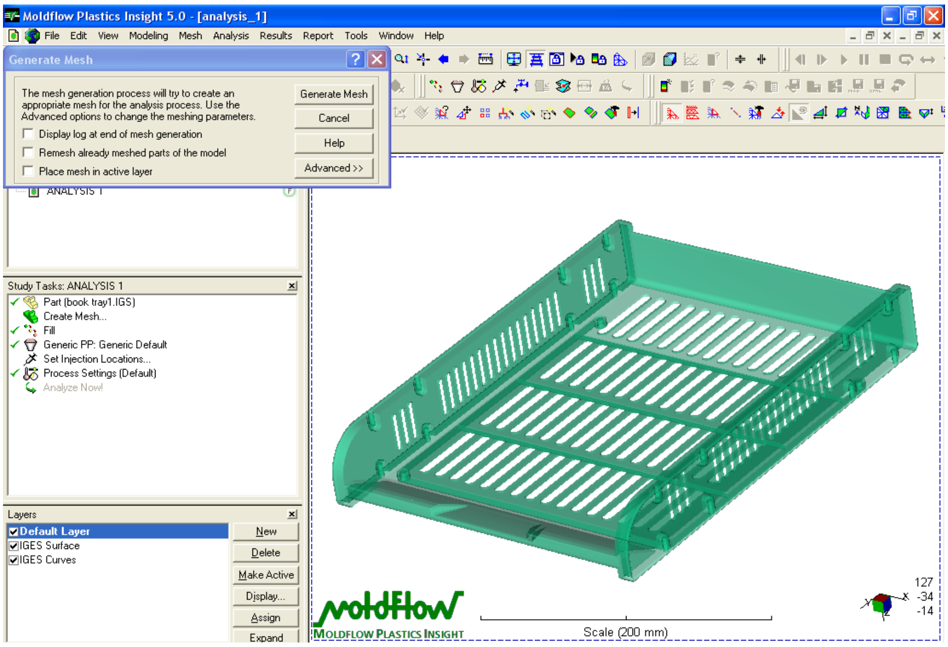

Figure 3.11: Generate mesh

iii.Mesh pattern was appeared as selected mesh type

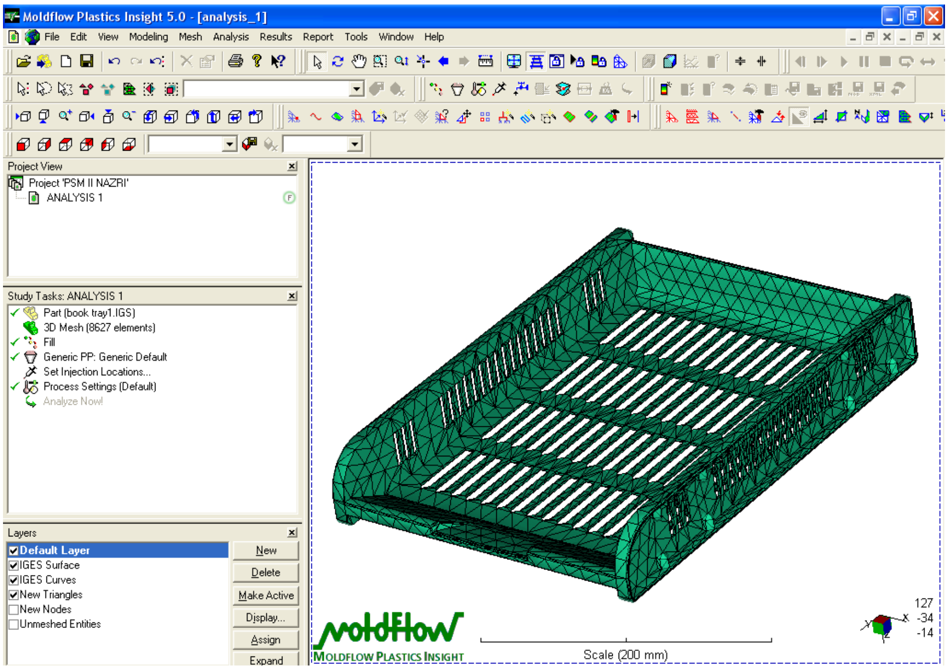

Figure 3.12: Mesh pattern appeared on Book Tray product (fusion)

d) Set analysis sequence

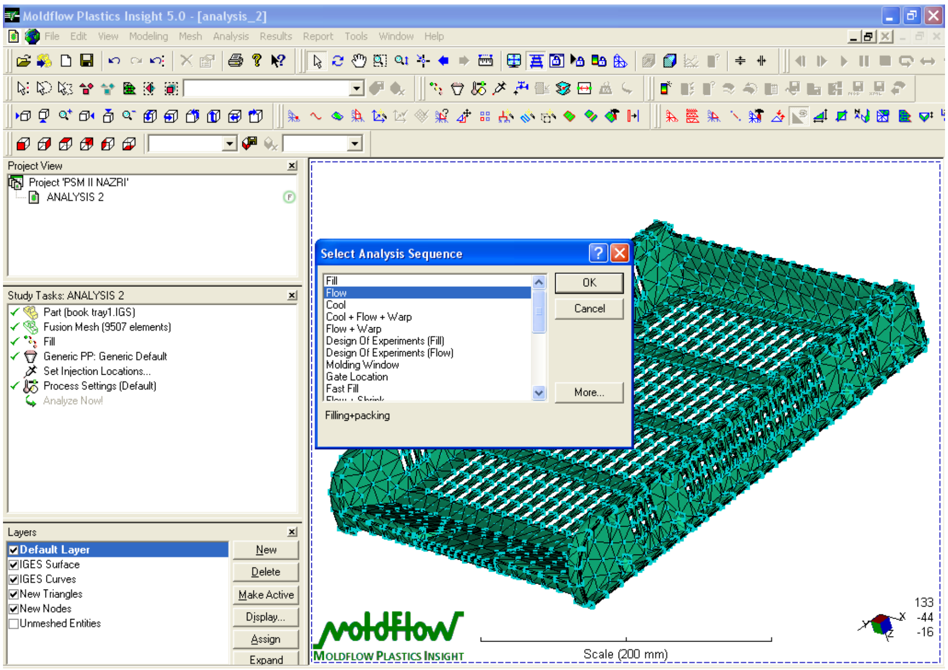

Figure 3.13: Analysis sequence wizard (flow analysis)

e) Set gate location and type of gate

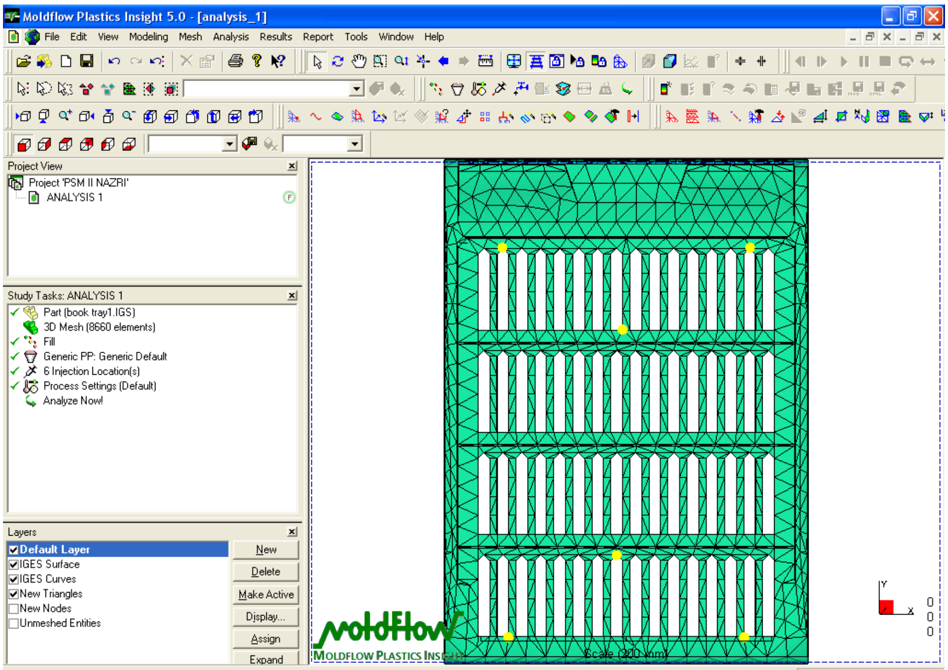

Figure 3.14: Gate location

f) Set runner and gate system

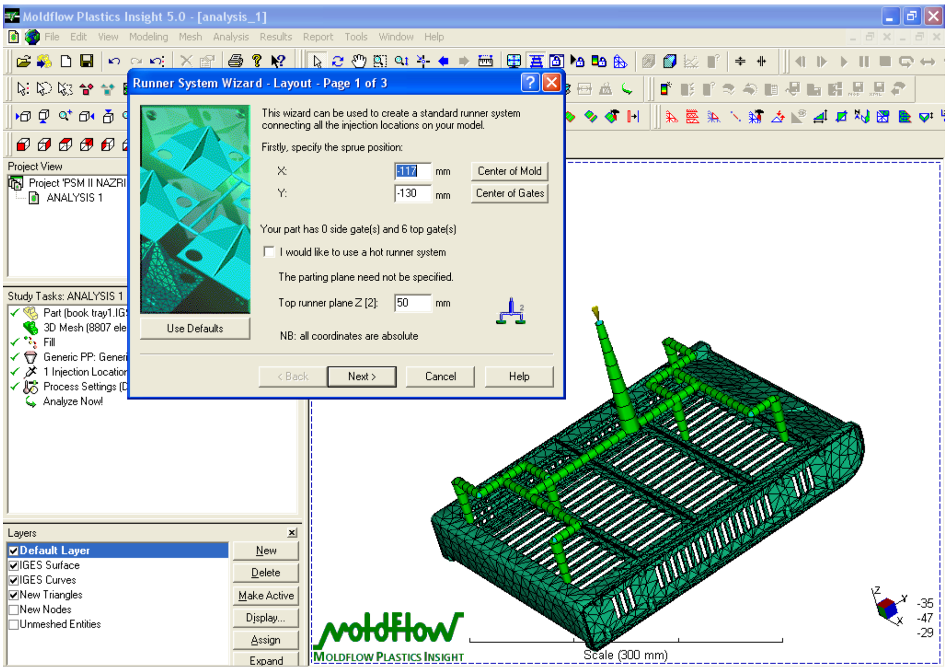

Figure 3.15: Runner and gate system setup

g) Set cooling system

i.Set cooling system wizard

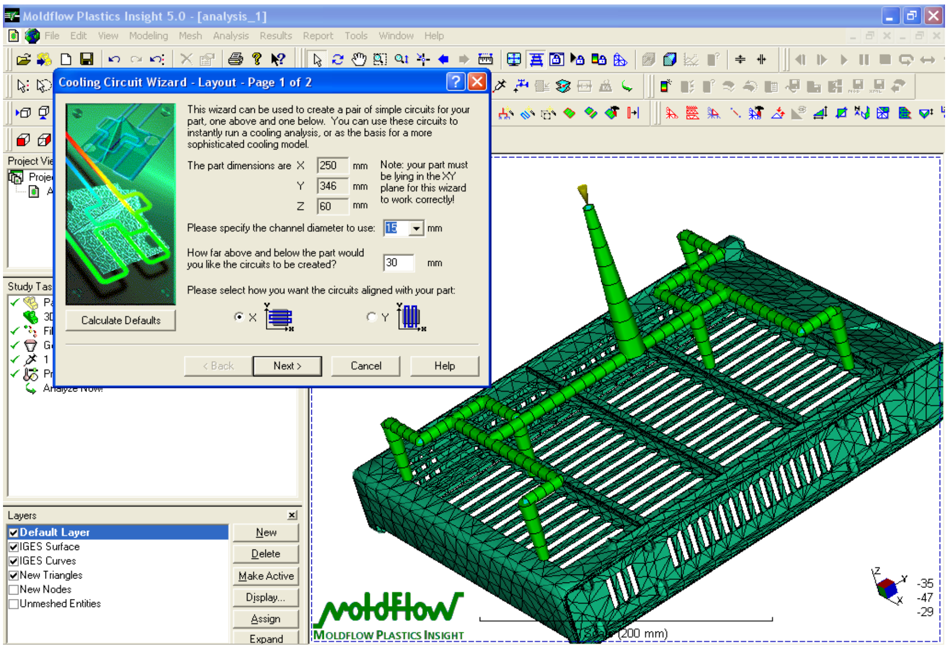

Figure 3.16: Cooling system type setup

ii.Set parameter in cooling system

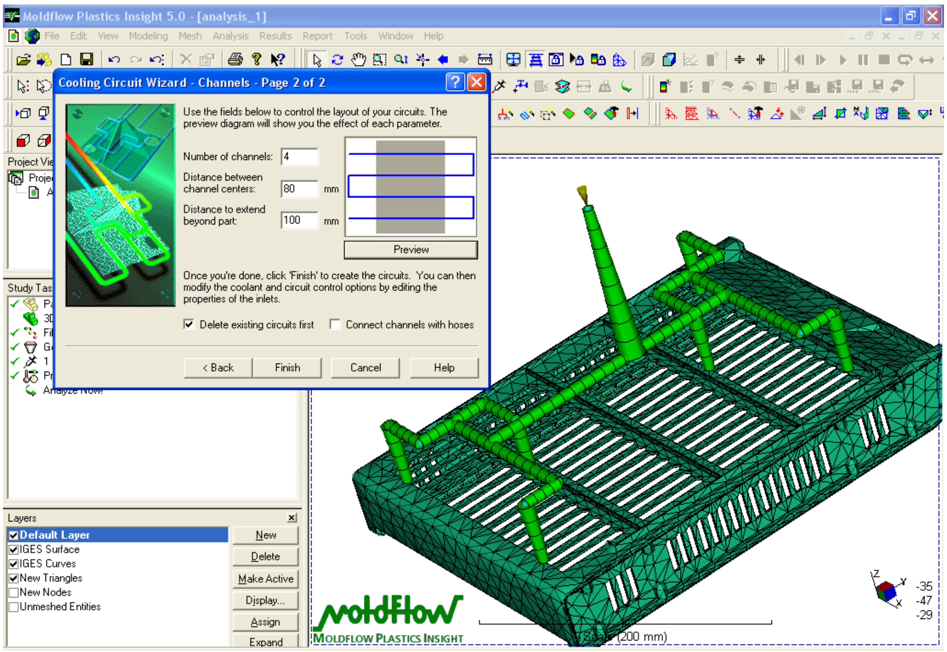

Figure 3.17: Parameter in cooling system setup

iii.Cooling system was appeared

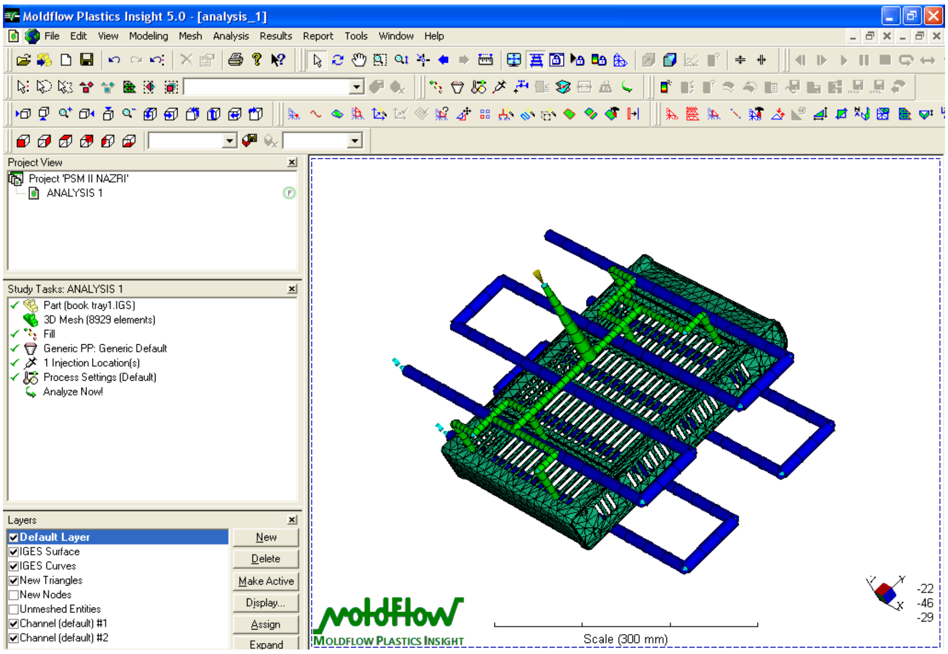

Figure 3.18: Complete modelling with cooling and runner system

h) Set type of plastic raw material.

