UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF POST CONDITIONING INJECTION MOLDING PROCESS CONTROL ON GLASS FILLED NYLON (POLYAMIDE 6) COMPOSITES FOR GLOBAL PRODUCT ENGINEERING

ABDUL AZIM BIN ABDUL RAHMAN

FK 2019 77

DEVELOPMENT OF POST CONDITIONING INJECTION MOLDING PROCESS CONTROL ON GLASS FILLED NYLON (POLYAMIDE 6) COMPOSITES FOR GLOBAL PRODUCT ENGINEERING

By

ABDUL AZIM BIN ABDUL RAHMAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Engineering

August 2019

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Engineering

DEVELOPMENT OF POST CONDITIONING INJECTION MOLDING PROCESS CONTROL ON GLASS FILLED NYLON (POLYAMIDE 6) COMPOSITES FOR GLOBAL PRODUCT ENGINEERING

By

ABDUL AZIM BIN ABDUL RAHMAN

August 2019

Chair : Mohd Khairol Anuar bin Mohd Ariffin, PhD
Faculty : Engineering

The wide use of glass filled nylon (Polyamide 6) composites material in office furniture industry has put higher demands on engineers to conduct more accurate and increasingly sophisticated analysis of materials in order to endure the performance of the molded parts under the end-use conditions characterized by varying humidity, temperature, and dynamic load or deformation. Glass Filled Nylon (Polyamide 6) Composites is a hygroscopic material where it is very sensitive to moisture which is an important factor to be considered during material pre-selection, parts design, mechanical performance prediction, testing and evaluation process. The effect of moisture can be a major factor in products and parts evaluation that were exposed to different weather conditions due to changing in seasons or geographic locations. Due to this effect of moisture absorption in uncontrolled condition, rejection % increased from 3% to 20% due to inconsistent of testing results during in process inspection. This also caused some of the production lot to be quarantined until further verification. This resulted loss and reduced of the profit of the company as well as wastage of material and resources. The research focused on process control of conditioning the nylon parts and components after molded before proceeding with testing and evaluation. Post Conditioning machine was developed for quantify the optimize process control of Glass Filled Nylon (Polyamide 6) Composites parts. These process control covered a wide range for 3 process parameters for conditioning; temperature (from 20 to 80-degree C), relative humidity (from 30% to 80% RH) and time (unlimited variables control). The variation of these parameters may result in significantly different moisture absorption rates, equilibrium levels and mechanical properties. The results comprehensive up to date information and critical understanding on the impact of moisture and temperature on testing and evaluation of Glass Filled Nylon (Polyamide 6) Composites parts and components. This method of the post conditioned machine accelerated the moisture absorption from 0.001 percent to 0.125 percent which is incremental by 12,400 percent compare to current industry practice. This able to stabilize the parts in short time and able to proceed for evaluation. It will give better recommendations on process control of conditioning the nylon parts and components to make sure that all the testing and evaluation result valid and standardize between different seasons and geographical locations.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Kejuruteraan

PEMBANGUNAN KAWALAN PEMERIKSAAN SEMULA PENGENDALIAN PROSES MUDAH KEPADA KANDUNGAN KULIAH NILAI (POLYAMIDE 6) KOMPOSIT UNTUK KEJURUTERAAN PRODUK GLOBAL

