

COMPUTER AIDED DIE DESIGN OF PLASTIC SHAMPOO BOTTLE

SHAMILA BT. ABDUL GAFFOOR
9531068

SUBMITTED IN PARTIAL FULFILLMENT OF THE
DEGREE OF BACHELOR OF ENGINEERING
IN MANUFACTURING ENGINEERING

FACULTY OF ENGINEERING
INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA
MARCH 2000



الجامعة الإسلامية العالمية ماليزيا
INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA
بِوَسِيْلَةِ سَلَامٍ اِنْبَارًا يَجْنِبًا مِلْدِيْنًا

ABSTRACT

Nowadays most products are produced at a very rapid phase and not forgetting their life cycle too is getting shorter and shorter. Noticeably these products are mostly produced from plastics material since this method of plastic production is not only very fast but also very accurate and flexible.

Thus the author has taken the initiative to work on a project on how to design and then to machine the shampoo bottle mould specifically for the blow moulding process both in using CAM software and Vertical Machining Center (VMC) respectively. The design of the shampoo bottle was firstly derived from the real life survey conducted and targeted at for middle age group. And the original design was translated to the 2D and then 3D drawings using CAM software. Later the simulation of machining was carried out before the program was post-processed to the VMC machine for machining verification.

Proceeding with this project too is the rapid prototype of the hinged cap of the shampoo bottle, which was first designed and developed using CAM software and then translated to the FDM 2000 rapid prototyping machine for rapid modeling.

A shampoo bottle mould cavity was successfully machined using the VMC machine and a prototype of the shampoo bottle's hinged cap was produced from the FDM 2000 machine.

ACKNOWLEDGEMENT

In the name of Allah, the most Merciful and the Most Beneficent, I begin on this section by firstly praising and thanking Allah S.W.T, for His ever ending blessings and Barakah on me so that I would be able to complete this project right on its time.

Secondly, my respectful advisor, Dr. Ahsan Ali Khan, whom I am really grateful of. I take this opportunity to thank him for all the patience, tolerance and most importantly his ever willingness to listen to all the problems that I went through. Not forgetting, I would like to express my gratitude and acquiescence to Mr. Lim Wooi Keat, Assistant Manager CAD/CAM Support of IME Technology Sdn. Bhd. for giving me the extra training and guidance on MasterCAM software. Also to Bro. Fadly Darshi Dashivan and Bro. Israd Hakim for extending their help and support during the design development and machining stages. To Bro. Zakaria Zain, the Tool and Die Lab Technician, I thank you for understanding and always helping me to carry out this project especially in taking charge of the 50 kg mould.

Last but not least, to my parents and parents-in-law for always extending their prayers to me in whatever that I perceive in especially in doing this project. Most importantly to my husband, Mr. Shahid Qayum, there is no words that I can use to describe his patience and the amount of sacrifices that he had to do for me in order to support and assist me in making this project to the level that it is today. Thank you very much Ji. Finally, to my three months plus old son, Mohd. Ismat Qayum, for always being the inspiration and vision of joy to me all throughout the hurdles that I came across. Indeed I dedicate this whole compilation for him. Insyallah.

TABLE OF CONTENTS

ABSTRACT	i
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF FIGURES	vii
LIST OF TABLES	x
CHAPTER ONE: INTRODUCTION.....	1
1.1 BACKGROUND STUDY	1
1.2 SCOPE OF WORK.....	3
1.3 PROJECT METHODOLOGY	4
CHAPTER TWO: LITERATURE SURVEY.....	8
2.1 OVERVIEW OF PLASTICS.....	8
2.2 USAGE AND TYPES OF PLASTICS.....	8
2.2.1 Semi-Crystalline Plastics	11
2.3 OVERVIEW OF BLOW MOULDING PROCESS.....	16
2.3.1 Continuous Parison Blow Moulding.....	17
2.4 OVERVIEW OF INJECTION MOULDING PROCESS	21
2.5 CNC MACHINES	24
2.5.1 Tree's 1060 Model	24
2.5.2 Daewoo's Mynx500 Model.....	25
2.5.3 Vickers ZPS MCFV 1060LR Model	26
2.6 MATERIAL HARDNESS	27
2.6.1 Brinell Hardness Test.....	28
2.6.2 Vickers Hardness Test	29