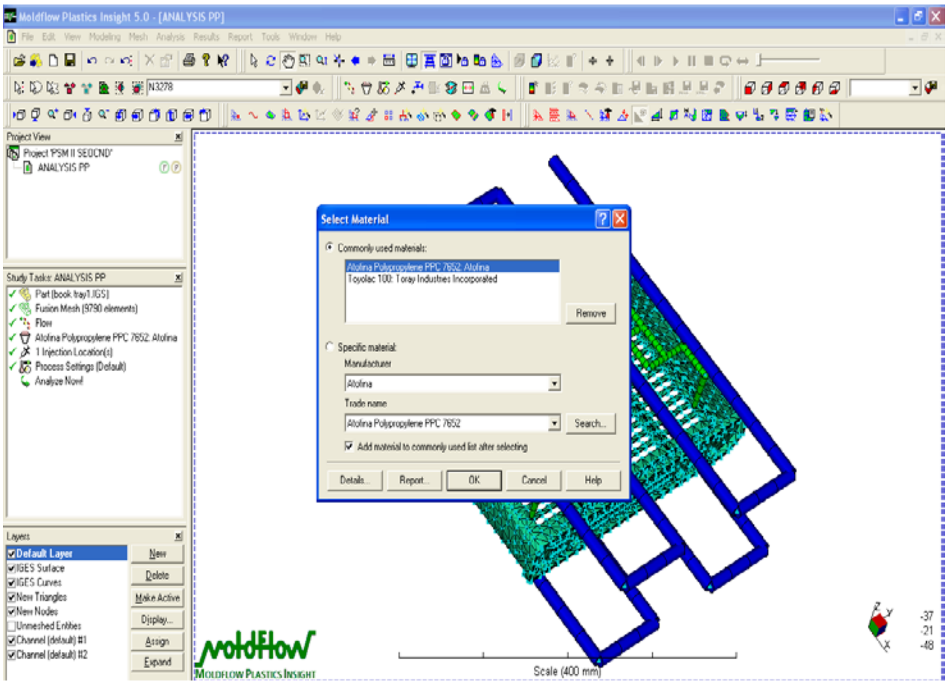

Figure 3.19: Plastic raw material setup

i) Set process parameters

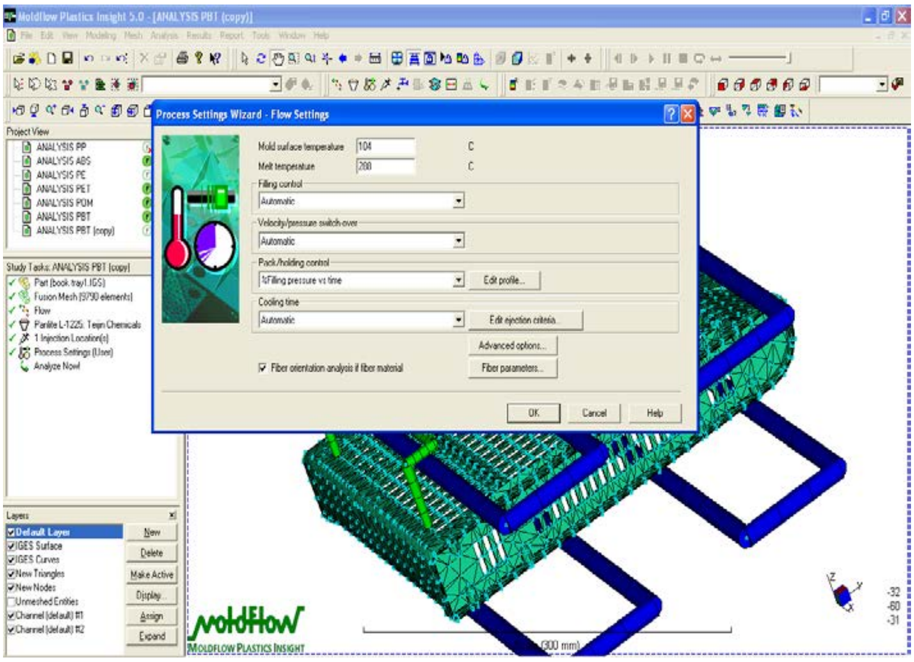

Figure 3.20: Process parameter setup

j) Perform the analysis

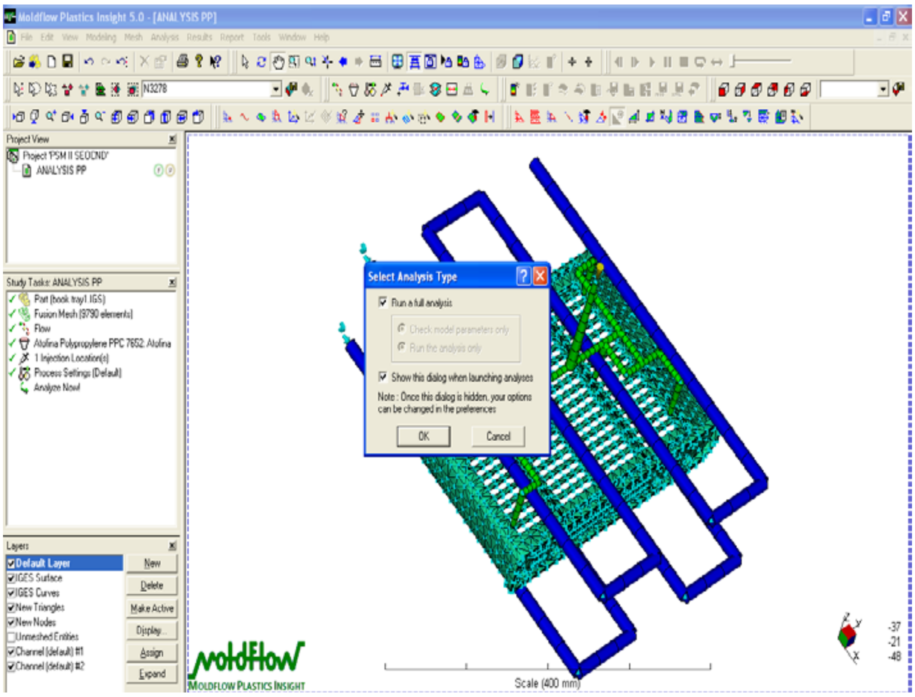

Figure 3.21: Perform the analysis

The analysis will running follows the entire step above. The analysis need to running with eight different plastic material and process parameter. Each plastic material analysis also need to run three times because to take average value of result. From that requirement, step (i) and step (h) need to change for each different plastic material analysis. The plastic material are involve in this project which are Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyethylene terephthalate (PET), Acetal (POM,Polyacetal), and Polybutylene terephthalate (PBT). In step (h) the process parameter that needs to change are plastics melt temperature and plastics mould temperature. The result for each analysis will collect and discussed.

3.5 DATA COLLECTION

Data collection is the process after the analysis process. The injection moulding parameter need to consider or record are filling time, initial injection time and cooling time in unit of second (s). Below is the table of data collection.

Table 3.1: Table of data collection

Plastic material	**Filling time (s)**				**Cooling time (s)**				**Initial injection time (s)**			
	1	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**	**1**	**2**	**3**	**Avg**
Acrylonitrile Butadiene Styrene (ABS)												
Polycarbonate (PC)												
Polyethylene (PE)												
Polypropylene (PP)												
Polystyrene (PS)												
Polyethylene terephthalate (PET)												
Acetal (POM,Polyacetal)												
Polybutylene terephthalate (PBT)												

3.6 RESULT COMPARISON

Result comparison will be start with calculate the cycle time (s) for each plastic material. Based on cycle time, the value of production capacity, product cost and profit can be calculated. All the calculation was follow the formulas below:

3.6.1 Formula for Calculate Cycle Time and Annual Production Cost

(a) Cycle Time Formula

Cooling time and filling time are two parameters that obtain from the result of Moldflow analysis. Those parameters are part of the cycle time and most important in cycle time of product. Below is the formula to calculate the complete cycle time in producing the book tray.

Complete cycle time = ∑ constant cycle time activity (s) + cooling time (s) +initial injection time (s) + filling time (s)

(Bryce.M.D. 1996)

(b) Production capacity

Production capacity is volume of products that can be generated by a production plant or enterprise in a given period by using current resources. In this project, the production capacity can be calculate based on cycle time for product a day. Below is the formula to calculate the production capacity.

Production capacity = [Working hour x 60 x 60] / cycle time
= pcs/day

(Campo.E.A. 2006)

(c) Product cost

The cost of product consists to two types which are material cost and processing cost. Below show the step to calculate the both costs.

(i)	Total shot weight	= [product weight x (No of cavity)] + Runner weight
(ii)	1 hour	= 3600 s
	Part/hour	= [3600 x No of cavity x machine utility] /cycle time
(iii)	Material cost	= [[total shot weight / No of cavity] x Resin waste] x Average material cost (RM/g)
(iv)	Processing cost	= Machine and labor costing / (part/hour)
(v)	Cost of product	= Material cost + Processing cost

(Campo.E.A. 2006)

(d) Profit

Profit of product for each material will calculate based on current book tray market price. Below is show the formula to calculate the profit of product.

Profit (RM/day) = Selling price – Production cost (RM/day)

(Campo.E.A. 2006)

3.6.2 Comparison for Each Plastic Material

Comparison process is step to define a good material for book tray product. The comparison will made based on production capacity and profit. The best plastic material will selected from the comparison in determine a good material for book tray. Below is show the comparison of production capacity and profit.

Table 3.2: Table of process parameter comparison

Plastic Material	**Production capacity (part/day)**	**Product cost (RM/day)**	**Profit in 8 hour (RM/day)**
Acrylonitrile Butadiene Styrene (ABS)			
Polycarbonate (PC)			
Polyethylene (PE)			
Polypropylene (PP)			
Polystyrene (PS)			
Polyethylene terephthalate (PET)			
Acetal (POM,Polyacetal)			
Polybutylene terephthalate (PBT)			

3.7 PRESENTATION AND DOCUMENTATION

Lastly, the final report writing and prepare the presentation. The presentation process will be held two times, at the last first semester and at the last second semester. First presentation should be present about project title, problem statement, objective, project scope, literature review and project methodology. Second presentation must be showing the result and the project outcome. The presentation session will be judge by three person of panel from Mechanical Engineering Faculty (FKM). For the report or documentation, the report draft chapter one until chapter three need to submit at the first semester. Second semester, the report must be complete and need to banding. All the report writing is guided by FKM thesis format and also guidance from supervisor. All task scheduled is take around fourteen weeks to complete.

CHAPTER 4

ANALYSIS RESULTS

4.1 INTRODUCTION

The analysis is the process to gather the result from equation or simulation. The analysis method that used in this project is simulating the plastic part using Moldflow software. Moldflow simulation software is one of computer aided engineering (CAE) software that used to gather the injection moulding parameter and eliminate the defect before the product will product with actual process. In this project, Moldflow software will used to find the cooling time, initial injection time and filling time in cycle of injection moulding process for different raw material. The purpose of this analysis is to know the effect of material selection on injection moulding parameter; cooling time, initial injection time and filling time. That parameter will effect the cycle time in injection moulding process. The best material will resulted the lower cycle time for injection moulding process and can gain the better production capacity and higher profit.

4.2 NAME OF MATERIAL IN MOLDFLOW

In Moldflow software, the type of material that will use in simulation cannot be setting by material name but need to setting by trade name and manufacturer of those materials. The trade name is alternative name to the real name of raw material. The trade name is given by manufacturer as their product brand. Below is showing the trade name for raw material that used in this analysis.

Table 4.1: Trade name for plastic material

Material	**Trade name**	**Manufacturer**
Acrylonitrile Butadiene Styrene (ABS)	Toyolac 100	Toray industry incorporation
Polycarbonate (PC)	Panlite L-1225	Teijin chemicals
Polyethylene (PE)	Dowlex 2517	Dow chemical (USA)
Polypropylene (PP)	Atofina polypropylene	Atofina petrochemical
Polystyrene (PS)	Austrex 103	Polystyrene Australia
Polyethylene terephthalate (PET)	Arnite AV 2370	DSM engineering plastics
Acetal (POM,Polyacetal)	Duracon M140	Polyplastic
Polybutylene terephthalate (PBT)	Duranex 3200	Polyplastic

Source: Trade name for plastic. 2009

4.3 PROCESS PARAMETER SETUP IN MOLDFLOW ANALYSIS

The process parameters need to setting in this project is melt and mould temperature. The melt and mould temperature for each plastic materials are different because viscosity each plastic materials are different. Below is showing the suggested melt and mould temperature for each plastic material.

Table 4.2: Table of suggested melt temperature for selected plastics material

Plastic material	**Temperature (^{o} C)**
Acrylonitrile Butadiene Styrene (ABS)	216
Polycarbonate (PC)	288
Polyethylene (PE)	210
Polypropylene (PP)	177
Polystyrene (PS)	199
Polyethylene terephthalate (PET)	280

Table 4.2: Continued

Plastic material	**Temperature (^{o} C)**
Acetal (POM,Polyacetal)	218
Polybutylene terephthalate (PBT)	230

Source:Bryce.M.D. 1996

Table 4.3: Table of suggested mould temperature for selected plastics material

Plastic material	**Temperature (^{o} C)**
Acrylonitrile Butadiene Styrene (ABS)	85
Polycarbonate (PC)	104
Polyethylene (PE)	43
Polypropylene (PP)	49
Polystyrene (PS)	82
Polyethylene terephthalate (PET)	100
Acetal (POM,Polyacetal)	99
Polybutylene terephthalate (PBT)	50

Source:Bryce.M.D. 1996

4.4 MOLDFLOW ANALYSIS RESULT

Analysis result for this project is the result gather from the Moldflow simulation analysis. The result consists of fill time, initial injection time and cooling time. Figure below are show the material selection, process parameter setting, fill time, initial injection time and cooling time for Acrylonitrile Butadiene Styrene (ABS).