Oleh

ABDUL AZIM BIN ABDUL RAHMAN

Ogos 2019

Pengerusi : Mohd Khairol Anuar bin Mohd Ariffin, PhD
Fakulti : Kejuruteraan

Penggunaan bahan nylon Bersama gentian kaca (Polyamide 6) komposit yang meluas di Industri Perabot Pejabat telah memberikan permintaan yang lebih tinggi kepada para jurutera untuk menjalankan analisis bahan yang lebih tepat dan semakin canggih untuk menanggung prestasi bahagian yang dibentuk di bawah keadaan penggunaan akhir yang dicirikan oleh kelembapan yang berbeza-beza, suhu, dan beban dinamik atau ubah bentuk. Kaca Diisi Nylon (Polyamide 6) komposit adalah bahan higroskopik di mana ia sangat sensitif terhadap kelembapan yang merupakan faktor penting untuk dipertimbangkan semasa pra-pemilihan bahan, reka bentuk bahagian, ramalan prestasi mekanikal, proses ujian dan penilaian. Kesan kelembapan boleh menjadi faktor utama dalam produk dan penilaian bahagian yang terdedah kepada keadaan cuaca yang berbeza kerana perubahan dalam musim atau lokasi geografi. Disebabkan kesan serapan kelembapan dalam keadaan tidak terkawal, penolakan % meningkat dari 3% ke 20% disebabkan keputusan ujian semasa proses pemeriksaan yang tidak konsisten. Ini juga menyebabkan sebahagian daripada hasil pengeluaran dikuarantin sehingga pengesahan lanjut. Ini menyebabkan kehilangan dan mengurangkan keuntungan syarikat dan juga pembaziran sumber dan bahan. Penyelidikan ini memberi tumpuan kepada kawalan proses penyaman komponen nilon dan komponen selepas diacu sebelum meneruskan ujian dan penilaian. Mesin Post - Conditioning telah dibangunkan untuk mengukur kawalan proses yang mengoptimumkan bahagian nilon. Kawalan proses ini meliputi pelbagai aspek untuk 3 parameter proses untuk penyaman; suhu (dari 23 hingga 80 darjah C), kelembapan relatif (dari 40% hingga 80% RH) dan masa (kawalan pembolehubah tanpa had). Variasi parameter ini boleh mengakibatkan kadar penyerapan kelembapan, paras keseimbangan dan sifat mekanik yang berbeza. Keputusan-keputusan adalah komprehensif. terkini dan memberi pemahaman kritikal mengenai kesan kelembapan dan suhu pada pengujian dan penilaian komponen dan komponen Kaca Diisi Nylon (Polyamide 6) komposit. Dengan cara menggunakan mesin Post – Condition, kadar serapan kelambapan dipercepatkan dari 0.001 peratus kepada 0.125 peratus yaitu penaikkan sebanyak 12,400 peratus dari keadaan yang berada di industri kini. Ia akan memberi cadangan yang lebih baik mengenai kawalan proses penyaman komponen nilon

dan komponen untuk memastikan bahawa semua keputusan ujian dan penilaian itu sah dan bersandar di antara musim dan lokasi geografi yang berbeza.

ACKNOWLEDGEMENTS

This work was carried out at Steelcase Office Solutions and the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra of Malaysia.

I would like to express my deep appreciation and utmost gratitude to my supervisor Professor Ir. Dr. Mohd Khairol Anuar Mohd Ariffin for his guidance, patience, and continuous support throughout my study in Universiti Putra Malaysia.

I would also like to thank Professor Mohd Sapuan b. Salit and Professor, Ir. Dr. Faizal Mustapha and Kurt Heirdmun for serving in my supervisor committee and for the insightful feedback throughout.

I would like to acknowledge the financial support from Ministry of Higher Education (MOHE).

This journey would have been really difficult without the continuous dua' and strong support from my family. A special thank you to my wife Elya binti Mohd Nor and my three wonderful children Ahmad Haikal, Ameera Aisya and Aleeya Sofea for supporting me in many ways.

To my parents, thank you so much for the continuous dua' and being my true source of inspiration.

I certify that a Thesis Examination Committee has met on (date of viva voce) to conduct the final examination of (student's name) on his (her) thesis entitled ("Title of Thesis") in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the (insert the name of relevant degree).

