

DESIGN OF PLASTIC RIM FOR INDUSTRIAL AND COMMERCIAL
LIGHT VEHICLES USING MODELING AND SIMULATION TOOLS

Dilan Lakmal Gunapala

(138255C)

Degree of Master of Science in Polymer Technology

Department of Chemical and Process Engineering

University of Moratuwa
Sri Lanka

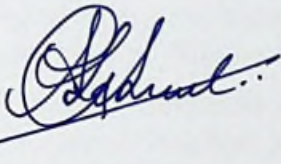
April 2017

66 " 17 "
678(043)

Declaration

"I declare that this is my own work and this ~~thesis~~/dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the right to reproduce and distribute my thesis/dissertation, with prior approval in whole or in part in print, electronic or other medium.

Signature: 

Date: 14th June 2017

The supervisor/s should certify the ~~thesis~~/dissertation with the following declaration.

The above candidate has carried out research for the Masters/~~MPhil~~/PhD thesis/
Dissertation under my supervision.

UOM Verified Signature

Signature of the supervisor:

Date 14.06.2017

Abstract

The present research was devoted to designing a plastic rim for industrial and commercial light vehicles using modeling and simulation tools.

The main objective of the design project was to design a rim structure that would be capable of sustaining the required load and performing under provided service conditions. In order to select a suitable thermoplastic composite a series of plastics was experimented. The selection of material was based on several factors, including mechanical strength under dynamic load, resistance to prolonged action of elevated temperatures and ability to be molded with conventional techniques. The materials which were considered for the design included Polyamide 6, Polyamide 6 with 50% long glass fibers, Polyamide 6 with 50% short glass fibers and Polyamide 6 with 30% short glass fibers, out of which Polyamide 6 with 30% short glass fibers was selected due to it being less brittle, that aided the material to withstand service and accidental impact. Another criterion that supported selected material was associated with its ability to be injection molded with conventional type injection molding techniques.

Four models were developed based on general plastic product design standards. Each model was simulated in order to identify areas of potential failure. After that model was optimized by changing its structural arrangements so as the stresses in the potential failure areas were reduced. Next step in modification and optimization of the model was done for product mold-ability.

The model which comprised a solid body of rim portion with a center bore configured to receive axle hub, an inner band, a circumferentially extended outer band that margined the rim portion, a nave ring that extended outwardly and radially of said center bore wherein a plurality of holes were circularly positioned that were configured to receive bolts, a plurality of ribs extending outwardly and radially at right angles from the nave ring up to the outer band were positioned both sides of the rim configured to improve flexural rigidity of the structure was accepted for fabrication by means of reinforcement of hub hole area with metal plate.

A manufacturing method of plastic rim was selected based on the material processibility, manufacturing cost and efficiency for serial manufacturing and commercialization. Prototype Injection mold was manufactured using cheap and easy to machined steel P-20. Produced standard mold was modified to improve ventilation and to facilitate flow of the plastic melt through the flow path of the injection mold from machine nozzle to cavity

The successful prototypes and destructive tests carried out affirmed suitability of the Solidwork Design package and Solidwork Simulation Package for designing, manufacturing and prediction of load bearing capability of the plastic rim. The application of Solidwork Simulation Package during designing stage lead to reduced implementation cost and reduced reproduction numbers of prototypes to evaluate product suitability, thereby making implementation of the final product efficient.

The main advantages of using plastic composite material for automotive rims included energy efficiency and easy maintenance due to lower weight

Acknowledgement

I would like to make this a chance to express my sincere gratitude and thanks for everyone who helped, guided, directed, advised and encouraged to present this MSc thesis project as a completed and successful one.

First I would like thank my supervisor Dr. Mrs Shantha M. Egodage , Senior Lecturer of Department of Chemical and Process Engineering , University of Moratuwa for sharing her valuable knowledge and experience in helping, guiding, directing, advising and encouraging to make the project and project report “Design of plastic rim for industrial and commercial light vehicles using modeling and simulation tools” a success.

I would also like to thank the experts who were involved in the validation this research project: “Design of plastic rim for industrial and commercial light vehicles using modeling and simulation tools” Without their passionate participation and genuine input, the validation could not have been successfully conducted.

I would also like to acknowledge all the senior academics that were not mentioned earlier for valuable their input on this thesis, and I am gratefully indebted to them very valuable comments on this thesis.

Finally, I must express my very profound gratitude to my mother and my late father for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without you. Thank you.