2.6.3	Rockwell Hardness Test.....	30
-------	-----------------------------	----

CHAPTER THREE: EXPERIMENTAL PROCEDURES AND TECHNIQUES32

3.1	QUESTIONNAIRE AND SURVEY.....	32
3.1.1	Preparation and Conduct of Questionnaire.....	32
3.1.2	Evaluation and Conclusion from Survey	33
3.2	2D DRAWING OF PLASTIC BOTTLE AND HINGED CAP	36
3.2.1	Tools Used in MasterCAM to Produce 2D Drawing.....	36
3.2.2	2D Technical Drawing.....	38
3.3	3D DRAWING OF PLASTIC BOTTLE AND HINGED CAP	39
3.3.1	Tools Used in MasterCAM to Produce 3D Drawing.....	39
3.3.2	3D Technical Drawing of Shampoo Bottle	41
3.3.3	Mould of the shampoo bottle.....	42
3.3.4	3D Technical Drawing of Hinged Cap.....	42
3.4	3D DRAWING TO MACHINE SETUP AND SIMULATION.....	43
3.4.1	Definition.....	43
3.4.2	Tools and Machining Setup Used in MasterCAM.....	44
3.4.3	Machining Simulation.....	50
3.5	MACHINING OF MOULD.....	56
3.5.1	Preparation of the Stock to be Machined.....	56
3.5.2	Setting Up of the Vickers Machine	57
3.5.3	Setting up of the Stock into the Vickers	58
3.5.4	Registering the Part Program from Diskette into the Program Manager ...	59
3.5.5	Quick Check of the Part Program Registered	59
3.5.6	Pre-running and Final Running of the Part Program	60
3.5.7	Details of VMC Features Used For Machining	60
3.6	3D TO RAPID PROTOTYPING TRANSLATION.....	63
3.6.1	Tools Used To Create Rapid Prototyping	63
3.6.2	Importance of Rapid Prototyping to Product Design	67

CHAPTER FOUR: RESULTS	68
4.1 RESULTS	68
CHAPTER FIVE: DISCUSSIONS	70
5.1 PROBLEMS ENCOUNTERED	70
5.1.1 Lack of Expertise in Choosing the Right Toolpaths and Toolbits	70
5.1.2 Tool Removal from the Spindle	71
5.1.3 Set Up Time.....	71
5.1.4 Manual Programming.....	72
5.1.5 Adjustment of Feedrates	72
CHAPTER SIX: CONCLUSIONS.....	73
6.1 ACCOMPLISHMENT	73
6.2 RECOMMENDATIONS.....	73
6.2.1 CAD/CAM.....	74
6.2.2 VMC Machine.....	75
6.2.3 FDM 2000	75
6.3 FUTURE WORKS	76
6.3.1 Blow Moulding Parameters to be Considered	76
6.3.2 Injection Moulding Parameters to be Considered	81
REFERENCES.....	83

APPENDIX A QUESTIONNAIRE

**APPENDIX B IMPORTANT CONTROL BUTTONS AND MODELING MECHANISMS OF
RAPID MODELER FDM 2000**

APPENDIX C VERTICAL MACHINING CENTER (VMC) GUIDELINES

APPENDIX D MASTERCAM MILL 7.2 GUIDE

APPENDIX E TECHNICAL DRAWINGS AND 3D CAPTIONS

LIST OF FIGURES

Figure	Title	Page
Figure 2.2-a	Chain Molecules of Partial Crystalline Material	12
Figure 2.3-a	Stage One of Continuous Parison Blow Moulding	18
Figure 2.3-b	Stage Two of Continuous Parison Blow Moulding	19
Figure 2.3-c	Stage Three of Continuous Parison Blow Moulding	20
Figure 2.3-d	Stage Four of Continuous Parison Blow Moulding	21
Figure 2.4-a	Operation Sequence of Injection Moulding	23
Figure 2.5-a	Tree's 1060 VMC Machine	24
Figure 2.5-b	Daewoo's Mynx500 VMC Machine	25
Figure 2.5-c	Vickers ZPS MCFV 1060LR VMC Machine	26
Figure 3.2-a	The Main Screen of a MasterCAM Software	37
Figure 3.2-b	MasterCAM-Shampoo Bottle	38
Figure 3.2-c	MasterCAM-Hinged Cap	39
Figure 3.3-a	Coon Surface	40
Figure 3.3-b	3D Shampoo Body	41
Figure 3.3-c	Mould of Shampoo Body	42
Figure 3.3-d	3D Hinged Cap	43
Figure 3.4-a	Job Setup of Stock Material to be Machined	46
Figure 3.4-b	Tool Parameter User-Input Window	48
Figure 3.4-c	Simulation of Mould Cavity Machining	49
Figure 3.4-d	Roughing Parameter User-Input Window	51
Figure 3.4-e	Radial Parameter User-Input Window	51
Figure 3.4-f	Operations Manager Window	55
Figure 3.5-a	Determining the Stock Origin	58