Members of the Thesis Examination Committee were as follows:

Associate Professor
Department of Electrical & Electronics
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Professor
Department of Electrical & Electronics
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Associate Professor
Department of Electrical & Electronics
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Professor
Departments
University
(External Examiner)

____
RUSLI HAJI ABDULLAH, PHD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Engineering.

The members of the Supervisory Committee were as follows:

Mohd Khairol Anuar b. Mohd Ariffin, PhD
Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Sapuan b. Salit, PhD
Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Faizal Mustapha, PhD
Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Kurt Heidmann, PhD
Chief Engineer
Department Advance Engineering Application & Seating Product Development,
Steelcase Inc.
United States of America
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: __________________

Name and Matric No.: Abdul Azim bin Abdul Rahman (GS38278)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ____________________
Name of Chairman of Supervisory Committee: Mohd Khairol Anuar b. Mohd Ariffin

Signature: ____________________
Name of Member of Supervisory Committee: Mohd Sapuan b. Salit

Signature: ____________________
Name of Member of Supervisory Committee: Faizal Mustapha

Signature: ____________________
Name of Member of Supervisory Committee: Kurt Heidmann

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Globalization pressures have begun to have a major impact on the practice of Product Engineering across a wide range of industries. A new paradigm has emerged whereby companies are utilizing skilled engineering teams dispersed around the world to design and develop the products in collaborative manner. Best practice in Product Development (PD) is now rapidly migrating from local, cross functional collaboration to a mode of Global collaboration [1].

Global Product Development therefore represents a major transformation for business, and it applies to a broad range of industries. There are main 5 reasons for Global Product Development being implemented; Lower Cost, Improve Process, Global Growth, Optimize resources of engineers & materials and Technology Access.

Product Engineering, Operations and Supply Chain are the main impacted by this Global product development practice. Products and components that been produced everywhere in the world must be maintained and kept same quality standard. Transporting components around the world also required proper plan and standard to comply.

According to Global Market Inc., the injection molded plastic market has established itself as one of the most dynamically evolving businesses in recent times. As one of the most commonly-used processes for product manufacturers, plastic injection molding is a precise method that can fabricate nearly any type of plastic part. Technologies, processes and materials used in injection molding continue to advance, allowing manufacturers better insight to design, develop and produce the highest performing and cost-efficient plastic parts.

Plastics provide many unique advantages when used in product design. Plastic parts or components can be designed and formed in any shape and this gives a lot of freedom for the designers and engineers to innovate and developing the products. From a cost perspective, plastics offer not only a low cost per unit volume of material, but also low manufacturing and assembly costs due to their ability to be easily formed into net shape products containing assembly features [2].

Plastic is material consisting of any of a wide range of synthetic or semi-synthetic organic compounds that are malleable and so can be molded into solid objects. There are a lot types of plastic that can be choose depending on the part/ components function and usability. Due to complexity of the product and standard requirement to comply, as well as optimization and efficiency, engineering plastic has been introduced and been used widely in most of the industries like automotive, aircraft, furniture, electronics and construction. Engineering plastics are materials designed generally for industrial applications that demand exceptionally durable materials. Basically, engineering plastics are significantly stronger than conventional kinds. They're designed to provide strength and/or durability according to one or more metrics (e.g., heat resistance). For the most part, engineering plastics fall into the category of thermoplastics, which, unlike thermosetting plastics, may be reshaped and reused when needed. The overall global engineering plastics market is forecast to reach $104.32 billion by 2024, growing 5.4 percent per year between 2017 and 2024 [3].

There is a huge variety of these kinds of plastics, in a wide range of applications. Engineering plastics include Polyamide (PA), Polyamide-imide (PAI), Polybenzimidazole (PBI), Polycarbonate (PC), Polyetherimide (PEI), Polyether ether ketone (PEEK), Polyethylene terephthalate (PETE), Polyimide (PI), Polymethyl methacrylate (PMMA), Polyoxymethylene (POM), Polyphenylene sulfide (PPS), Polyphenylsulfone (PPSU), Polysulfone (PSU), Polytetrafluoroethylene (PTFE).