Table of Content

Declaration	ii
Abstract	iii
Acknowledgement	iv
Table of Content	v
Table of Figures	viii
List of Tables	xii
1. Introduction	1
1.1. Background	1
1.2. Objectives.....	3
2. Literature Review	4
2.1. Importance of using plastic components in automobile industry.....	4
2.2. High Performance plastics	5
2.3. Engineering thermoplastics	6
2.3.1. Acrylonitrile Butadiene Styrene (ABS).....	6
2.3.2. Polycarbonate.....	7
2.3.3. Polyethylene Terephthalate (PET).....	8
2.3.4. Nylons.....	9
2.4. Type of glass fibers used for nylon reinforcement.....	11
2.5. Nylon Processing.....	14
2.5.1. The tendency of nylon to absorb water.....	14
2.5.2. Nylon Injection molding	16
2.5.3. Shrinkage	20
2.5.4. Injection Molding Defects	22
2.6. Design of plastic components	29
2.6.1. Nominal Wall thickness.....	29
2.6.2. Uniform Wall thickness	30

2.6.3.	Corners.....	31
2.6.4.	Coring	33
2.6.5.	Draft and texture design.....	34
2.6.6.	Structural reinforcement design.....	35
2.7.	Application of simulation tools in polymer industry	38
2.8.	Finite Element Analysis	41
2.9.	Use of FEA in Automobile Industry	44
3.	Material and Methodology.....	46
3.1.	Selection of the suitable material for manufacture of rim.....	46
3.1.1.	Nylon 6.....	46
3.1.2.	Nylon 6 with 50% long glass fibers.....	46
3.1.3.	Nylon 6 with 30% short glass fibers.....	47
3.1.4.	Nylon 6 with 50% short fibers.....	47
3.2.	Characterization of plastics	47
3.2.1.	Specific Gravity	47
3.2.2.	Melting Temperature	48
3.3.	Designing Tools and Product Design.....	48
3.3.1.	Design of Rim.....	49
3.3.2.	Stress vs. Contact Angle	50
3.4.	FEM Modeling	51
3.4.1.	3D CAD Model designing	51
3.4.2.	Material Properties.....	51
3.4.3.	Identification of Fixtures and external forces	52
3.4.4.	Mesh Refinement Metrics.....	52
3.5.	Designing of Nylon Rim	53
3.6.	Comparison of rim models.....	55
3.8.	Injection Molding.....	57

3.8.1.	Injection mold	57
3.8.2.	Injection Molding Machine.....	58
3.8.3.	Molding procedure.....	59
3.8.4.	Injection molding of Nylons filled with glass fibers	60
3.8.5.	Injection molding steps-start up.....	61
3.9.	Tire Testing machine (Bench test)	61
3.9.1.	Static test.....	62
3.9.2.	Dynamic test	62
4.	Results and Discussions	64
4.1.	Properties of materials.....	64
4.2.	Designing of Rim	64
4.2.1.	Evaluation and Simulation of steel rim.....	64
4.2.2.	Evaluation and Simulation of plastic rim.....	65
4.3.	Production Stage	72
4.3.1.	Injection molding	72
4.3.2.	Injection molding of Nylon 6 rim	73
4.3.3.	Long fibers filled PA 6	73
4.3.4.	Short fibers reinforced PA 6.	74
4.3.5.	Test results of molded rims under static and dynamic test conditions. .	75
5.	Conclusion	80
6.	Future recommendation.....	81
	References.....	82
	Appendix 1.....	90
	Appendix 2.....	91
	Appendix 3.....	92
	Appendix 4.....	93
	Appendix 5.....	94

Table of Figures

Figure 1 PEEK polymers	5
Figure 2 Polyamide-imides	5
Figure 3 Acrylonitrile Butadiene Styrene	6
Figure 4 Styrene rigidity vs. processibility	7
Figure 5 Esterification process.....	7
Figure 6 Phosgenation.....	8
Figure 7 PET	8
Figure 8 Hydrolysis of PET	9
Figure 9 Chemical structure of Nylon 4/6	9
Figure 10 Chemical structure of Nylon 6/10	9
Figure 11 Chemical structure of Nylon 6/12	10
Figure 12 Short and long glass fiber	12
Figure 13 Compounding of short fiber nylon	12
Figure 14 Coating of long glass fibers.....	13
Figure 15 Vacuum-drying curve of nylon	15
Figure 16 Nylon screw design	17
Figure 17 Barrel for nylon injection molding machine	17
Figure 18 Nozzle for nylon injection molding.....	18
Figure 19 back-flow check valve nozzle	19
Figure 20 none return ball valve figure.....	19
Figure 21 Hydraulic clamp	19
Figure 22 Toggle clamp	20
Figure 23 Effect of % Glass fiber in resin	21
Figure 24 Brittleness example	22
Figure 25 Hydrolytic degradation of Nylons 6 compared to Nylon 6/12	23