Figure	Title	Page
Figure 3.5-b	Author with Mould of Shampoo Bottle	62
Figure 3.5-c	Machined Mould Cavity of Shampoo Bottle	62
Figure 3.6-a	Rapid Modeler Set – FDM 2000 and Silicon Graphics	64
Figure 3.6-b	Modeling of Hinged Cap in Progress	66
Figure 6.3-a	Parison Wall Thickness Control	77
Figure 6.3-b	Single and Multi Cavity Moulds	78
Figure 6.3-c	Nipping Action During Moulding	79
Figure 6.3-d	Main Part of Single Cavity Mould	80
Figure B1.1-a	SML Icon Button	B01
Figure B1.1-b	Directional Button	B01
Figure B1.1-c	Positioning of FDM Tip	B02
Figure C1.1-a	Pendant Handwheel	C01
Figure C1.1-b	Spindle Speed and Feedrate Override Button	C02
Figure C1.1-c	Emergency Stop Button	C03
Figure C1.1-d	Pendant LCD	C03
Figure C1.2-a	Single Block Button	C04
Figure C1.2-b	Single Loop Button	C05
Figure C1.2-c	Optimal Stop Button	C05
Figure C1.2-d	Dry Run Button	C06
Figure C1.2-e	Coolant Stop Button	C06
Figure C1.2-f	Coolant Restart Button	C07
Figure C1.2-g	Spindle Stop Button	C07
Figure C1.2-h	Spindle Restart Button	C08
Figure C1.2-i	Data Reset Button	C08
Figure C1.2-j	Handwheel Button	C09

Figure	Title	Page
Figure C1.2-k	Cycle Start Button	C10
Figure C1.2-l	Power Feed Controls	C10
Figure C1.3-a	Setting of Tram Surface Length	C15
Figure C1.4-a	VMC System Block Diagram	C19
Figure D1.2-a	User-Input Window for Machining	D03
Figure E1.1-a	2D Technical Drawing of Shampoo Bottle	E01
Figure E1.1-b	2D Technical Drawing of Hinged Cap	E02
Figure E1.1-c	3D Shampoo Bottle Caption in MasterCAM Software	E03
Figure E1.1-d	3D Hinged Cap Caption in MasterCAM Software	E04

LIST OF TABLES

Table	Title	Page
Table 1.3-a	Stage and Task Level for the Proposed Project	04
Table 1.3-b	Information Required in Designing Shampoo Bottle and Hinged Cap	05
Table 2.2-a	Category and Key Attributes of Semi-Crystalline Plastics	11
Table 2.2-b	Thermal Properties of Selected Plastics	13
Table 2.2-c	Short-Term Properties of Selected Plastics	14
Table 2.6-a	Advantages and Disadvantageous of Brinell Test	29
Table 2.6-b	Advantages and Disadvantageous of Vickers Test	30
Table 2.6-c	Advantages and Disadvantageous of Rockwell Test	31
Table 3.1-a	Summary of Survey for Multiple Choice Questions	34
Table 3.1-b	Assessment of Key Appearance Parameters	35
Table 3.4-a	Tool and Roughing Parameters	52
Table 3.4-b	Tool and Semi-Finishing Parameters	53
Table 3.4-c	Tool and Finishing Parameters	54
Table C1.1-a	Thermal Properties of Selected Plastics	C01
Table C1.1-b	Short-Term Properties of Selected Plastics	C03
Table C1.3-a	Procedures for Loading Part Program from Disc	C11
Table C1.3-b	Procedures for Activating Program from External Source	C12
Table C1.3-c	Procedures for Setting of Tram Surface Length	C15
Table C1.3-d	Procedures for Setting of Tool Length	C16
Table C1.5-a	G Code Listings and Usage	C20
Table C1.6-a	M Code Listings and Usage	C23
Table D1.2-a	MasterCAM Mill 7.2 Function Buttons	D07

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND STUDY

Since the early history of man, metal has played an important part of their daily lives. Metal was used in most of their activities i.e. hunting, cooking, cutting, constructing etc. Even weapons of war were made from metal ranging from the basic spear to the more sophisticated guns and cannons.