In the past 30 – 40 years engineering plastic have been competing with materials such as steel, aluminum and concrete in cars, aircraft, buildings, bridges, bicycles, furniture and everyday sports goods. Polyamide (Nylon), one of the most widely used engineering thermoplastics, is an extremely versatile engineering plastic. An excellent combination of mechanical performance (toughness, low coefficient of friction, and good abrasion resistance) and cost make Nylon an ideal replacement for a wide variety of materials from metal to rubber. One of the main example is in the furniture industry where most of the Task Chair back structure frame is made from Nylon with Glass filled plastic material replacing aluminium material. Steelcase Inc. is the largest office furniture in the world as well as leading in the innovation of the product has been using plastic material to replace metal or aluminium material since 30 years ago and recently with the advancement of the plastic material process Steelcase even able to develop plastic chair control mechanism that conventionally full of metal and spring.

Nylon material is hygroscopic and absorbs relatively much moisture compared to other thermoplastic polymers. In addition, nylon moisture content has a large influence on the properties (weight and mechanical), which have an influence on the behavior strength, stiffness, elongation and natural frequency. Nylon is a unique material where it required dry condition during the injection process and after injection, it need sometimes to stabilize and depending on the environment of the injection factory. In the room temperature, 23deg C/ 50% RH, nylon material parts with 2 – 3mm thickness will need 1 month to fully stabilize and parts with >5mm thickness will need about a year to stabilize [4]. The condition will become unknown when the parts been storage in the warehouse with uncontrolled temperature and humidity.

1.2 Problem Statement

The wide use of Glass Filled Nylon (Polyamide 6) Composites material in the product design has put higher demands on engineers to conduct more accurate and increasingly sophisticated analysis of materials to endure the performance of the moulded parts under the end-use conditions characterized by varying humidity, temperature, and dynamic load or deformation. According to Glass Filled Nylon Market by Type (Polyamide 6, Polyamide 66), End Use Industry (Automotive, Electrical & Electronics, Industrial), Manufacturing Process (Injection Molding, Extrusion Molding), Glass Filling and Region Global Forecast to 2024 report, the market size for glass filled nylon targeted to be USD 8.2 billion in 2019 and increase to USD 10.8 billion in 2024. The market growth is attributed to the increased demand from automotive and electrical & electronic industries. Automotive is expected to be the largest end-use industry of glass filled nylon between 2019 and 2024 and Asia Pacific is the largest region of the usage.

Glass Filled Nylon (Polyamide 6) is a hygroscopic material where it is very sensitive to moisture [10]. This is an important factor to be considered during material pre-selection, parts design, mechanical performance prediction, testing and evaluation process. The effect of moisture can be a major factor in products and parts evaluation that were exposed to different weather conditions due to changing in seasons or geographic locations.

Glass Filled Nylon (Polyamide 6) required dry condition during the injection process and after injection. It needs time to stabilize and it is depending on the environment of the injection factory where different region has different weather condition especially temperature and humidity contents. It is getting worst with four seasons region where different season has different temperature and humidity. At room temperature 23℃ / 50% RH, Nylon material parts with 2 mm – 3mm thickness will need 1 month to fully stabilize and parts with more than 5mm thickness will need about a year to stabilize [4]. The condition will become unknown when the parts been storage in the warehouse with uncontrolled temperature and humidity.

With this condition, it will be difficult for manufacturer that produce molded Nylon injection part to scheduling in-process checking and evaluation especially when it need to perform destructive test as part of the in-process control. Performing destructive test is very important to confirm variation of material and process is under control but without understanding the impact of environmental and how to control the condition after molded injection to nylon material part then the result from the testing can be misleading to the engineers.

After molded the nylon part condition is in dry condition (0 ~ 0.2% moisture content) and conducting the destructive during this time will not represent in actual application condition and normally, molder or manufacturer will let the parts stable for few hours and sometimes will be overnight. This condition will create risk of the part produce during this time in term of validation until destructive testing is conducted to proof the material and process is stable and consistent. But if the testing failure then the parts that has been produced during the waiting time is either quarantine or scrap. This condition created wastage of time, cost and resources. One of the example based on this condition was happened at Steelcase flag chair named Gesture. One of the components of the Gesture chair which is arm bracket made from Nylon with 30% Glass Filled required in process destructive test to verify consistency of material and injection process. Arm Bracket is one of the very critical structural components of the chair.