(Refer to Appendix D for others plastic materials analysis result figures)

4.4.1 Acrylonitrile Butadiene Styrene (ABS)

(i) Material selection

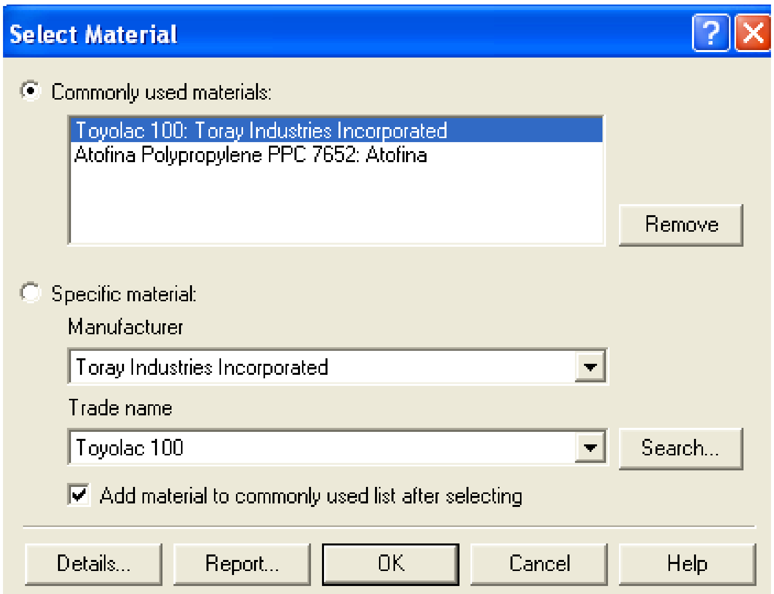

Figure 4.1: Material selection (ABS)

(ii) Process parameter

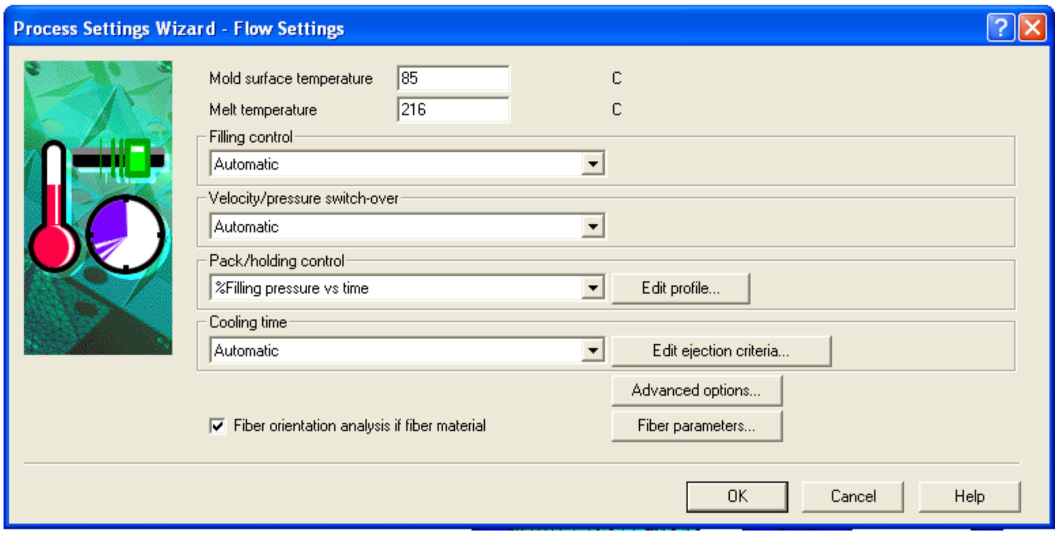

Figure 4.2: Melt and mould temperature (ABS)

(iii)Fill time

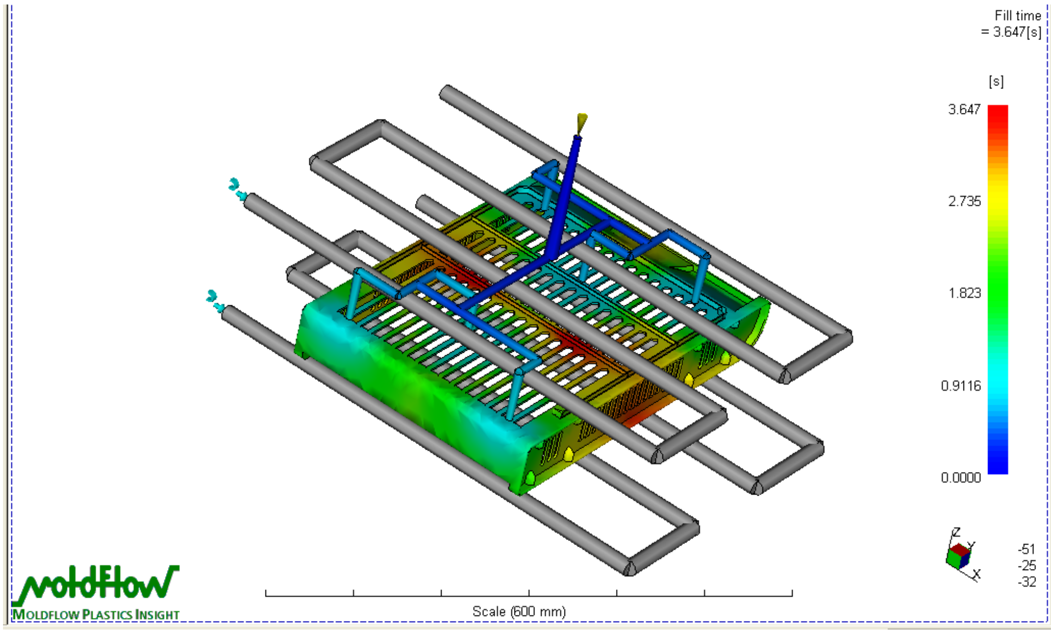

Figure 4.3: Fill time (ABS)

(iv)Cooling and initial injection time

```
Temperature Settings
---------------------------------------------------------------------------

Melt temperature:                                216.0000 C

Mold cavity_side temperature:                     85.0000 C

Mold core-side temperature:                       85.0000 C
---------------------------------------------------------------------------


Injection Settings
---------------------------------------------------------------------------

Injection control method: Injection Time

Injection Time:                     3.0536 s

Nominal Flow rate:                104.2900 cm^3/s

Packing pressure profile

          Duration                 Pressure
             (s)                     (MPa)

            0.0000                  82.5316
           10.0000                  82.5316

Cooling time:                                     44.2488 s

---------------------------------------------------------------------------
```

Figure 4.4: Cooling and initial injection time (ABS)

4.5 DATA COLLECTION

The analysis result is taking from eight analyses with different plastic material. The eight analyses were repeated with three times and the result of filing, cooling and initial injection time will take into the table. The average result of filing, cooling and initial injection time for each material will calculate and placed on the table. Below show a few table for data collection from the analysis.

Table 4.4: Constant process parameter

Parameters	Value
Dosage (m^3)	320
Max. Injection press (Mpa)	180
Packing press (Mpa)	80
Clamp force (kN)	3,630
Mould temp (^{o}C)	Based on material
Melt temp (^{o}C)	Based on material
Volume flow rate (m^3/s)	(Default) based on material

Source: Moldflow analysis

Table above is show the result of constant parameters in Moldflow analysis. A few parameter need to setting by user such as mould temperature and melt temperature. Other parameter above are set or suggested by Moldflow software based on product and plastic material. Dosage is the total volume of cavity added with volume of runner, sprue and gate. Maximum injection pressure is the maximum pressures that need to push the molten plastic material into the cavity. Packing pressure also known as holding pressure is pressures to hold the molten plastic material while in packing process. Clamp force is force powered by hydraulic mechanism to hold the mould while in filling and packing process.

Table 4.5: Result of filling time (s)

Plastic material	**Filling time (s)**			
	1	**2**	**3**	**Average**
Acrylonitrile Butadiene Styrene (ABS)	3.647	3.856	3.507	3.670
Polycarbonate (PC)	2.202	2.360	2.340	2.301
Polyethylene (PE)	1.827	1.970	1.910	1.902
Polypropylene (PP)	1.099	1.364	1.267	1.243
Polystyrene (PS)	3.645	3.798	3.586	3.676
Polyethylene terephthalate (PET)	2.584	2.645	2.543	2.591
Acetal (POM,Polyacetal)	3.507	3.697	3.725	3.643
Polybutylene terephthalate(PBT)	2.165	2.356	2.253	2.258

Table 4.6: Result of cooling time (s)

Plastic material	**Cooling time (s)**			
	1	**2**	**3**	**Average**
Acrylonitrile Butadiene Styrene (ABS)	44.249	42.365	43.756	43.457
Polycarbonate (PC)	8.500	8.645	8.598	8.581
Polyethylene (PE)	10.750	10.745	11.190	10.895
Polypropylene (PP)	13.500	13.650	13.713	13.621
Polystyrene (PS)	11.750	11.643	11.825	11.740
Polyethylene terephthalate (PET)	2.450	2.500	2.542	2.500
Acetal (POM,Polyacetal)	9.251	9.273	9.374	9.300
Polybutylene terephthalate(PBT)	6.750	6.842	6.734	6.775

Table 4.7: Result of initial injection time (s)

Plastic material	Initial injection time (s)			
	1	**2**	**3**	**Average**
Acrylonitrile Butadiene Styrene (ABS)	3.054	3.187	3.122	3.121
Polycarbonate (PC)	1.954	2.097	2.164	2.072
Polyethylene (PE)	1.710	1.834	1.754	1.766
Polypropylene (PP)	0.977	1.132	1.246	1.118
Polystyrene (PS)	3.298	3.320	3.240	3.286
Polyethylene terephthalate (PET)	2.443	2.598	2.487	2.509
Acetal (POM,Polyacetal)	3.298	3.345	3.320	3.321
Polybutylene terephthalate(PBT)	1.344	1.435	1.326	1.368

All of three tables above are the major parameter in this project. From the result, the value of filling, cooling, and initial injection are different for each material. The effect of that parameter can be generating in calculation of cycle time, production capacity and product cost. From the calculation, the comparison can be made to know the effect of material on injection moulding parameter.

4.6 CALCULATION

4.6.1 Cycle Time

The complete injection moulding process cycle will produce a few product based on number of cavity. In the cycle, the cycle time was important because it will be effect the production. The cycle time consist to ten cycle activities such as gate closing time, mould closing time, initial injection time, injection hold/filling time, cooling time, screw return time, mould open time, ejection time, part removal time and mould inspection, clean, spray time. In this project, all the time will be constant except filling time, initial injection time, and cooling time. Below is the result of cycle time for each material.

Table 4.8: Constant cycle time activity

Parameter or cycle time activity	**Average value**
Gate closing time	1 second
Mould closing time	4 seconds
Screw return time	8 seconds
Mold open time	4 seconds
Ejection time	1 second
Part removal time	2 seconds
Mold inspection, clean, spray time	2 seconds
Totals (∑ **)**	22 seconds

Source: Bryce.M.D. 1996

Cooling time, initial injection time, and filling time are three parameters that obtain from the result of Moldflow analysis. Those parameters are part of the cycle time and variable in cycle time of product. Sum of others cycle time activity will be added with the cycle time activity from the analysis. The complete cycle time for each material will be calculated and place on table below.

Complete cycle time = ∑ constant cycle time activity (s) + cooling time (s)
+initial injection time (s) + filling time (s)

(Bryce.M.D. 1996)

Example calculation:

a) ABS = 22 seconds + 43.457 seconds + 3.121 seconds + 3.670 seconds
= 72.248 seconds

The calculation of complete cycle time for each different plastic material will repeated follow calculation above. Table below is show all the cycle time for each material.

Table 4.9: Process cycle time

Plastic Material	**Cycle time (s)**
Acrylonitrile Butadiene Styrene (ABS)	72.248
Polycarbonate (PC)	34.954
Polyethylene (PE)	36.563
Polypropylene (PP)	37.982
Polystyrene (PS)	40.702
Polyethylene terephthalate (PET)	29.600
Acetal (POM,Polyacetal)	38.264
Polybutylene terephthalate (PBT)	32.401

4.6.2 Production Capacity

Production capacity is volume of products that can be generated by a production plant or enterprise in a given period by using current resources. In this project, the production capacity can be calculate based on cycle time for product in a day. Working hour in producing this product is eight hour per day. The production capacity will be calculated based on eight hour working a day and will result the amount of product that will produce in a day period.

Production capacity = [Working hour x 60 x 60] / cycle time
= part/day

(Campo.E.A. 2006)

Example calculation:

a) ABS = [8 hour/day x 60 x 60] / 72.248 seconds
= 399 parts/day

The calculation of production capacity for each different plastic material will repeated follow calculation above. Table below is show all the cycle time for each material.

Table 4.10: Production capacity

Plastic Material	**Production capacity (part/day)**
Acrylonitrile Butadiene Styrene (ABS)	399
Polycarbonate (PC)	824
Polyethylene (PE)	788
Polypropylene (PP)	758
Polystyrene (PS)	708
Polyethylene terephthalate (PET)	973
Acetal (POM,Polyacetal)	753
Polybutylene terephthalate (PBT)	889

4.6.3 Product Cost

The cost of product consists to two types which are product material cost and processing cost. Firstly, the product material cost is a cost of material in producing the product. Costs of product for each plastic material was different because of each material have its own material price. Weight of product for each plastic material was also different because each material has its own density. These two variable need to define for each plastic material before calculate the product material cost. Then, the processing cost is including the cost of injection moulding machine and labour (work force) in producing the product. Below is show a few calculation and tables in define the product material cost and processing cost.

Table 4.11: Item in cost calculation

Item	**Value**
No of Cavity	1
Product volume	320 m^3
Resin waste	10 %
Machine utility	90%
Working hour	8 hour/day

Source: Actual mould, Moldflow analysis and Campo.E.A. 2006

First calculation is to determine the total shot weight of product for each plastic material. Total shot weight is sum of product and runner weight. Below is the example calculation and the table value of total shot weight for each plastic material.

Total shot weight = [product weight x (No of cavity)] + Runner weight

Example calculation:

a) ABS = [273g x 1] + 67g
= 340 g

Table 4.12: Weight of product and runner system based on material

Plastic Material	**Product weight (g)**	**Runner system weight(g)**	**Total shot weight (g)**
Acrylonitrile Butadiene Styrene (ABS)	273	67	340
Polycarbonate (PC)	310	76	386
Polyethylene (PE)	212	53	265
Polypropylene (PP)	183	42	225
Polystyrene (PS)	266	67	333
Polyethylene terephthalate (PET)	412	101	513
Acetal (POM,Polyacetal)	314	78	392
Polybutylene terephthalate (PBT)	378	95	473

Second calculation is to determine the material cost of product for each plastic material. The average plastic raw material cost for each plastic material need to define first before calculates the material cost for the product.

Table 4.13: Average cost for plastic raw material (€/ litre)

Thermoplastic	**Min**	**Max**	**Average**
PE, PVC, PS, PP	*0.8*	*4*	*2.4*
ABS, SAN, SMA	*3*	*5*	*4*
PMMA, PC, PA, POM, PET, PBT, PPE	*3*	*8*	*5.5*
PPS, PSU	7	30	18.5
PEI,PAI	20	40	30
PTFE	25	50	37.5
PEEK, LCP	20	120	70
ETFE, ECTFE, FEP, PFA	60	220	100

Source: Biron.M. 2009

The table previously is show the average cost of plastic material in unit euro (€) per litre. The costs of the plastic material need to convert to Ringgit Malaysia (RM) per gram.