However, with the turn of this century plastic is now modern mans daily usage. It would be difficult to imagine our modern world without plastics. Today they are an integral part of everyone's lifestyle with applications varying from commonplace domestic articles to sophisticated scientific and medical instruments. It has taken over most of the products initially made from metal due to its lightweight, economic cost and abundance. It can be easily transformed from one form to another without involving high cost. Also, from certain aspects, plastic performs better than metal with certain plastic products having better physical stability compared to metals.

Nowadays designers and engineers readily turn to plastics because they offer combinations of properties that is not available in any other materials, even the metal alloys. Therefore, it was only logical to carry out a research on plastic products, as they are becoming even more important with new developments happening in this field frequently.

Plastic has become an important and useful product, especially to consumers. In all of our daily lives we come in direct contact with plastic either as a raw material, intermediate or finished product. Having such a wide range of usage, it was difficult to design a product made out of plastic without narrowing down the scope first. As such it was decided that the product to be chosen and further made research upon would fulfill the following criteria:

- Consumer oriented product;
- Used commonly and frequently by consumers;
- Targeted for every level income group of consumers; and
- Different design of the proposed product is available in the market for further assessment;

Based on the criteria set above, it was decided to choose personal hygiene products regularly used by consumers. Among these, several plastic product were assessed i.e. shower bottle, shampoo bottle, powder bottle etc. Finally, after conducting a quick market survey and consultation with the advisor, shampoo bottle was chosen as the product to be researched upon.

Here the author chooses to design on the die design of plastic shampoo bottles due to the prime fact that almost all of us use shampoos in our daily lives, thus the market is definitely out there for these shampoo bottles. Shampoos are considered a daily must for every consumer and it is far more important and definitely a favorite among the people. Thus it is worth considering to invest time in improving and refining the existing design

and process used to produce this product. Furthermore, this seems suitable as almost all parts of the world are going through a recession period. Thus improvement on the die design of the shampoo bottle would not be particularly demanding or financially consuming if compared to other highly technology intensified automotive or aviation inventions.

1.2 SCOPE OF WORK

This project is intended to design a mould for the shampoo bottle by utilizing the sophisticated and advanced machines available in the Tool and Die Lab of Kulliyah of Engineering, International Islamic University Malaysia (IIUM). This entails designing and machining of the shampoo bottle mould specifically for the blow molding process both using the CAM software and VMC machine respectively. The design of the shampoo bottle was based from questionnaire which was developed and distributed at Project I (MFG 4110) level. *Section 3.1* details out further preparation and conduct of the questionnaire and survey

Included within the scope of work is also a rapid prototype of the hinged cap of the shampoo bottle, which was designed and developed using the CAM software and then translated into the FDM 2000 rapid prototyping machine which functions as a rapid modeler.

1.3 PROJECT METHODOLOGY

The proposed project on the computer aided die design of plastic shampoo bottle was carried out in three main stages, with each stage encompassing different tasks enduring several weeks. Among other things, it ranges from literature survey right up to design of the product with complete dimensions incorporated into it. *Table 1.3-a* summarizes the three stages to this project and also lists the tasks performed for each of the stage.

Table 1.3-a *Stage and Task Level for the Proposed Project*

<i>Stage</i>	<i>Tasks</i>
Stage 1	<ul style="list-style-type: none"> • Selection of Product; and • Literature Survey.
Stage 2	<ul style="list-style-type: none"> • Preparation of Questionnaire; • Conduct Survey; • Analyze Survey; and • Conclusion from Survey
Stage 3	<ul style="list-style-type: none"> • Design of Shampoo Bottle; • Design of Hinged Cap; • Modifications; and • Dimensions

Once, it was ascertained, from discussions with the project supervisor, that products made of plastic, specifically a shampoo bottle was to be designed, the next step was to carry out an extensive literature survey on the design of a plastic bottle.

Several information that required further research and relevant reading for designing a shampoo bottle and hinged cap was undertaken including accessing the internet. These

information include, but not limited to, the following items listed out in *Table 1.3-b* below. Details of the literature survey is given in Chapter Two of this project.