It required destructive test 1 set in every 3 hours production. In an hour production able to produce 30 sets of arm bracket. The results of the testing inconsistent depending on the time of the day as well as months in the year due to seasonal changed. It makes it worst when the arm bracket tooling located in Malaysia and the other one in Europe have different results because of the different environment and climate. The failure of the testing caused rejection increased from normal standard 3% to 20%. This definitely impact production capacity and waste of money for scrap.

Due to this condition most of the molder/ manufacturer is taken extreme step to soak the nylon material parts into water in a hope that it will fasten the stabilization of the material and conducting the destructive after that to proof the consistency of the process, but the problem of this method caused the parts reached the saturation level where the dimensions will grow 2 – 3% and seen swell from the parts [5]. The soaking could be few hours to a day without any proper understanding and control. It impacted the strength and stiffness of the parts as well it is not representing the actual absorption moisture condition during daily usage of the product. Fitment and function also is the main issues consequence from this soaking method.

During the product development stage, validation testing is required to verify the design, material and process and this is part of getting regulation requirement or certification. Anyway, during validation testing, the engineers always face the challenge with test failure and need very quick judgment to fix the issue. The simple solutions taking by the engineer is over engineered it to make it pass the test and have more margin on safety but most of the root cause is the samples for testing is not in proper control condition. It happened with engineers at Steelcase where the Gesture Arm Mount Bracket having inconsistent test results as mentioned in previous paragraph and the solutions are to increase thickness and grade of material. Furthermore also, engineers are not fully understanding the variations on material and process that been impacted by environmental. Optimization on design is very crucial nowadays for the company to survive as well as reduce wastage of resources, timeline and cost.

Globalization becoming important and common nowadays for cost, resources and material optimization especially in parts/ components supply chain where parts/ components is being produced in one country and supply globally or produced in one region supplying to the other region [6]. This condition has exposed the parts to different environment and weather depending on geographical locations. It makes it worst with the four seasonal countries where it will have extreme weather, cold and dry or hot and humid. This always an issue for nylon components where there are a lot of cases of part breakage during shipment and handling.

Finally, the purpose of this research is to design and develop post conditioned Glass Filled Nylon (Polyamide 6) process control machine and develop the frame work for post conditioned process control where it will propose accurate and better way of handling Nylon material part before destructive test, shipment and handling.

1.3 Project Goals and Objectives

The overall aim of the study is to develop the framework for the process control of conditioning the nylon parts and components after molded before proceeding with testing and evaluation. It develops more in depth understanding on how to handle nylon parts or components after molded especially related to in-process checking and evaluation as well as to verify the design and process itself.

Therefore, this study commences with the following objectives:

1) Analyzing the current industry practice and what it impacts on the part design, testing, timeline and cost using Test Specimen.
2) To design and develop post-conditioned plastic nylon material with Glass Filled Nylon (Polyamide 6) process control machine.
3) To validate and verify the post-conditioned process control machine using test specimen as per ASTM D790.
4) To develop Standard Operating Procedure for process control and evaluation method.

1.4 Significance of This Study

The study outcome significantly contributes towards improvement in productivity and reduction cost during the product development stage as well as manufacturing processes through the post condition process control of Glass Filled Nylon (Polyamide 6). Hence, the results of the study help the designer/ engineer to optimize the design and make good judgment during developing stage. Also, helps injection molder to be able to optimize the process control as well as rejection rate and cost. Overall timeline of developing parts, testing and manufacturing will be able to optimize. Global supply chain will get full benefit where supplying the parts cross regions and continents able to maintain quality and consistency regardless to or from different geographical locations where there environmental could be main effect factor for the Nylon parts. Moreover, indirectly this study helps the company be more competitive globally.