Convert litre to kg

1 litre = 0.001 m^3

1 litre plastic material = 0.001 m^3 x [SG x 1000 kg/m^3]

= kg

Convert euro (€) to Ringgit Malaysia (RM)

1 euro (€) = RM 5.04 (current exchange)

Raw material cost (€) / litre = [RM5.04 x material cost (€) / litre] / [Raw material weight for a litre]

Example calculation:

For ABS raw material:

a) 1 litre ABS = 0.001 m^3 x [1.05 x 1000 kg/m^3]

= 1.05 kg @ 1050 g

b) 4 euro (€) / litre = [RM 5.04 x 4] /1.05 kg

= RM 19.2 /kg

The calculation of convert material cost in euro (€)/litre to RM/kg for each different plastic material will repeat follow calculation above. Table below is show all the cost in RM/kg for each raw material.

Table 4.14: Material cost in euro (€)/litre to RM/kg

Plastic Material	**Specific gravity (SG)**	**Raw material weight in 1 litre (g)**	**Raw material cost euro/litre**	**Raw material cost RM/kg**
Acrylonitrile Butadiene Styrene (ABS)	1.05	1050	4	19.20
Polycarbonate (PC)	1.4	1400	5.5	19.80
Polyethylene (PE)	0.94	940	2.4	12.90
Polypropylene (PP)	0.9	900	2.4	13.40
Polystyrene (PS)	1.05	1050	2.4	11.50
Polyethylene terephthalate (PET)	1.67	1670	5.5	16.60
Acetal (POM,Polyacetal)	1.42	1420	5.5	19.50
Polybutylene terephthalate (PBT)	1.53	1530	5.5	18.10

Material cost = [[total shot weight / No of cavity] x Resin waste] x Average raw material cost (RM/g)

Example calculation:

For ABS material:

Material cost = [[340 g / 1] x 1.10] x [RM 19.20/1000 (RM/g)]
= RM 7.18 /pcs

The calculation of product material cost for each different plastic material will repeat follow calculation above. Table below is show all the product material cost for each plastic material.

Table 4.15: Product material cost

Plastic Material	**Product material cost (RM/pcs)**
Acrylonitrile Butadiene Styrene (ABS)	7.18
Polycarbonate (PC)	8.41
Polyethylene (PE)	3.76
Polypropylene (PP)	3.31
Polystyrene (PS)	4.21
Polyethylene terephthalate (PET)	9.37
Acetal (POM,Polyacetal)	8.41
Polybutylene terephthalate (PBT)	9.42

The last calculation is to determine the processing cost. Processing cost is the cost in operate the injection moulding machine. In operate the injection moulding machine, involve two costs which is machine operating cost and labor cost. The machine operating cost will calculate by the electric power cost that used to run the injection moulding machine. The labor cost will calculate by cost of cost of workforce in an hour working. Below is a few calculation and table to determine the processing cost.

Machine operating cost;

Machine type:	= ARBURG 520 C
Pump motor power	= 30.0 kW
Heating capacity	= 14.2 kW
TNB tariff (industry)	= RM 0.28 / kWh
Machine operating cost	= [30.0 kW + 14.2 kW] x RM 0.28/ kWh
	= RM 12.38 / hour

Labor cost;

Worker = a person

Salary = RM 700/ month

Working day = 5 day / week

Working hour = 8 hours / day

Labor cost = RM 700/ [[30/7] x 5 x 8]

= RM 4.08 / hour

Example calculation:

For ABS material:

Part / hour = [[3600 x No of cavity x machine utility]/cycle time]

Processing cost = Machine and labor costing per hour / [part/hour]

= Machine and labor costing per hour / [[3600 x No of cavity x machine utility]/cycle time]

= [RM 12.38 + RM 4.08] / [[3600 x 1 x 0.9] / 72.248]

= RM 0.37 / pcs

Total cost of product;

Material cost = RM 7.18 /pcs

Processing cost = RM 0.36 / pcs

Total cost of product = RM 7.18 + RM 0.37

= RM 7.55

The calculation of processing cost and total cost of product for each different plastic material will repeat follow calculation above. Table below is show all the processing cost and total cost of product for each plastic material.

Table 4.16: Processing cost and total cost of product

Plastic Material	**Processing cost (RM/pcs)**	**Total cost of product (RM/pcs)**
Acrylonitrile Butadiene Styrene (ABS)	0.37	7.55
Polycarbonate (PC)	0.18	8.59
Polyethylene (PE)	0.19	3.95
Polypropylene (PP)	0.19	3.50
Polystyrene (PS)	0.21	4.42
Polyethylene terephthalate (PET)	0.15	9.52
Acetal (POM,Polyacetal)	0.19	8.60
Polybutylene terephthalate (PBT)	0.17	9.56

4.6.4 Profit

Generally, profit is the making of gain in business activity for the benefit to the business. In producing the plastic product, profit is important to gain the money. In this project, the profit of product selling for each plastic material will calculate based on the market price. Below are showing the figure of book tray market price and calculation of profit.

Figure 4.5: Book tray market price

Source: MYDIN kuantan

Book tray market price	= RM 5.90
Production cost (RM/day)	= Product cost (RM/pcs) x Production capacity
Selling price (RM/day)	= Market price x Production capacity
Profit (RM/day)	= Selling price – Production cost (RM/day)

Example calculation:

For ABS material:

Production cost	= RM 7.55 x 399
	= RM 3012.45
Selling price	= RM 5.90 x 399
	= RM 2354.1
Profit	= RM 2354.1 – RM 3012.45
	= - RM 658.35

The profit was calculated based on production capacity for eight hours working day. The calculation of profit for each different plastic material will repeat follow calculation above. The graph was draw after calculate all of profit. Based on graph, only three plastic materials can gain the profit when the product sold with current market price. Those plastic materials are polyethylene (PE), polypropylene (PP), and polystyrene (PS). Table and graph below is show all the profit of product for each plastic material

Table 4.17: Profit of product selling

Plastic Material	Production capacity (part/day)	Production cost (RM/day)	Selling price (RM/day)	Profit (RM/day)
Acrylonitrile Butadiene Styrene (ABS)	399	3012.45	2354.1	- 658.35 (No)
Polycarbonate (PC)	824	7078.16	4861.6	- 2216.56 (No)
Polyethylene (PE)	788	3112.60	4649.2	1536.60 (Yes)
Polypropylene (PP)	758	2653.00	4472.2	1819.20 (Yes)
Polystyrene (PS)	708	3129.36	4177.2	1048.36 (Yes)
Polyethylene terephthalate (PET)	973	9262.96	5740.7	-3522.26 (No)
Acetal (POM,Polyacetal)	753	6475.80	4442.7	-2033.10 (No)
Polybutylene terephthalate (PBT)	889	8498.84	5245.1	-3253.74 (No)

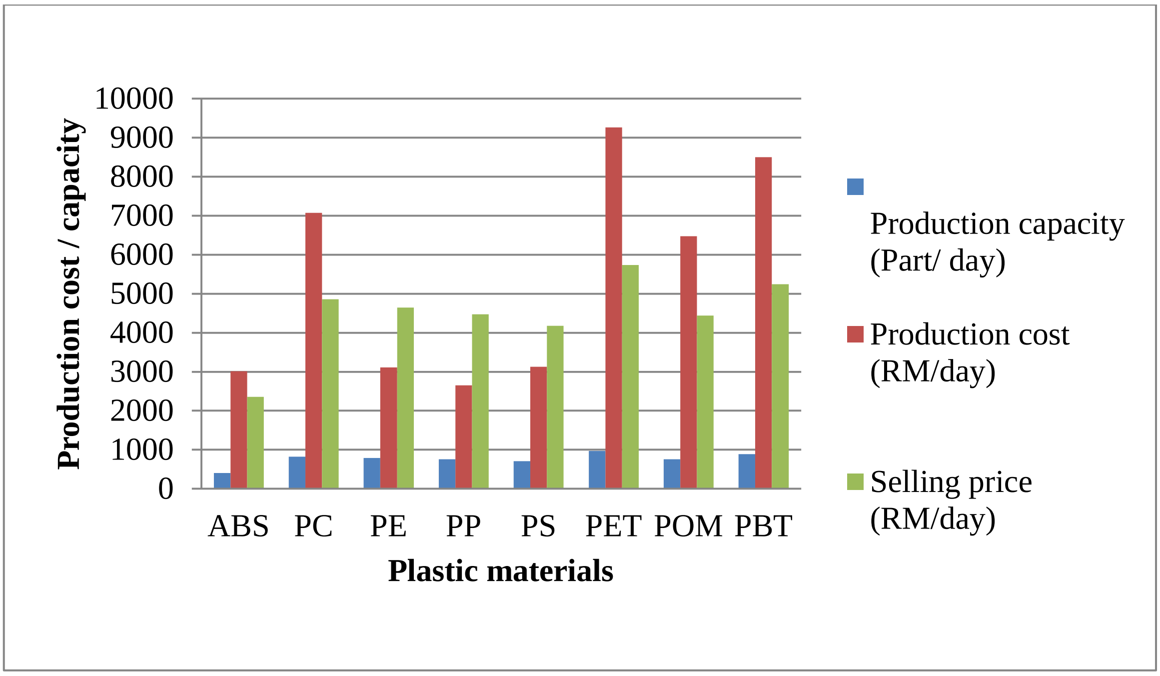

Figure 4.6: Graph production Cost/capacity versus plastic materials

4.7 RESULT COMPARISON

The result comparison is last process in this project analysis. The item needs to compare are value of cycle time (s), production capacity (part/day), product cost (RM/day) and product selling profit (RM/day). Weight factor for cycle time and production capacity was assumed lower than product cost and product selling profit because in actual plastic production, the plastic manufacturer more considered on profit from others characteristics. Profit was importance in production because to gain the benefit and income to the manufacturer. That why, the material selection was importance in producing the plastic product. Below is showing the comparison for each plastic material to determine a good material for book tray.

Table 4.18: Table of material selection matrix

Resin	Item								Total score
	Item 1: Cycle time (s)		**Item 2: Production capacity (part/day)**		**Item 3: Product cost (RM/day)**		**Item 4: Product selling profit (RM/day)**		
	Value/ Rank	WF=3 **Score**	**Value/ Rank**	WF=3 **Score**	**Value/ Rank**	WF=5 **Score**	**Value/ Rank**	WF=5 **Score**	
ABS	1	3	1	3	5	25	5	25	56
PC	6	18	6	18	4	20	3	15	71
PE	5	15	5	15	7	35	7	35	100
PP	*4*	*12*	*4*	*12*	*8*	*40*	*8*	*40*	*104*
PS	2	6	2	6	6	30	6	30	72
PET	8	24	8	24	2	10	1	5	63
POM	3	9	3	9	3	15	4	20	53
PBT	7	21	7	21	1	5	2	10	57

Rank references;

Cycle time(S) = 1 – 8 = longest – shortest

Production capacity (part/day) = 1 – 8 = low – high

Product cost (RM/day) = 1 – 8 = expansive – cheap
Product selling profit (RM/day) = 1 – 8 = low – high

From the analysis and table of material selection matrix, the best material for book tray product is Polyethylene propylene (PP). This plastic material was selected because Polyethylene propylene (PP) gains a high score among others engineering resins in table of material selection matrix. Polyethylene propylene (PP) get the high score in material selection based on analysis term of effect of injection moulding parameters and production profit. Those parameters are cooling time, initial injection time and filling time. Based on analysis result, that parameters more effected on product cycle time, production capacity and processing cost. From the analysis also can conclude that the plastic that have lowest cycle time doesn't mean can gain higher profit. Polyethylene propylene (PP) also suitable for mass production because with average production capacity, its can gain the more profit to the manufacturers.

CHAPTER 5

CONCLUSION AND FUTURE RECOMMENDATION

5.1 INTRODUCTION

The project was done successfully with archiving the project objective. However, during the project stage was occur a few problem and the problem need to solve in way to done the project. Beside that, the project was running guidance by the scope of project. It is because limitation of time and equipment to done the project. But, the project can be continued based on future recommendation in way to achieve the better result for the project. The project that has better result can be significant to the next researcher and as the references.

5.2 PROBLEM

This subchapter is about the problem was occur before, and during the project running. The problem was occurring in different stage such as literature review stage, design stage and analysis stage. The detail problem will showed below.

5.2.1 Literature Review Problems

The problem encountered during literature review is mainly about the difficulty to gather the journal that related to this project title. The journal paper is most important to gain the idea about the project. The ideal can guide how to continue and done this project. The limited book resource also can be problem in gather the information about the project. From that problem, more books that related to project title are needed to find and combine as the idea to finish this project.

Problem also occur while to find the recourse about plastic raw material price in Ringgit Malaysia (RM). The price of plastic raw material was difficult to find and just stated on a few book but not detail. The price needs to convert to Ringgit Malaysia (RM) and assume as the current average price.

5.2.2 Design Problems

In design stage, not more problem was occurring because these projects just need redrawing process to draw the plastic product. The problem is to take the dimension of plastic product at the actual mould. It needs to use the good measuring device because the shape of mould is complicated. The measuring device that used is vernier caliper because this device can measure at complex area accurately such as the depth of hole, chamfer, and fillet. The next problem is to redraw the product using computer aided design (CAD) software. The problem is comes in process to definite the axis plane to draw the 3D product solid modeling. The axis plane of 3D solid modeling drawing must be Z-axis because to prevent gate location setup problem occur in Moldflow analysis software.

5.2.3 Analysis Problems

Analysis for this project is using Moldflow simulation software. The problems occur in process to learn how to use this software and during the analysis. The problem is come from the FKM laboratory need to transfer to the UMP pekan. All equipment such as computer with software and machine can’t be used temporary and need to wait several weeks. The project schedule is delayed a while and find the others solution. The next problem is to prove the analysis using actual injection moulding process. This process can’t be run because injection moulding at UMP pekan not ready to used. But, this process can be suggested for future recommendation in way to gather the better result.

5.3 FUTURE RECOMMENDATION

Several future recommendations would like to express to the faculty for future final year project are:

(i) Prove the analysis using actual injection moulding process
(ii) Make the analysis of material selection based on raw material properties.
(iii) Make the analysis of material selection based on the parts that produce by using multi-cavity mould.

5.4 CONCLUSION

As conclusion, at the end of analysis all the project objective was achieve. The problem had been occur also can be solve by alternative method in way to done the project. From the analysis, the suitable material was selected for book tray product is Polypropylene (PP). Polypropylene (PP) is selected based on the effect of injection moulding parameters and production profit. From the project, also can know the effect of cycle time to the product cost. The cycle time only effect on processing cost not the material cost. Based on result also, it can reduce the cost in make the material selection using manual method because the best plastic material for product will find using the Moldflow simulation software.

REFERENCES

Ashby,M.F. 2009. *Materials and the Environment: Eco-Informed Material Choice.* Published by: Elsevier Ltd. All right reserved.

Beaumont.J.P. 2004. *Runner and Gating Design Handbook.* Hanser publisher, Munich.

Beaumont, J. P., Nagel, R., and Sherman, R. 2002. *Successful Injection Molding*. Cincinnati: Hanser Pub.

Bill fry. 1999. *Working with polyethylene*. Published by: Society of Manufacturing Engineers Dearbone, Michigan.

Biron,M. 2009. *Thermoplastics and Thermoplastic Composites*. Published by: Elsevier Ltd. All right reserved.

Bryce,M.D. 1996. *Plastic Injection Molding: manufacturing process fundamentals*. Published by: Society of Manufacturing Engineers Dearbone, Michigan.