Table 1.3-b Information Required in Designing Shampoo Bottle and Hinged Cap

<i>Items</i>	<i>Description</i>
Plastics	<ul style="list-style-type: none"> • Ascertain types, characteristics and behavior of plastics; • Recommend type of plastic suitable as a raw material for the shampoo bottle and hinged cap
Molding processes	<ul style="list-style-type: none"> • Discover the different molding processes available in the industry; • Recommend the process most suitable for manufacturing shampoo bottle and hinged cap
Computer Numerical Control (CNC) Machines	<ul style="list-style-type: none"> • Determine the various types of CNC machines (vertical, horizontal, etc.) available • List out the specifications and special functions of these machines;
Materials	<ul style="list-style-type: none"> • Seek out types and characteristics of materials suitable for machining; • Establish appropriate type of material to be used for machining including physical properties i.e. hardness, material strength etc.

The next step was to establish consumers design choice of a shampoo bottle which was determined by conducting a survey. Questionnaires were distributed to selected category of people to gauge the type and design of a shampoo bottle most preferred. Further details of the survey including results and discussions from the questionnaire are discussed in *Section 3.1*.

Upon completion of Stage 2, the next stage is to design the shampoo bottle and its hinged cap utilizing a proprietary software, MasterCAM. The designs of both components were done in 2D which was then transferred to 3D view. This was followed by simulation of machining process for the shampoo bottle using MasterCAM. After successfully simulating the machining process in MasterCAM, the shampoo bottle was then physically machined on a stainless steel workpiece using the VMC machine, model ZPS MCFV 1060LR.

The 3D design of MasterCAM software, has the capability of converting *.MC7 machine files to *.STL rapid prototyping files which is readable by the rapid prototyping software, QuickSlice. Design of the shampoo bottle's cap was translated via this method before modeling it with FDM 2000. During the entire design process, continuous modifications and changes to the dimensions were carried out in order to ensure smooth machining and modeling processes. Stage 3 involving design of the shampoo bottle and its hinged cap right up to the physical machining process is explained in Chapter Three of this project.

Chapter Four provides results achieved after undertaking this project. This includes a sample of the body shampoo mould which was machined using stainless steel as the cavity and a prototype of the hinged cap via rapid modeling. Discussions pertaining to the project including problems and difficulties encountered are highlighted in Chapter 5.

The final Chapter Six is devoted to providing conclusions as well as relevant recommendations from the project. Included in this chapter are suggested works for future undertaking.

CHAPTER TWO

LITERATURE SURVEY

2.1 OVERVIEW OF PLASTICS

Pitch, amber, lac, wax, etc., are all plastics, but plastics materials as we now know them have been around since the middle 1800's. It was the Second World War that brought about the need for plastic products to be mass-produced and to replace more traditional materials such as steel, aluminum and iron. Since that time the word 'plastic' has come to mean 'imitation' or 'cheap and nasty', i.e. 'plastic food' for instance. But, as far from being either cheap or nasty, many high quality things used at home or at work cannot be made out of anything else. And the complainers would really have something to moan about if all the plastics suddenly disappeared. Half the kitchen equipment would vanish. There would be no telephones, televisions, refrigerators etc., in fact, no electricity, because most of the insulation is made from plastics. We would all have to walk to work, too – not that it would be worth going, because most industrial processes need plastics somewhere in their machinery to keep going. Therefore, the statement "everything seems to be made out of plastic these days" is not far from the truth.

2.2 USAGE AND TYPES OF PLASTICS

More things are made of plastics, and there are now hundreds of materials, which are plastic, produced by various complicated processes which combine oil, air and other chemicals. Plastics offer advantages such as lightness, resilience, resistance to corrosion,

color fastness, transparency, ease of processing, etc., and although they have their limitations, their exploitation is limited only by the ingenuity of the designer.

The term plastic refers to a family of materials, which includes nylon, polyethylene and PTFE just as zinc, aluminum and steel fall within the family of metals. This is an important point because just as it is accepted that zinc has quite different properties from steel, similarly nylon has quite different properties from PTFE. This analogy can be taken still further because in the same way that there are different grades of steel there are also different grades of, say, polypropylene. In both cases a good designer will recognize this and select the most appropriate material and grade on the basis of processability, toughness, chemical resistance, etc.