1.5 Scope of the Work

The scope of work is developing and experimental evaluations of the Post condition machine. The specimen is prepared according to ASTM D790 standard and all the testing throughout the experiments are according to ASTM D790. The specimen is produce using injection molding process as the study to improve the post condition process control of Glass Filled Nylon (Polyamide 6).

This project will be accomplished in the following five phases:

Phase 1: Build up test specimen to validate current condition of process control and testing included calculation and simulation

Phase 2: Design and Development of Post Condition Machine

Phase 3: Post Condition process control Machine verification

Phase 4: Experimental Validation with Flexural Modulus Testing and Analysis

Phase 5: Development of New Post Condition Process Control (Standard Operation Procedure)

1.6 Thesis Organization

This study has been divided into 5 phases; **-** Phase 1: build-up test specimen to validate current condition of process control and testing included calculation and simulation, Phase 2: Design and Development of post condition process control machine, Phase 3: Post Condition process control Machine verification, Phase 4: Experimental Validation with Flexural Modulus Testing and Analysis, Phase 5: Development of New Post Condition Process Control (Standard Operation Procedure).

Chapter 1 provides an overview of this study and the objectives derived from problem statements. Chapter 2 presents a comprehensive literature reviews from the relevant areas associated with this topic in this research. Chapter 3 provides the overall research methodology applied in this research. Chapter 4 presents the comprehensive results and discussion from experiments. Finally, Chapter 5 consists of the summary of this research. General conclusions are presented for each phase. Lastly, a recommended future research is presented.

REFERENCES

[1] S. D. Eppinger and A. R. Chitkara, "The Practice of Global Product Development," *MITSloan Management Review*, 2009.

[2] M. Kutz, *Applied Plastics Engineering Handbook*. 2011.

[3] O. J. Blanchard and D. Leigh, "Growth Forecast Errors and Fiscal Multipliers," *American Economic Review*, 2013.

[4] P. R.T.D, A. T.L, and L. A., "Influence of Moisture Absoprtion on Properties of Fiber Reinforced Polyamide 6 Composites," *Materials Research Division, Ris - National Labarotary for Sustainable Energy, Technical University of Denmark*, 2011.

[5] Lanxess, "Conditioning of Parts made From Durethan Polyamide Resin," *Product information*, 2005.

[6] Pedzi Makumbe, Warren Seering and Eric Rebentisch, "Beyond Cost: Product Complexity and the Global Product Development Location Advantage," *International Conference on Engineering Design ICED*, 2009.

[7] Ahmed M. Eltayef, Plastic, 2003.

[8] A. Krzyzak, J. Gaska, and B. Duleba, "Water absorption of thermoplastic matrix composites with polyamide 6," *Scientific Journals Maritime University of Szczecin*, 2013.

[9] M. Kutz, *Handbook of Materials Selection*. Wiley, 2002.

[10] N. Jia, H. A. Fraenkel, and V. A. Kagan, "Effects of moisture conditioning methods on mechanical properties of injection molded nylon 6," *Journal of Reinforced Plastics and Composites*, 2004.

[11] ASTM, "D790-03-Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulation Materials," *ASTM Standard*, 2015.

[12] https://plastics.americanchemistry.com/Lifecycle-of-a-Plastic-Product/, "https://plastics.americanchemistry.com/Lifecycle-of-a-Plastic-Product/." .

[13] M. Gauthier, *Engineered Materials Handbook Desk Edition*. 1995.

[14] K. Robin, "Periodic Table of Polymer," 2008. [Online]. Available: http://www.pcn.org/Technical Notes - Periodic Table of Polymers.htm.

[15] M. Kohan, *Nylon Plastic Handbook*. Cincinnati, OH, 1995.

[16] J. Clark, "Polyamides," *Chemical Guide*, 2015. .

[17] DSM, “Nylon (Polyamides),” *British Plastic Federation*, 2017.

[18] S. Dasgupta, W. B. Hammond, and W. A. Goddard, “Crystal structures and properties of nylon polymers from theory,” *Journal of the American Chemical Society*, 1996.