Campo.E.A. 2006. *The Complete Part Design Handbook.* Carl Hanser Verlag, Munich.

Direct industry. 2002. *Mold Flow catalogue*. pdf.directindustry.com/pdf/moldflow/moldflow-plastics-insight-mpi.html. (13 April 2009)

Gastrow. 2002. *Injection Molds: 130 proven Designs.* 3rd ed. Carl Hanser Verlag.Munich.

Henderson.J, Ball.A.K, and Zhang.J.Z. 2006. *Cycle Time Reduction for Optimization of Injection Molding Machine Parameters for Process Improvement.* Technology Western Carolina University, Cullowhee, North Carolina. www.ijme.us/cd_06/PDF/ENT%20105-039.pdf (25 Mac 2009)

Imtech technology. 2005. *Moldflow simulation*. www.imtechdesign.com (15 April 2009)

Kalpakjian, Serope, and Schmid Steven R. 2002. *Manufacturing Engineering and Technology*. 5th ed. Upper Saddle River, NJ: Prentice Hall.

K. M. Au and K. M. Yu. 2005-2006. *A scaffolding architecture for conformal cooling design in rapid plastic injection moulding*. (**19**: 297-301).www.springerling.com (20 Mac 2009)

Menges, Michaeli, and Mohren. 2001. *How to Make Injection Molds.* 3rd ed. Carl Hanser Verlag.Munich.

Rees.H and Catoen.B. 2006. *Selecting Injection Molds.* Carl Hanser Verlag.Munich

Trade name for plastic. 2009. *Plastic Raw Material Manufacturer*. http://www.ets-corp.com/tradenames/pa.htm

APPENDIX A
GANTT CHART

A1 Gantt Chart/ Project Schedule for FYP 1

A2 Gantt Chart/ Project Schedule for FYP 2

APPENDIX B1

MATERIALS PROPERTIES, ADVANTAGES, DISADVANTAGES, AND APPLICATION FOR ACRYLONITRILE-BUTADIENE-STYRENE (ABS)

a) The general properties of ABS have been carried out by Campo.E.A. (2006) are:

Table B1.1: General properties of ABS

General properties of ABS	
Specific gravity	1.05
Tensile modulus @ 73 ^{0} F (Mpsi)	0.3
Tensile strength @ yield (Kpsi)	5.0
Notch Izod impact @ 73 ^{0} F (ft-lb/in)	2.50-12.0
Thermal limits service temp. (^{0} F)	167-185
Shrinkage (%)	0.4-0.7
T_g (^{0} F)	185-240
Vicat point (^{0} F)	237
Process temp. (^{0} F)	410-518
Mold temp. (^{0} F)	122-176
Drying temp. (^{0} F)	176-185
Drying time (h)	2.0-4.0

Source: Campo.E.A. 2006

b) Campo.E.A. (2006) has stated that the advantages of ABS are:

(i) Good impact resistance (toughness) and rigidity properties
(ii) Low creep
(iii) Good dimensional stability
(iv) High strength properties
(v) Metal coatings have excellent adherence to ABS

c) Campo.E.A. (2006) has stated that the disadvantages of ABS are:

(i) ABS is resistant to acids (except concentrated oxidizing acids), alkalis, salts, essential oils, and a wide range of food and pharmaceutical products. It is however, attacked by many solvents, including ketone and ester.

(ii) Low dielectric strength

(iii) Only low elongation available

(iv) Low continuous service temperature

d) Campo.E.A. (2006) has stated that the application of ABS are:

(i) Refrigerator such as door and food liner for interior surface of refrigerator

(ii) Small appliance housing and power tool application such as hair dryer and curling iron.

(iii) Automotive application such as instrument panel, arm rest, and seat belt retainer.

(iv) Drain such waste, vent pipe, and pipe fitting.

(v) Telecommunication such telephone housing and keyboard key

(vi) Others application such as briefcases, cosmetic cases, and toys.

APPENDIX B2

MATERIALS PROPERTIES, ADVANTAGES, DISADVANTAGES, AND APPLICATION FOR ACATEL (POM,POLYACETAL)

a) The general properties of POM have been carried out by Campo.E.A. (2006) are:

Table B2.1: General properties of acatel (pom,polyacetal)

General properties of Acatel (POM,Polyacetal)	
Specific gravity	1.42
Tensile modulus @ 73 ^{0} F (Mpsi)	360.00
Tensile strength @ yield (Kpsi)	8.5
Notch Izod impact @ 73 ^{0} F (ft-lb/in)	1.20
Thermal limits service temp. (^{0} F)	175-200
Shrinkage (%)	2.0-2.5
T_m (^{0} F)	330
T_g (^{0} F)	-90
Process temp. (^{0} F)	340-420
Mold temp. (^{0} F)	125-185
Drying temp. (^{0} F)	N/A
Drying time (h)	N/A

Source: Campo.E.A. 2006

b) Campo.E.A. (2006) has stated that the advantages of POM are:

(i) High mechanical properties, tensile strength, rigidity, and toughness
(ii) Glossy molded surface
(iii) Low static and dynamic coefficient of friction
(iv) Retains electrical and mechanical properties up to 250 ^{0} F
(v) Low gas and vapor permeability
(vi) Approved for applications used in contact with food

c) Campo.E.A. (2006) has stated that the disadvantages of POM are:

(i) Poor resistance to acids and bases
(ii) High mold shrinkages
(iii) Subject to UV degradation, if special acetal grades are not used
(iv) Flammable
(v) Excessive process melt temperature over 450 ^{0}F can result in significant thermal degradation of the material, with the release of formaldehyde gases.
(vi) Difficult to bond when the acetal surface is not treated

d) Campo.E.A. (2006) has stated that the application of POM are:

(i) Industrial such as conveyor link and slats, cams, bearings, wear stop and hose connectors.
(ii) Automotive such as fuel handling systems, trims, instrument panel components, and under the hood component.
(iii) Home electronic such as keyboard, telephone, modular component, and audio and video tape players and recorder.

APPENDIX B3

MATERIALS PROPERTIES, ADVANTAGES, DISADVANTAGES, AND APPLICATION FOR POLYCARBONATE (PC)

a) The general properties of PC have been carried out by Campo.E.A. (2006) are:

Table B3.1: General properties of polycarbonate (PC)

General properties of polycarbonate (PC)	
Specific gravity	1.40
Tensile modulus @ 73 ^{0} F (Mpsi)	1.25
Tensile strength @ yield (Kpsi)	19.00
Notch Izod impact @ 73 ^{0} F (ft-lb/in)	1.7-3.0
Thermal limits service temp. (^{0} F)	220-265
Shrinkage (%)	0.15-0.6
T_g (^{0} F)	293-300
T_m (^{0} F)	267-495
Vicat point (^{0} F)	305-310
Process temp. (^{0} F)	430-620
Mold temp. (^{0} F)	175-250
Drying temp. (^{0} F)	250-260
Drying time (h)	2.0-4.0

Source: Campo.E.A. 2006

b) Campo.E.A. (2006) has stated that the advantages of PC are:

(i) High impact strength
(ii) Low flammability
(iii) Electrical shielding ability
(iv) Gamma sterilizability
(v) Wear resistance

(vi) High heat deflection temperatures

(vii) Good dimensional stability

(viii) Good electrical properties

(ix) Process able by all thermoplastic methods

c) Campo.E.A. (2006) has stated that the disadvantages of PC are:

(i) Soluble in selected chlorinated hydrocarbons

(ii) Exhibits crazing in acetone and is attacked by bases

(iii) Its surface is relatively soft and therefore can be scratched

(iv) Heavy wall thickness drastically reduces the impact strength property of the molded part

(v) Snap-off undercuts for undercuts for assembly are not recommended

d) Campo.E.A. (2006) has stated that the application of PC are:

(i) Electronic and business equipment such as business machine housings, computer part and connector.

(ii) Appliances such as food processor, electrical kitchen component, and power tool housing.

(iii) Transportation such as tail and head light, signal light lens, and seat belt.

(iv) Medical such as tubing connectors, dialysis component and device, filter housing, and lenses.

APPENDIX B4
MATERIALS PROPERTIES, ADVANTAGES, DISADVANTAGES, AND APPLICATION FOR POLYBUTYLENE TEREPHTHALATE (PBT)

a) The general properties of PBT have been carried out by Campo.E.A. (2006) are:

Table B4.1: General properties of polybutylene terephthalate (PBT)

General properties of Polybutylene Terephthalate (PBT)	
Specific gravity	1.53
Tensile modulus @ 73 ^{0} F (Mpsi)	1.35
Tensile strength @ yield (Kpsi)	17.50
Notch Izod impact @ 73 ^{0} F (ft-lb/in)	0.90
Thermal limits service temp. (^{0} F)	200-250
Shrinkage (%)	0.30-2.30
T_g (^{0} F)	113-140
T_m (^{0} F)	437
Process temp. (^{0} F)	470-530
Mold temp. (^{0} F)	110-200
Drying temp. (^{0} F)	250-300
Drying time (h)	2.5-5.5

Source: Campo.E.A. 2006

b) Campo.E.A. (2006) has stated that the advantages of PBT are:

(i) Excellent resistance to water up to 122 ^{0} F temperature. It also resist most aqueous salt solutions, weak acids and bases, most organic solvents hydrocarbons, glycol and cleaning solutions at room temperature.

(ii) Excellent electrical properties, including high dielectric strength and insulation resistance.

c) Campo.E.A. (2006) has stated that the disadvantages of PBT are:

(i) Sensitive to alkaline oxidizing acid, hot water, strong bases, aromatic solutions, and ketones above ambient temperatures.

(ii) Unmodified PBT is notch sensitive. High levels of glass filler make the material brittle.

(iii) Part warpage caused by different cooling rates resulting from part geometry or tool design lead to differential shrinkage.

d) Campo.E.A. (2006) has stated that the application of PBT are:

(i) Building and construction such as housewares, lawn and garden

(ii) Automotive such as grilles, body panels, fenders, wheel covers and mirror

(iii) Electrical and electronic such as switches, relays, motor housing and tube sockets.

(iv) Material handling such as conveyor chain links, gear wheels and monorail hanger.

APPENDIX B5

MATERIALS PROPERTIES, ADVANTAGES, DISADVANTAGES, AND APPLICATION FOR POLYETHYLENE TEREPHTHALATE (PET)

a) The general properties of PET have been carried out by Campo.E.A. (2006) are:

Table B5.1: General properties of polyethylene terephthalate (PET)

General properties of Polyethylene Terephthalate (PET)	
Specific gravity	1.67
Tensile modulus @ 73 ^{0} F (Mpsi)	1.50
Tensile strength @ yield (Kpsi)	22.0
Notch Izod impact @ 73 ^{0} F (ft-lb/in)	1.60
Thermal limits service temp. (^{0} F)	392
Shrinkage (%)	0.20-0.90
T_g (^{0} F)	158
T_m (^{0} F)	482-490
Process temp. (^{0} F)	510-565
Mold temp. (^{0} F)	150-250
Drying temp. (^{0} F)	250-275
Drying time (h)	2.0-4.0

Source: Campo.E.A. 2006

b) Campo.E.A. (2006) has stated that the advantages of PET are:

(i) Excellent resistance to water up to 122 ^{0} F temperature; also resists most aqueous salt solutions, weak acids and bases, gasoline, and cleaning solutions. PET is not attacked by most oils and greases.

(ii) Excellent electrical properties, including high dielectric strength and insulation resistance, consistent dielectric constant, low dissipation factor.

c) Campo.E.A. (2006) has stated that the disadvantages of PET are:

(i) Sensitive to alkaline oxidizing acid and hot water

(ii) PET required drying of resin from 2-4 hour at 275 ^{0}F to reach a 0.02 % of moisture before processing.

(iii) Part warpage caused by different cooling rates, which are result of part geometry or tool design, leads to differential shrinkage.

d) Campo.E.A. (2006) has stated that the application of PET are:

(i) Automotive such as body panels, spoiler, door handles, rotor, and head lamp.

(ii) Electrical and electronic such as swich, relay, motor housing and fuse cases.

(iii) Consumer uses such as vacuum cleaner parts, fans, gears, furniture and iron skirts.

APPENDIX B6

MATERIALS PROPERTIES, ADVANTAGES, DISADVANTAGES, AND APPLICATION FOR POLYETHYLENE (PE)

a) The general properties of PE have been carried out by Campo.E.A. (2006) are:

Table B6.1: General properties of polyethylene (PE)

General properties of Polyethylene (PE)	
Specific gravity	0.94
Tensile modulus @ 73 ^{0} F (Mpsi)	0.2
Tensile strength @ yield (Kpsi)	3.75
Notch Izod impact @ 73 ^{0} F (ft-lb/in)	No break
Thermal limits service temp. (^{0} F)	158-176
Shrinkage (%)	1.1-1.4
T_g (^{0} F)	-150
T_m (^{0} F)	257-275
Process temp. (^{0} F)	400-535
Mold temp. (^{0} F)	50-140
Drying temp. (^{0} F)	150
Drying time (h)	3.0

Source: Campo.E.A. 2006

b) Campo.E.A. (2006) has stated that the advantages of PE are:

(i) Low resin cost
(ii) Good impact resistance
(iii) Good properties at low temperature
(iv) Food grades are available

c) Campo.E.A. (2006) has stated that the disadvantages of PE are:

(i) High coefficient of thermal expansion
(ii) Poor UV and weathering resistance
(iii) Flammable

d) Campo.E.A. (2006) has stated that the application of PE are:

(i) Packaging such as packaging films, rigid and semi rigid packaging product
(ii) Medical such as hygiene products and medical application trays.

APPENDIX B7

MATERIALS PROPERTIES, ADVANTAGES, DISADVANTAGES, AND APPLICATION FOR POLYPROPYLENE (PP)

a) The general properties of PP have been carried out by Campo.E.A. (2006) are:

Table B7.1: General properties of polypropylene (PP)

General properties of Polypropylene (PP)	
Specific gravity	0.90
Tensile modulus @ 73 ^{0} F (Mpsi)	0.17
Tensile strength @ yield (Kpsi)	4.00
Notch Izod impact @ 73 ^{0} F (ft-lb/in)	0.5-18.0
Thermal limits service temp. (^{0} F)	212
Shrinkage (%)	0.5-2.0
Vicat point (^{0} F)	320
T_m (^{0} F)	329-338
HDT (^{0} F) @ 264 psi	120-140
Process temp. (^{0} F)	390-525
Mold temp. (^{0} F)	85-175
Drying temp. (^{0} F)	175
Drying time (h)	2.0-3.0

Source: Campo.E.A. 2006

b) Campo.E.A. (2006) has stated that the advantages of PP are:

(i) Lighter and low density polymer (0.90g/cm^3)
(ii) High melting point
(iii) End use temperature
(iv) Good chemical resistance
(v) Good fatigue resistance

c) Campo.E.A. (2006) has stated that the disadvantages of PP are:

(i) Degraded by UV
(ii) Flammable, but flame retardant grades are available
(iii) Attacked by chlorinated solvents and aromatic solution
(iv) Difficult to bond
(v) Several metal accelerate oxidative degrading

d) Campo.E.A. (2006) has stated that the application of PP are:

(i) Flexible packaging film
(ii) Biaxially oriented packaging films
(iii) Stretched and oriented monofilament, tapes for textiles, carpeting, insulated medical fabrics and woven carpet backing.
(iv) Automotive interiors, bumpers, spoilers, air vent systems and under hood component.