It is usual to think that plastics are a relatively recent development but in fact, as part of the larger family called polymers, they are a basic ingredient of animal and plant life.

Polymers are different from metals in the sense that their structure consists of very long chain-like molecules. Natural materials such as silk, shellac, bitumen, rubber and cellulose have this type of structure. However, it was not until the nineteenth century that attempts were made to develop a synthetic polymeric material and the first success was based on cellulose. This was a material called Parkesine, after its inventor Alexander Parkes, and although it was not a commercial success it was a start and it led to the development of Celluloid. This material was an important breakthrough because it became established as a good replacement for natural materials, which were in short supply – for example ivory for billiard balls.

Plastics, more than any other design material, offer such a wide spectrum of properties that they must be given serious consideration in most component design. However, this does not imply that there is a plastic with the correct combinations of properties for every application. It simply means that the designer must have an awareness of the properties of the range of plastics available and keep an open mind. One of the most common faults in design is to be guided by pre-conceived notions. For example, an initial commitment to plastics based on an irrational approach is itself a serious design fault. A good design always involves a judicious selection of material from the whole range available, including non-plastics. Generally, in fact, it is only against a background of what other materials have to offer that the full advantages of plastics can be realized.

The various forms of plastics, commonly available in the industry today, are listed below:

- Engineering plastics or thermoplastics;
- Thermosets;
- Composites;
- Structural foam;
- Elastomers;
- Polymer alloys; and
- Liquid Crystal Polymers (LCP).

For this project, semi-crystalline plastics a sub category of engineering plastics is suggested as raw material for manufacturing of the shampoo bottle. The following section details out important elements and characteristics of this type of plastics.

2.2.1 Semi-Crystalline Plastics

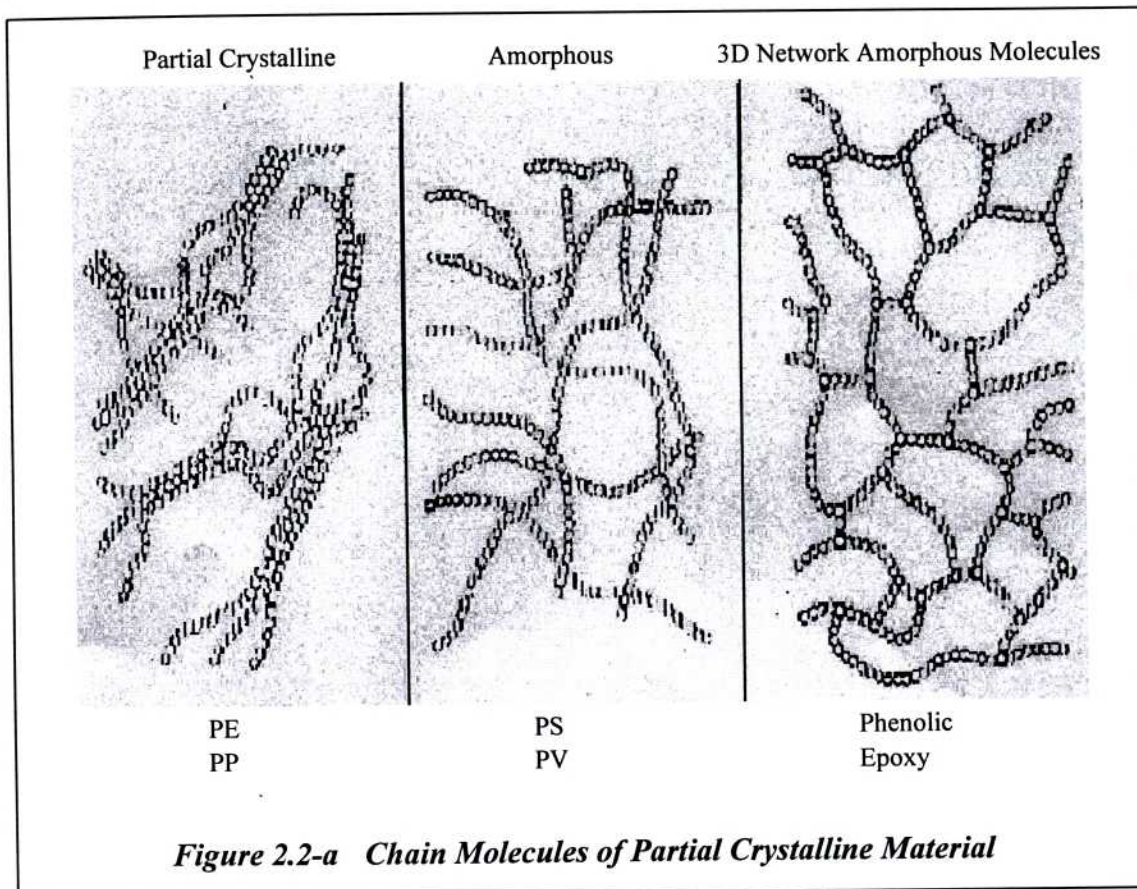
It is noted from experience gained by the researcher during Industrial Training (IT) that manufacturers of consumer and daily household products prefer semi-crystalline plastics as a base for shampoo containers. However, there are various forms and grades of this type of plastic which require further evaluation prior to selection of material. *Table 2.2-a* below summarizes key characteristics and nature of each plastic material from this category.