[19] C. a. Harper and E. M. Petrie, *Plastics materials and processes- A concise encyclopedia*. 2003.

[20] P. K. Vagholkar, “Nylon (Chemistry , Properties and Uses),” *International Journal of Scientific Research*, 2016.

[21] P. R.T.D, A. T.L, and L. A., “Influence of Moisture Absorption on Properties of Fiber Reinforced Polyamide 6 Composites,” *Mater. Res. Div. Ris - Natl. Labarotary Sustain. Energy, Tech. Univ. Denmark*, 2011.

[22] M. F. Arif, F. Meraghni, Y. Chemisky, N. Despringre, and G. Robert, “In situ damage mechanisms investigation of PA66/GF30 composite: Effect of relative humidity,” *Composites Part B Engineering*, vol. 58, pp. 487–495, 2014.

[23] B. Mouhmid, A. Imad, N. Benseddiq, S. Benmedakhène, and A. Maazouz, “A study of the mechanical behaviour of a glass fibre reinforced polyamide 6,6: Experimental investigation,” *Polymer Testing*, vol. 25, no. 4, pp. 544–552, 2006.

[24] S. Barbouchi, V. Bellenger, A. Tcharkhtchi, P. Castaing, and T. Jollivet, “Effect of water on the fatigue behaviour of a pa66/glass fibers composite material,” *Journal Material Science*, vol. 42, no. 6, pp. 2181–2188, 2007.

[25] B. Corporation, “Tensile-Tensile Fatigue Behavior of Short Fiber Reinforced Polyamides,” pp. 2–7.

[26] ISO 291, “Plastics - Standard atmospheres for conditioning and testing.” 2005.

[27] I. S. I. 3167, “Plastic-multipurpose test specimen,” 2014.

[28] I. Carrascal, J. A. Casado, J. A. Polanco, and F. Gutirrez-Solana, “Absorption and diffusion of humidity in fiberglass-reinforced polyamide,” *Polymer Composites*, 2005.

[29] ASTM International, “ASTM D790-03 Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulation Materials,” 2003.

[30] DSM, “Process Datasheet of Recommendations for injection molding,” 2017.

[31] J. Thomason, J.L and Ali, J.Z. and Anderson, “Effects of hydrolysis ageing on performance and dimensional stability of glass-fiber reinforced polyamide 66,” in *Annual Technical Conference - ANTEC*, 2010.

[32] J. L. Thomason, “Structure-property relationships in glass-reinforced polyamide, Part 3: Effects of hydrolysis ageing on the dimensional stability and performance of short glass-fiber-reinforced polyamide 66,” *Polymer Composites,* 2007.

[33] I. Akyar, “Standard Operating Procedures (What Are They Good For ?),” in *Latest Research into Quality Control*, 2012.

[34] PERRITE, “Moisture Conditioning of Vitamide® Nylon,” 2013.

[35] Marmouch Hichem, Orfi Jamel, Benhamou Brahim, “STUDY OF A SOLAR HUMIDIFIER INTENDED FOR THE COOLING OF AIR”, 2006

[36] G. W. Drake, T. W. Hawkins, J. Boatz, L. Hall, and A. Vij, “Experimental and Theoretical Study of,” vol. 30, no. 2, pp. 156–163, 2005.

[37] Faissal Abdel-Hady, Mahmoud M. El-Halwagi, Mohammed Alghamdi, A.K. Mazher, Abdulrahim Alzahrani, "Experimental Study of Humidification and Dehumidification Desalination Process," *International Journal of Engineering and Technology (IJET),* 2018.

[38] O. F. Ac and P. For, “(12) Patent Application Publication (10) Pub. No.: US 2017/0139001 A1,” vol. 1, no. 19, 2017.

[39] Maximus Gladstone, “Design and Optimization of a humidifier for an HDH System," Massachussetts Institute of Technology, 2012.

[40] W. Brace and K. Thramboulidis, “From Requirements to design specifications - A formal approach,” in *International Design Conference - Design 2010*, 2010, pp. 639–650.