APPENDIX B8

MATERIALS PROPERTIES, ADVANTAGES, DISADVANTAGES, AND APPLICATION FOR POLYSTYRENE (PS)

a) The general properties of PS have been carried out by Campo.E.A. (2006) are:

Table B8.1: General properties of polystyrene (PS)

General properties of Polystyrene (PS)	
Specific gravity	1.05
Tensile modulus @ 73 ^{0} F (Mpsi)	0.45
Tensile strength @ yield (Kpsi)	6.0
Notch Izod impact @ 73 ^{0} F (ft-lb/in)	0.25-0.60
Thermal limits service temp. (^{0} F)	122-158
Shrinkage (%)	0.05-0.80
Vicat point (^{0} F)	200-227
T_m (^{0} F)	212
Process temp. (^{0} F)	390-480
Mold temp. (^{0} F)	50-175
Drying temp. (^{0} F)	160-200
Drying time (h)	2.0-3.0

Source: Campo.E.A. 2006

b) Campo.E.A. (2006) has stated that the advantages of PS are:

(i) Optical clarity
(ii) High gloss
(iii) FDA grades are available
(iv) Processable by all thermoplastic method
(v) Low cost

c) Campo.E.A. (2006) has stated that the disadvantages of PS are:

(i) Flammable, but flame retarded grade are available
(ii) Poor solvent resistance, attacked by many chemical
(iii) Homopolymers are brittle
(iv) Subject to stress and environmental cracking
(v) Poor thermal stability

d) Campo.E.A. (2006) has stated that the application of PS are:

(i) Single service items, such as plates, glasses and cups
(ii) Packaging items such as cassette boxes and compact disc jewel boxes
(iii) Consumer durables, such as house ware and cosmetic container
(iv) Blow molded medical and pharmaceutical packaging.
(v) Oriented polystyrene food contact articles such as cookie container and chocolate trays.

APPENDIX C
TECHNICAL DRAWING

Drawing No.1 Book Tray Orthographic and Isometric Drawing

APPENDIX D
FIGURE OF MOLDFLOW ANALYSIS RESULT

Below is showing the figure of Moldflow result analysis for each plastic material

1. Polycarbonate (PC)

a) Material selection

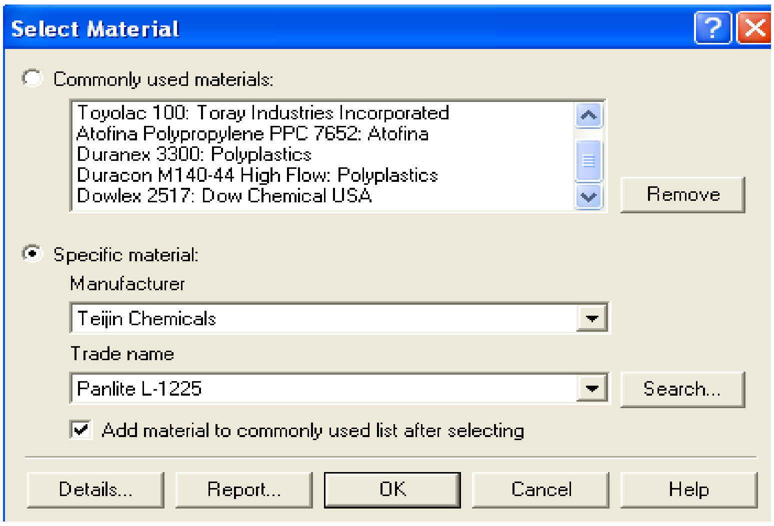

Figure C.1: Material selection (PC)

b) Process parameter

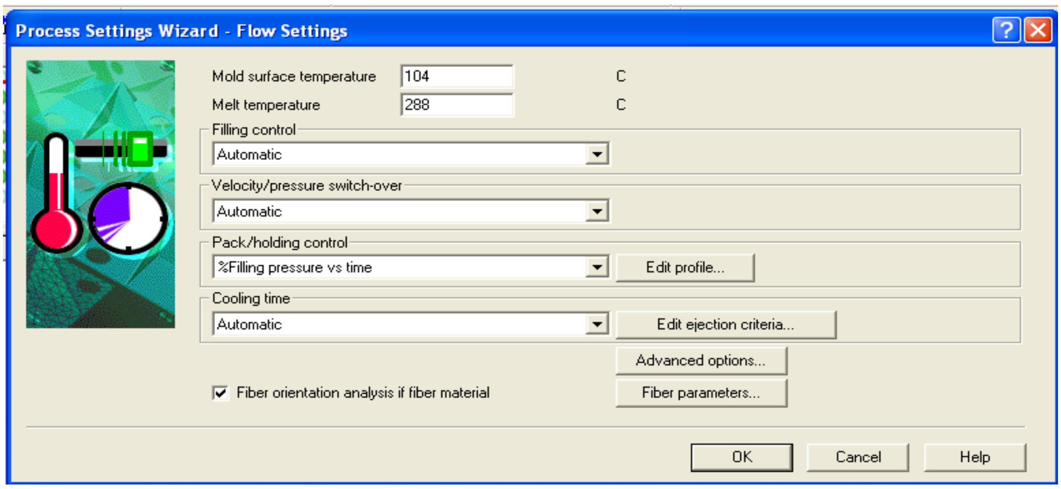

Figure C.2: Melt and mould temperature (PC)

c) Fill time

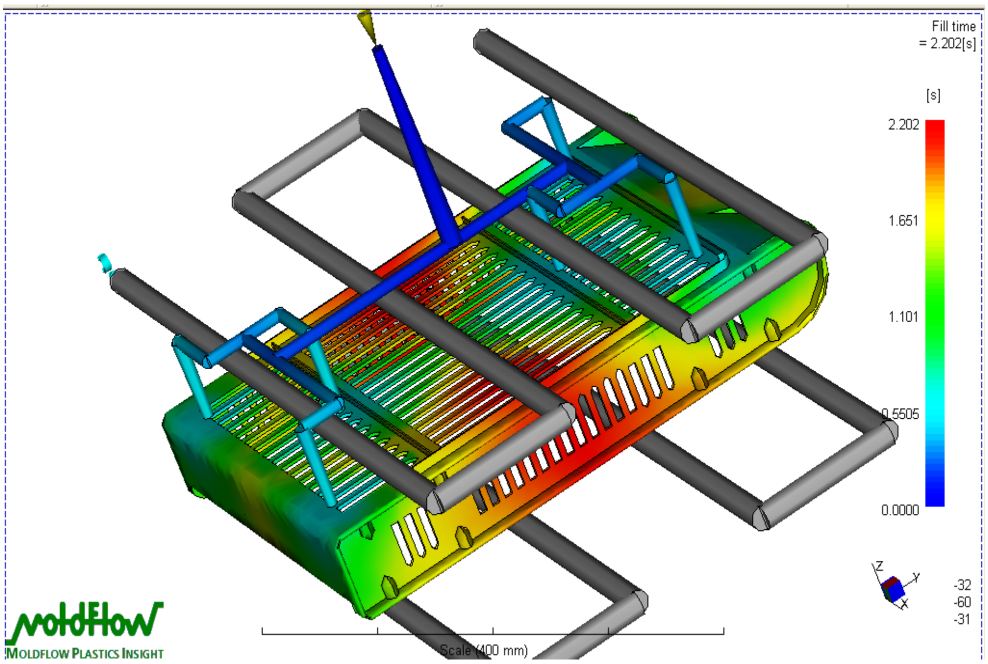

Figure C.3: Fill time (PC)

d) Cooling and initial injection time

```
Temperature Settings
------------------------------------------------------------------------

Melt temperature:                                      288.0000 C

Mold cavity_side temperature:                          104.0000 C

Mold core-side temperature:                            104.0000 C
------------------------------------------------------------------------


Injection Settings
------------------------------------------------------------------------

Injection control method: Injection Time

Injection Time:                    1.9543 s

Nominal Flow rate:               162.9540 cm^3/s

Packing pressure profile

            Duration                     Pressure
              (s)                          (MPa)

              0.0000                      96.7688
             10.0000                      96.7688

Cooling time:                                            8.4998 s

------------------------------------------------------------------------
```

Figure C.4: Cooling and initial injection time (PC)

2. Polyethylene (PE)

a) Material selection

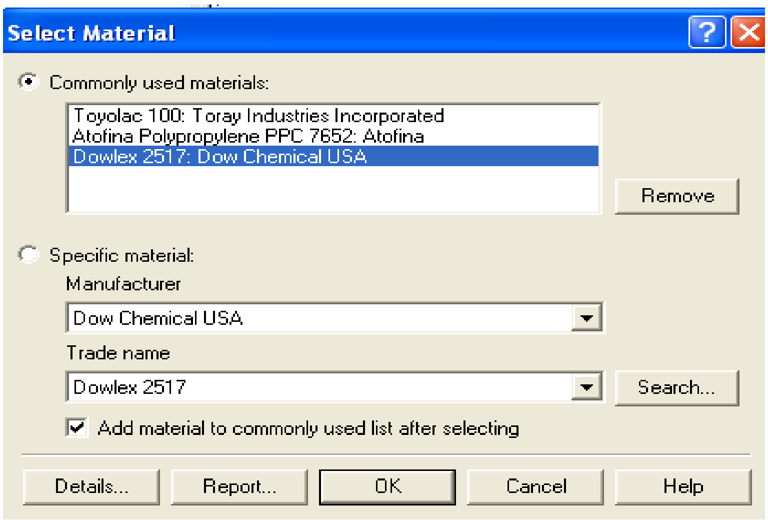

Figure C.5: Material selection (PE)

b) Process parameter

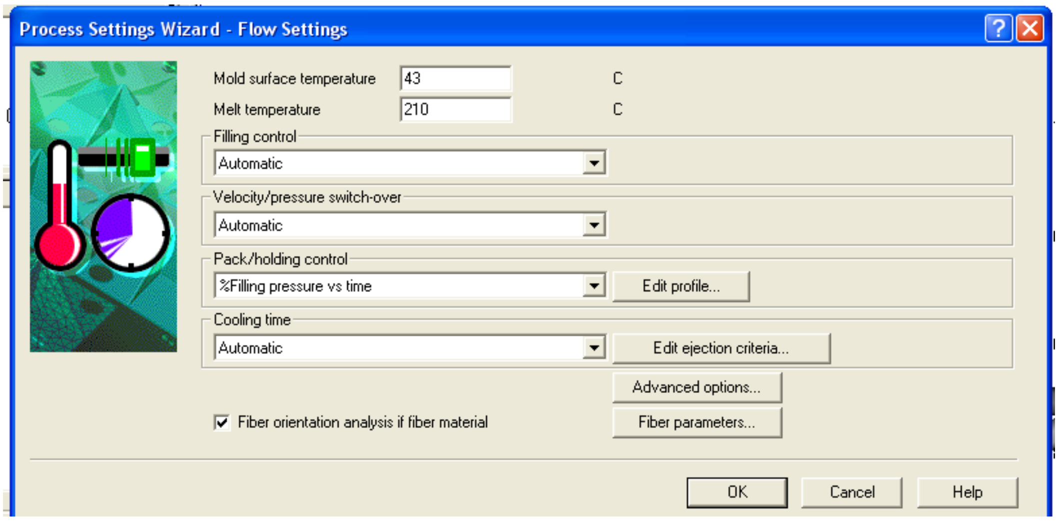

Figure C.6: Melt and mould temperature (PE)

c) Fill time

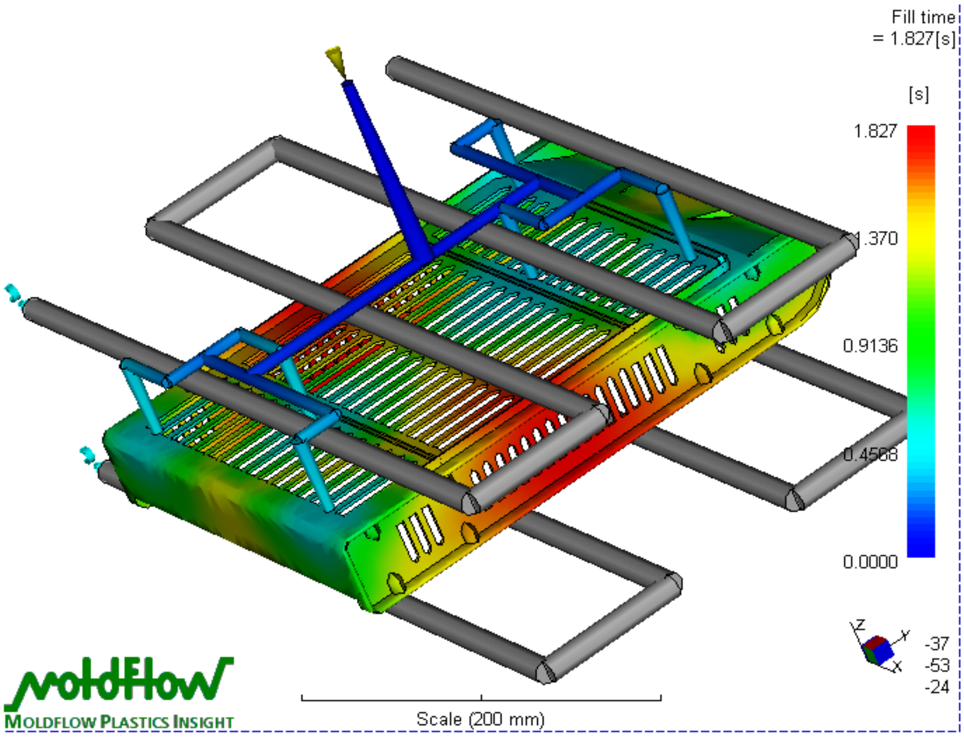

Figure C.7: Fill time (PE)

d) Cooling and initial injection time

```
Temperature Settings
--------------------------------------------------------------------

Melt temperature:                                  210.0000 C

Mold cavity_side temperature:                       43.0000 C

Mold core-side temperature:                         43.0000 C
--------------------------------------------------------------------


Injection Settings
--------------------------------------------------------------------

Injection control method: Injection Time

Injection Time:                     1.7100 s

Nominal Flow rate:                186.2330 cm^3/s

Packing pressure profile

          Duration                  Pressure
            (s)                       (MPa)

           0.0000                    22.4809
          10.0000                    22.4809

Cooling time:                                       10.7500 s

--------------------------------------------------------------------
```

Figure C.8: Cooling and initial injection time (PE)