Table 2.2-a *Category and Key Attributes of Semi-Crystalline Plastics*

Material Type	Description
Low density polyethylene (LDPE)	<ul style="list-style-type: none"> • Widely used in the UK (21% of total UK consumption of plastics); and • Very tough and flexible
Linear Low Density Polyethylene (LLDPE)	<ul style="list-style-type: none"> • It has a regular structure with short chain branches
High Density Polyethylene (HDPE)	<ul style="list-style-type: none"> • More expensive, stronger, stiffer; and • Numerous applications such as dustbins, bottle crates, general purpose fluid containers like in this project shampoo bottles and pipes.
Polypropylene (PP)	<ul style="list-style-type: none"> • Extremely versatile plastic, has the lowest density of all thermoplastics; and • Available in fiber form, film form.
Polyamides (nylon)	<ul style="list-style-type: none"> • High strength, stiffness and toughness, also known as engineering plastics.

For this project, polypropylene is recommended as plastic material for the bottle instead of polyethylene, which is preferred by manufacturers. Polypropylene (PP) is a type of

synthetic polymer, which falls under the crystalline thermoplastic category. An important attribute of a thermoplastic is that it will soften and melt easily on heating but solidify upon cooling. PP together with other plastic materials, i.e. polyethylene (PE), nylon (PA) and PET materials falls under the category of partial crystalline type of chain molecules, as illustrated in *Figure 2.2-a*.



Included in *Table 2.2-b* and *Table 2.2-c* are short-term properties of some important plastics including thermal properties of materials, which will give more insight to this suggested plastic material, polypropylene.

Table 2.2-b Thermal Properties of Selected Plastics

Material	Density (kg/m³)	Specific Heat	Thermal Conductivity (W/m/K)	Coeff. of Therm Exp. ($\mu\text{m}/\text{m}/\text{K}$)	Thermal Diffusivity (m²/s)x10⁻⁷	Max. Operating Temp (°C)
ABS (high impact)	1040	0.35	0.3	90	1.7	70
Acetal (homopolymer)	1420	0.35	0.2	80	0.7	85
Acetal (copolymer)	1410	0.35	0.2	95	0.72	90
Acrylic	1180	0.35	0.2	70	1.09	50
Cellulose acetate	1280	0.36	0.15	100	1.04	60
CAB	1190	0.35	0.14	100	1.27	60
Epoxy	1200	-	0.23	70	-	130
Modified PPO	1060	-	0.22	60	-	120
Nylon 66	1140	0.4	0.24	90	1.01	90
Nylon 66 (33% glass)	1380	0.3	0.52	30	1.33	100
PEEK	1300	-	-	48	-	204
PEEK (30% carbon)	1400	-	-	14	-	255
PET	1360	-	0.14	90	-	110
PET (36% glass)	1630	-	-	40	-	150
Phenolic (mineral filled)	1690	-	-	22	-	185
Polyamide-imide	1400	-	-	36	-	260
Polycarbonate	1150	0.3	0.2	65	1.47	125
Polyester	1200	-	0.2	100	-	-
Polyetherimide	1270	-	0.22	56	-	170
Polyethersulphone	1370	-	1.18	55	-	180
Polyimide	1420	-	-	45	-	260
Polyphenylene sulfide (30% carbon)	1460	-	-	16	-	200