Figure 26 Discoloration of plastics	24
Figure 27 Flow marks	26
Figure 28 Sink Mark	30
Figure 29 Warping and twisting	31
Figure 30 Mathematical definition of warpage.....	32
Figure 31 Correct design of sharp corners	32
Figure 32 of Stress concentration factor K and normal Stress.....	32
Figure 33 Corner design.....	33
Figure 34 Calculation of outside radii of corner design	33
Figure 35 Examples of correct corner design	33
Figure 36 Geometrical techniques to have uniform wall thickness.....	34
Figure 37 Draft angel definition	34
Figure 38 Method to add drafts for draft angles over 10 degrees.....	35
Figure 39 Efficiency of ribbed structure.....	36
Figure 40 Calculation parameters for ribbed design.....	37
Figure 41 1.Corrugated structure 2. A hexagonal array of interconnected ribs.....	37
Figure 42 Methods to improve sectional strength.....	38
Figure 43 Helical worm wheel.....	40
Figure 44 Tooth like worm wheel.....	40
Figure 45 Nodes and Elements for FEM	41
Figure 46 Local mesh refinement	43
Figure 47 The stresses in a plate with a hole, solved with different element sizes	43
Figure 48 The same finite element mesh, but solved with different element order.....	43
Figure 49 Nylon short glass fiber vs. long glass fibers.....	47
Figure 50 FEM stages	49
Figure 51 Effect of stress vs. contact angle	50
Figure 52 Effect of applied Stress Vs contact angle.....	50

Figure 53 Application of force on the steel rim of FEM model	51
Figure 54 Difficulty of identifying symmetry for repetition	53
Figure 55 Nylon tire design vs standard tire	54
Figure 56 Injection mold under manufacturing	57
Figure 57 Barrel on injection molding machine	58
Figure 58 Injection molding machine	58
Figure 59 General purpose screw design	58
Figure 60 General purpose heating nozzle.....	59
Figure 61 Tire testing bench	62
Figure 62 Rubber molded tire	63
Figure 63 Dynamic testing in process.....	63
Figure 64 Simulated results of steel rim	65
Figure 65 Standard steel rims (1).....	65
Figure 66 Plastic rim design number 01 (2).....	65
Figure 67 Design simulation results for design model number 01	66
Figure 68 Design number 01- Detailed drawing.....	66
Figure 69 Design number 02 - Detailed drawing.....	67
Figure 70 Design simulation results for design model number 02	68
Figure 71 3D drawing of design model number 03	69
Figure 72 Design simulation results for design model number 03	70
Figure 73 Steel ring holding mechanism	70
Figure 74 3D drawing of design model number 04	71
Figure 75 Design simulation results for design number 04 with 4 mm steel plate.....	71
Figure 76 Injection mold with multiple inserts.....	72
Figure 77 Whitening marks on the rim surface	75
Figure 78 Soft surface of the mold with increased injection molding temperature.....	75
Figure 79 Band after static test result font.....	76

Figure 80 Dynamic test result.....	78
Figure 81 Destructed wheel (destructive test)	79
Figure 82 Damaged steel rim Figure 83 Tire fitted to the dolly	81
Figure 84 Tire fitted to the dolly.....	81

List of Tables

Table 1 Typical shrinkage values for unreinforced nylons.....	21
Table 2 Wall Thickness vs. Mold Shrinkage.....	22
Table 3 Nominal wall thickness for thermoplastics.....	30
Table 4 Recommended draft angle for plastics.....	35
Table 5 Material Properties of Nylon 6	46
Table 6 Design comparison	55
Table 7 Four load step on Tire Test Bench.....	63
Table 8 Specific gravity and melting temperature of materials.....	64
Table 9 Steel rim stress & deformation	65
Table 10 Simulation results of the design model number 1.....	66
Table 11 Simulation results of the design model number 02.....	68
Table 12 Simulation results of the design model Number 03.....	70
Table 13 Simulation results of design model number 04	71
Table 14 Original steel rim vs. design model number 04	72
Table 15 Modification of the injection mold done after trial with Nylon 6	73
Table 16 Injection molding process parameters LF/GF PA 6	74
Table 17 Adjustments to the injection mold structure	74
Table 18 Static test results	76
Table 19 Step 1- speed 10 km/h.....	78
Table 20 Step2 speed 15 km/h.....	78