3. Polypropylene (PP)

a) Material selection

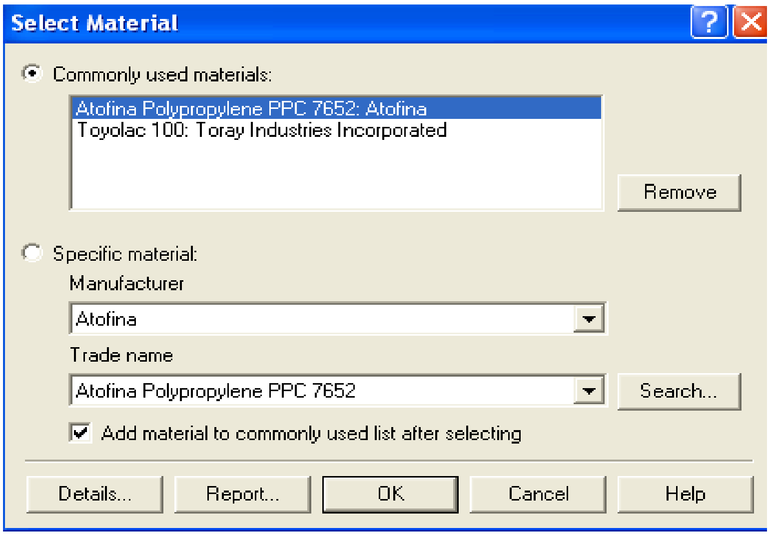

Figure C.9: Material selection (PP)

b) Process parameter

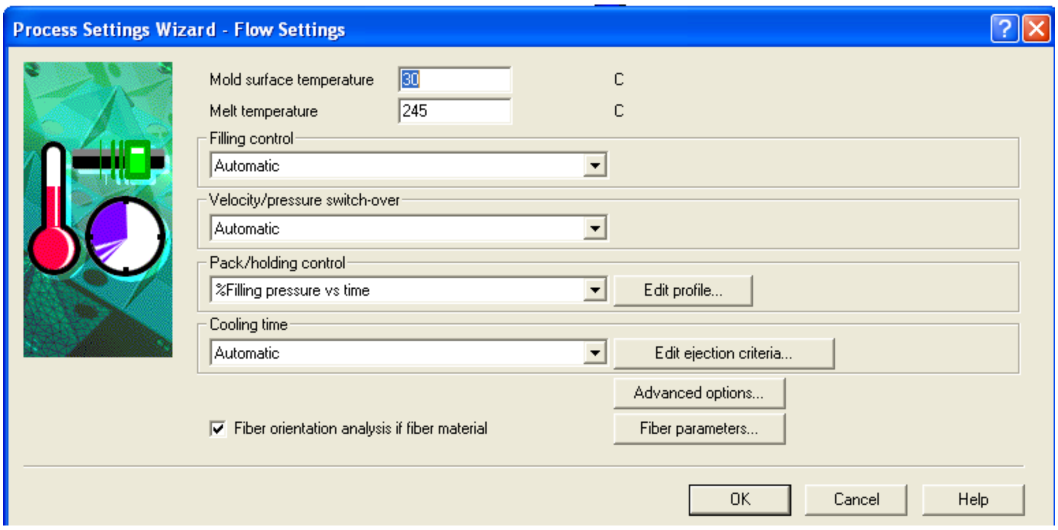

Figure C.10: Melt and mould temperature (PP)

c) Fill time

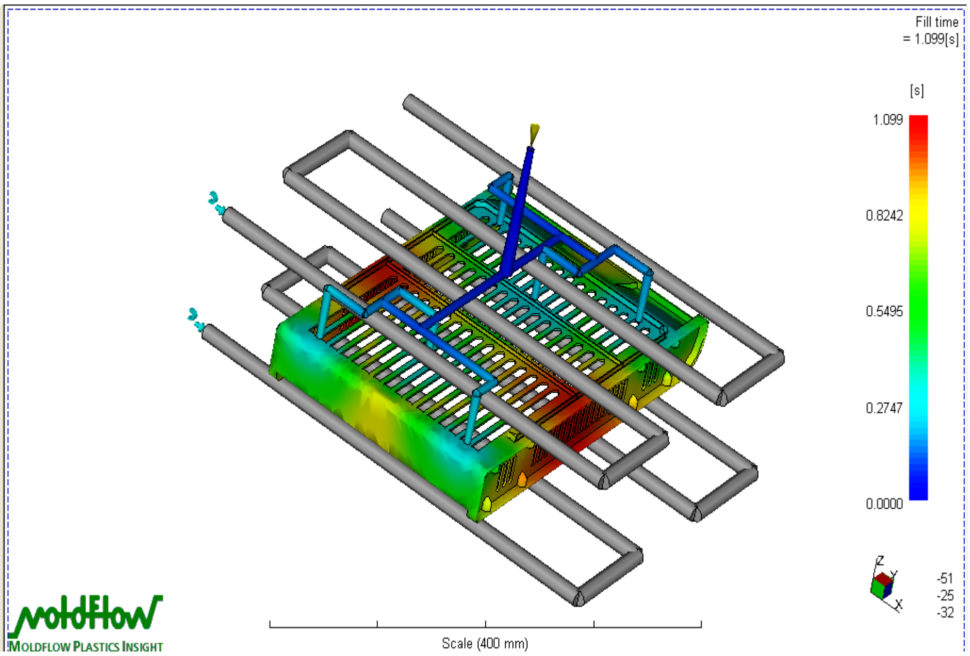

Figure C.11: Fill time (PP)

d) Cooling and initial injection time

```
Temperature Settings
---------------------------------------------------------------
Melt temperature:                                  245.0000 C
Mold cavity_side temperature:                       30.0000 C
Mold core-side temperature:                         30.0000 C
---------------------------------------------------------------

Injection Settings
---------------------------------------------------------------
Injection control method: Injection Time
Injection Time:                        0.9771 s
Nominal Flow rate:                   325.9080 cm^3/s
Packing pressure profile
          Duration                 Pressure
            (s)                     (MPa)

           0.0000                  30.3729
          10.0000                  30.3729
Cooling time:                                       13.5003 s
```

Figure C.12: Cooling and initial injection time (PP)

4. Polystyrene (PS)

a) Material selection

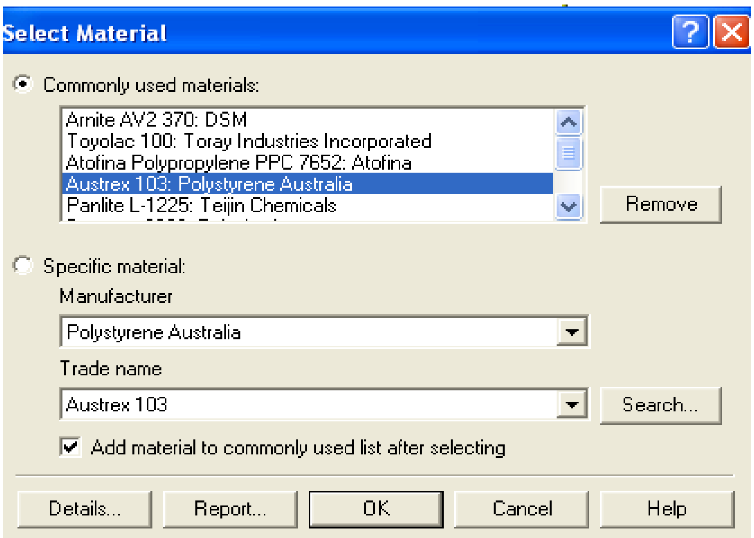

Figure C.13: Material selection (PS)

b) Process parameter

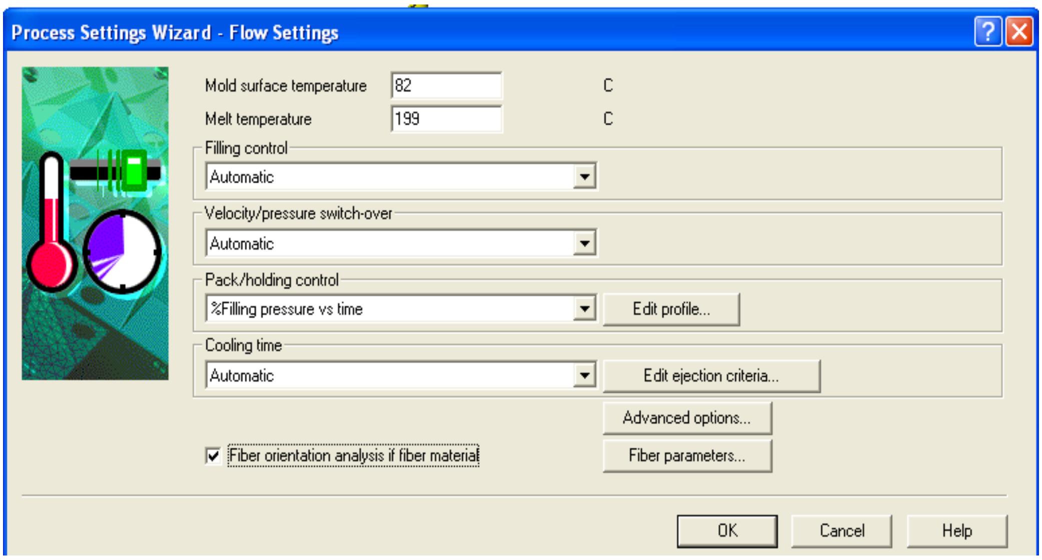

Figure C.14: Melt and mould temperature (PS)

c) Fill time

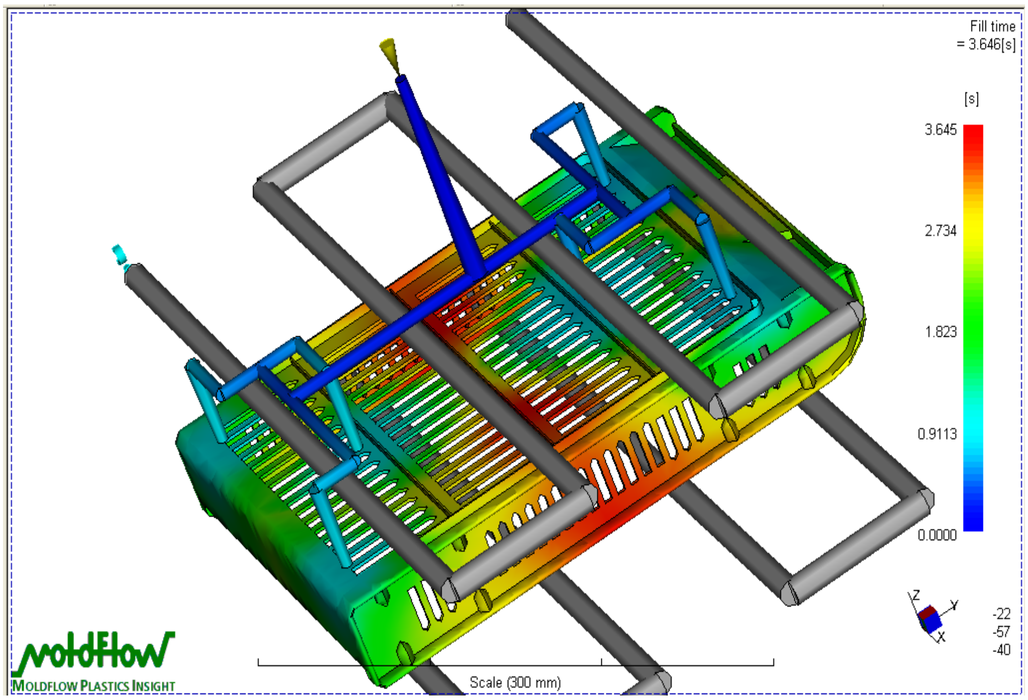

Figure C.15: Fill time (PS)

d) Cooling and initial injection time

```
Temperature Settings
-------------------------------------------------------------------

Melt temperature:                                  199.0000 C

Mold cavity_side temperature:                       82.0000 C

Mold core-side temperature:                         82.0000 C
-------------------------------------------------------------------


Injection Settings
-------------------------------------------------------------------

Injection control method: Injection Time

Injection Time:                    3.2979 s

Nominal Flow rate:                96.5652 cm^3/s

Packing pressure profile

          Duration                 Pressure
             (s)                     (MPa)

            0.0000                  47.2635
           10.0000                  47.2635

Cooling time:                                       11.7500 s

-------------------------------------------------------------------
```

Figure C.16: Cooling and initial injection time (PS)

5. Polyethylene Terephthalate (PET)

a) Material selection

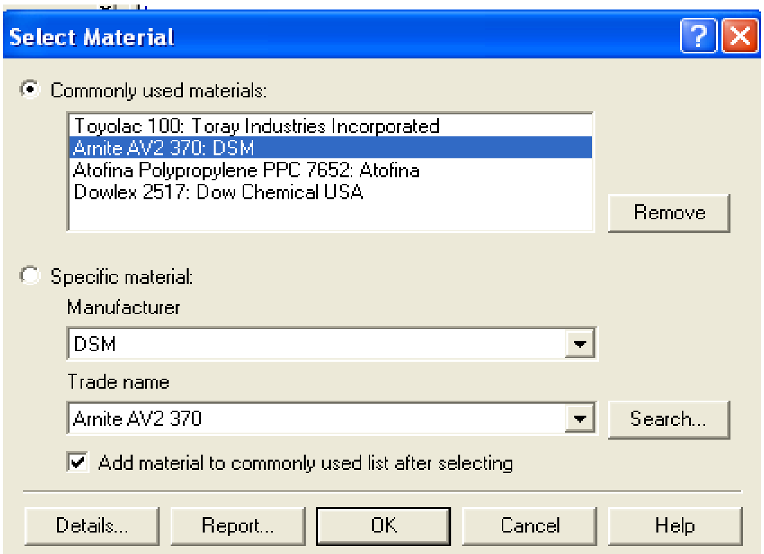

Figure C.17: Material selection (PET)

b) Process parameter

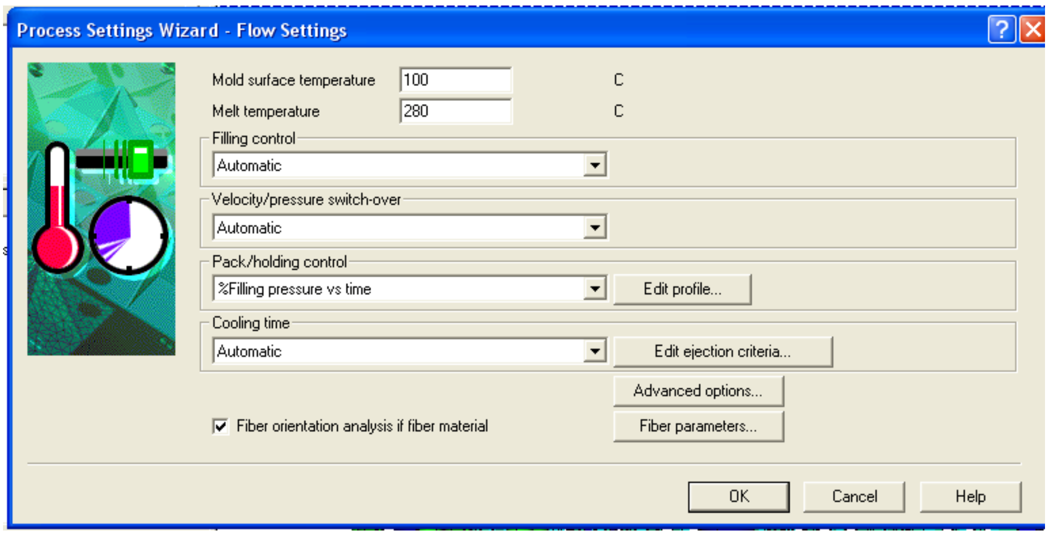

Figure C.18: Melt and mould temperature (PET)

c) Fill time

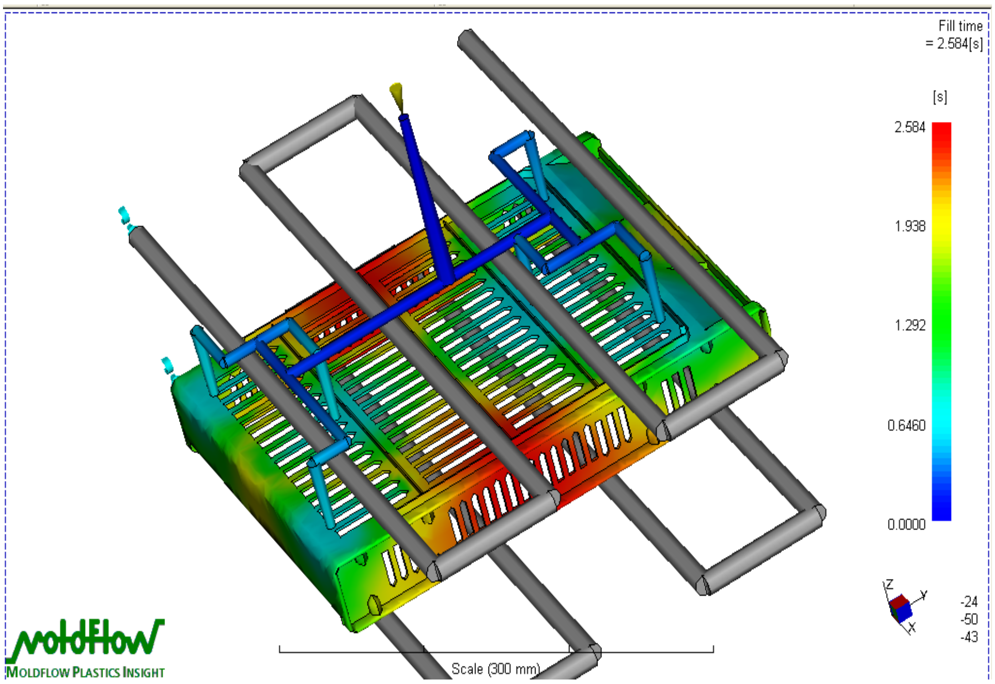

Figure C.19: Fill time (PET)

d) Cooling and initial injection time

```
------------------------------------------------------------------------


Temperature Settings
------------------------------------------------------------------------

Melt temperature:                               280.0000 C

Mold cavity_side temperature:                   100.0000 C

Mold core-side temperature:                     100.0000 C
------------------------------------------------------------------------


Injection Settings
------------------------------------------------------------------------

Injection control method: Injection Time

Injection Time:                   2.4429 s

Nominal Flow rate:              130.3630 cm^3/s

Packing pressure profile

          Duration                 Pressure
             (s)                     (MPa)

            0.0000                  78.0953
           10.0000                  78.0953

Cooling time:                                     2.4996 s

------------------------------------------------------------------------
```

Figure C.20: Cooling and initial injection time (PET)

6. Acetal (POM,Polyacetal)

a) Material selection

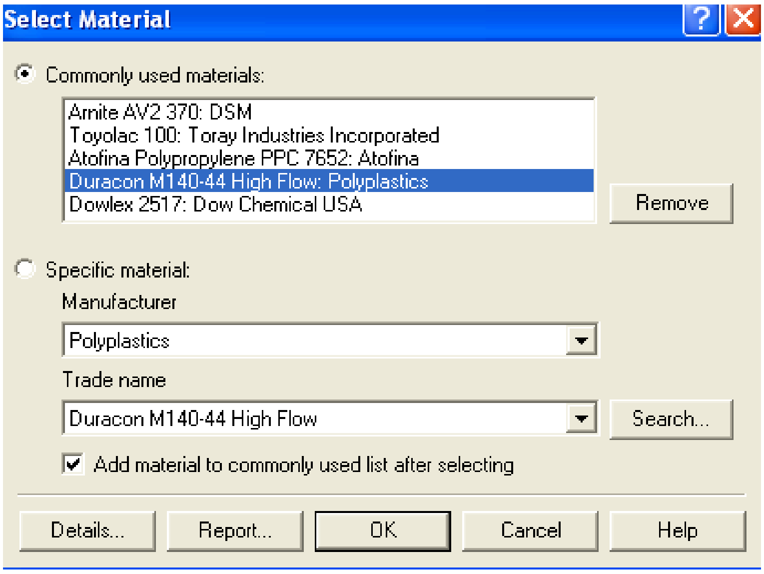

Figure C.21: Material selection (POM)

b) Process parameter

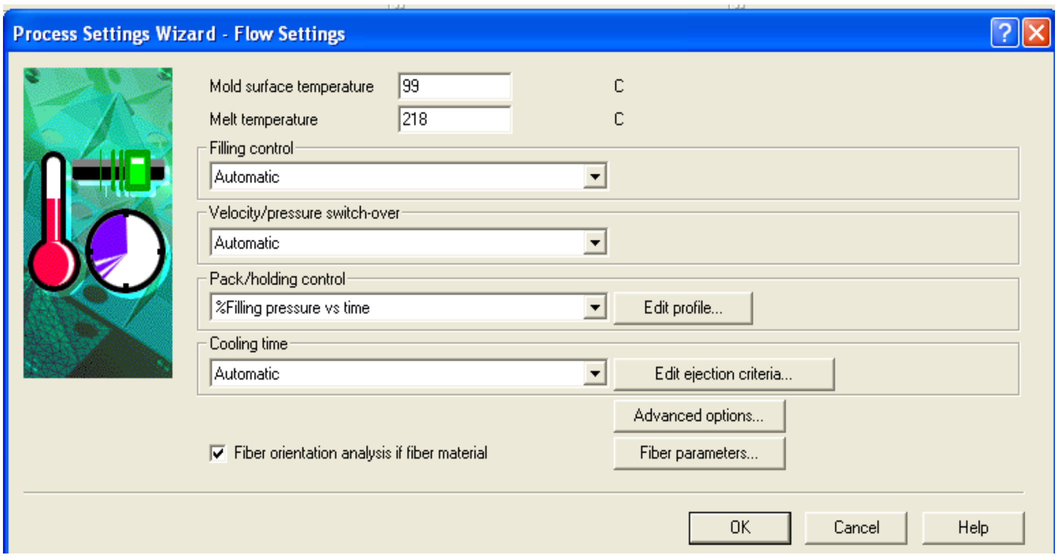

Figure C.22: Melt and mould temperature (POM)

c) Fill time

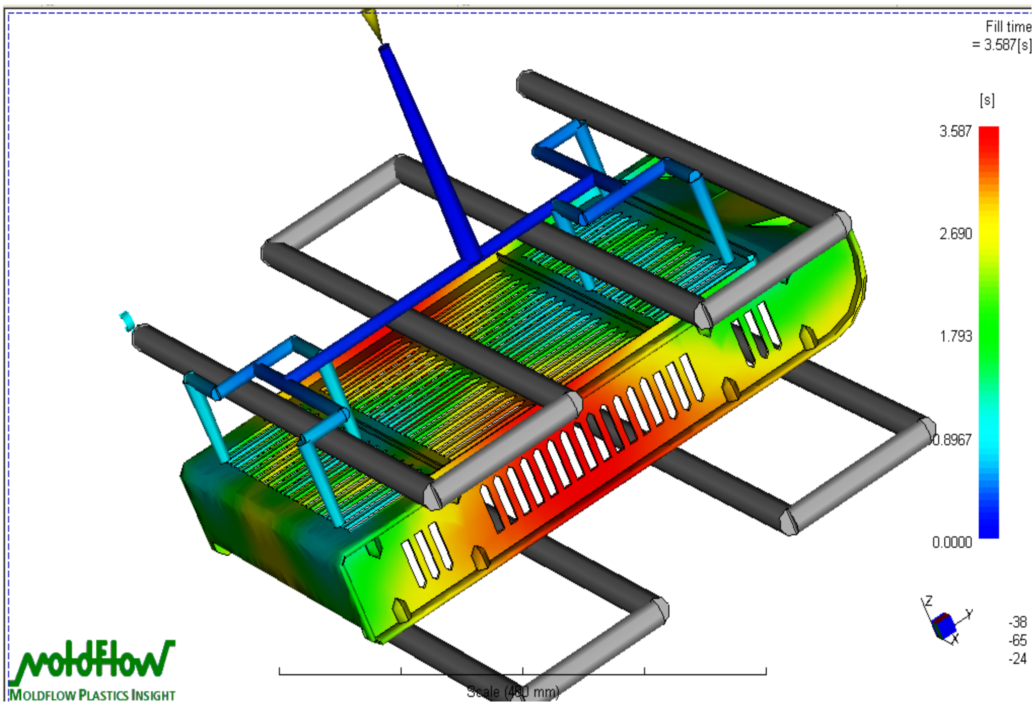

Figure C.23: Fill time (POM)

d) Cooling and initial injection time

```
Temperature Settings
------------------------------------------------------------------

Melt temperature:                                    218.0000 C

Mold cavity_side temperature:                         99.0000 C

Mold core-side temperature:                           99.0000 C
------------------------------------------------------------------


Injection Settings
------------------------------------------------------------------

Injection control method: Injection Time

Injection Time:                   3.2979 s

Nominal Flow rate:               96.5652 cm^3/s

Packing pressure profile

          Duration                Pressure
             (s)                    (MPa)

           0.0000                  48.2441
          10.0000                  48.2441

Cooling time:                                           9.2506 s
------------------------------------------------------------------
```

Figure C.24: Cooling and initial injection time (POM)

7. Polybutylene Terephthalate (PBT)

a) Material selection

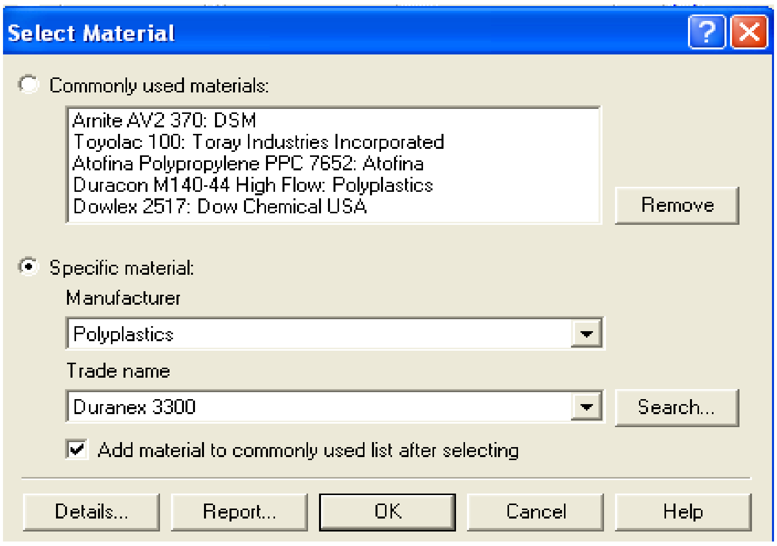

Figure C.25: Material selection (PBT)

b) Process parameter

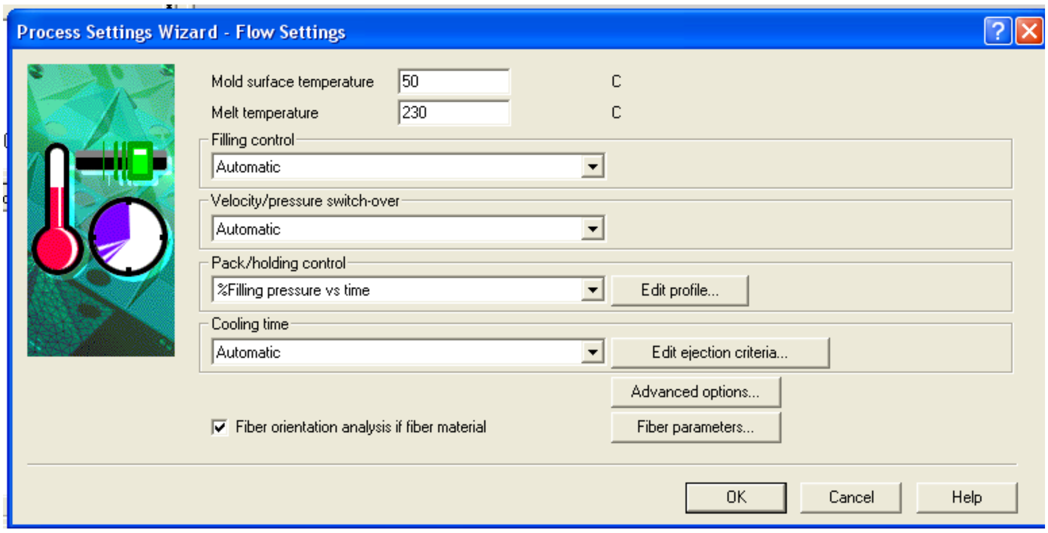

Figure C.26: Melt and mould temperature (PBT)

c) Fill time

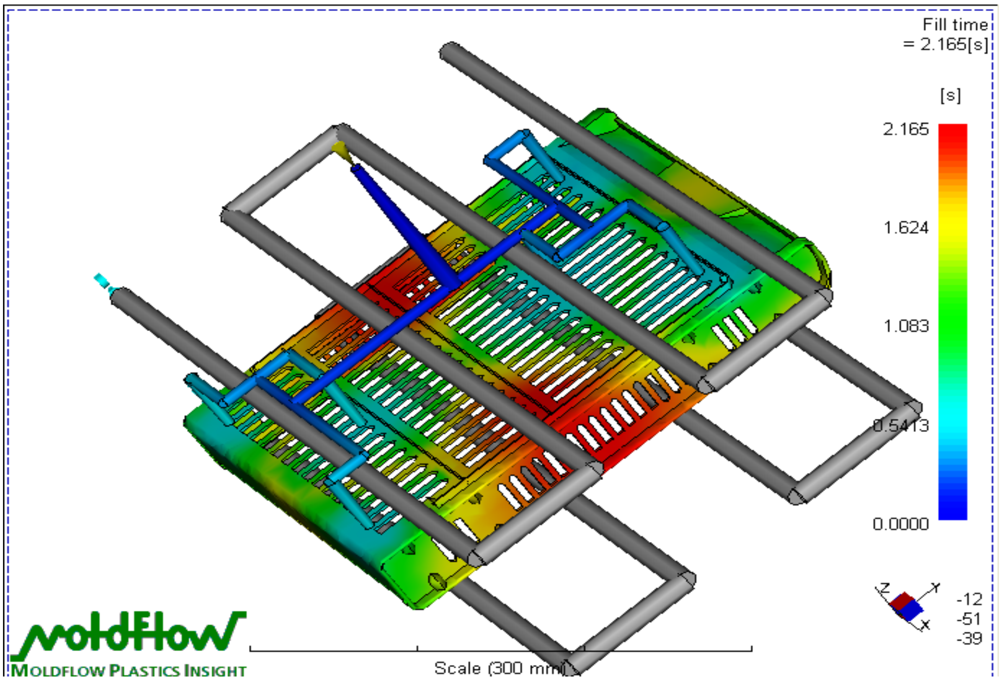

Figure C.27: Fill time (PBT)

d) Cooling and initial injection time

```
Temperature Settings
----------------------------------------------------------------------

Melt temperature:                                    230.0000 C

Mold cavity_side temperature:                         50.0000 C

Mold core-side temperature:                           50.0000 C
----------------------------------------------------------------------


Injection Settings
----------------------------------------------------------------------

Injection control method: Injection Time

Injection Time:                   1.3436 s

Nominal Flow rate:              237.0240 cm^3/s

Packing pressure profile

          Duration                  Pressure
            (s)                       (MPa)

            0.0000                   22.0214
           10.0000                   22.0214

Cooling time:                                          6.7497 s

----------------------------------------------------------------------
```

Figure C.28: Cooling and initial injection time (PBT)