[41] C. R. Harrison and K. M. Robinette, “CAESAR: Summary Statistics for the Adult Population (Ages 18-65) of the United States of America,” 2002.

[42] J. Zander, “Ergonomics in machine design : a case-study of the self-propelled combine harvester,” *Biological Journal of The Linnean Society - BIOL J LINN SOC.*, 1972.

[43] Eshan S. Jaiswal, “A Case Study on Quality Function Deployment (QFD),” *Journal of Mechanical and Civil Engineering*, 2012).

[44] Chan L.K. and Ming L Wu, “Quality Function Deployment: A Comprehensive Review of Its Concepts and Methods,” *Journal of Quality Engineering,* 2007)

[45] “Glass Filled Nylon Market Global Forecast to 2024 report”, www.marketsandmarkets.com, 2019

[46] N. Jia and V. A. Kagan, "Mechanical Performance of Polyamides with Influence of Moisture and Temperature –Accurate Evaluation and Better Understanding*",* *Plastics Failure: Analysis and Prevention,* 2001.

[47] Myer Kutz, “Applied Plastics Engineering Handbook”, 2011.

[48] L. Monson, M. Braunwarth, and C. W. Extrand, “Moisture absorption by various polyamides and their associated dimensional changes,” *Journal of Applied Polymer Science*, 2008.

[49] N M Kusaseh, D M Nuruzzaman, N M Ismail, Z Hamedon, A Azhari, and A K M A Iqbal, “Flexure and impact properties of glass fiber reinforced nylon 6-polypropylene composites”, *IOP Conf. Ser.: Mater. Sci. Eng*, 2018

[50] United States Environmental Protection Agency, “Guidance for Preparing Standard Operating Procedures (SOPs),” EPA/600/B-07/001, 2007

[51] Mordechai Lev, Sharon Du Puy, “Humidifier”, United States Patent Application Publication US2012/0222548 A1, 2012

[52] Dean Schuerich, “Basic Humidification 101,” General Aire University, 2009

[53] Yaprak OZEL, Zerrin Funda URUK, “Use of Plastic Materials in Furniture design and production,” *International Journal of Advance Research and View*, 2019

[54] G R E Maries and M Abrudan, “Thermoplastic Polymers in Product Design,” *IOP Conference Series: Materials Science and Engineering*, 2018

[55] Lavinia Ardelean, Christina Borton, Angela Podariu, Laura Rusu, “Manufacture of Different Types of Thermoplastic,” *Chapter 3 Thermoplastic – Composite Materials*, 2012

[56] Tim A. Osswald, Georg Menges, “Material Science of Polymers for Engineers,” 3rd Edition HANSER Publication, 2012

[57] Georg Menges, Edmund Haberstroh, Walter Michaeli, Ernst Schmachtenberg: Plastics Materials Science Hanser Verlag, 2002,

[58] Engineering Plastics, Engineering Materials Handbook, Vol. 2, ASM International, 883 pages, 1998

[59] Nakai A., Ikegaki S., Hamada M. and Takeda A., “Degradation of Braided Composites in Hot Water,” Composites Science and Technology, Vol. 60, 2000

[60] BASF Corporation, “Tensile Properties of Semi – Crystalline Thermoplastics – Performance Comparison under Alternative Testing Standard,” 2000

[61] W. Brace and K. Thramboulidis, “From Requirements to Design specifications – A Formal Approach,” International Design Conference, 2010

[62] Jerzy Smardzewski, Adam Majeswski, “Strength and Durability of Furniture drawers and doors,” *Materials and Design*, 2013

[63] D. J. Delgado & E.M Aspinwall, “QFD Methodology & Practical Applications – A Review,” *Proceeding of the Ninth Annual Postgraduate Research Symposium, The University of Birmingham*, 2003

[64] Elouni Chebbi, James Mars, Mondher Wali, Fakhreddine Dammak, "Fatigue Behavior of Short Glass Fiber Reinforced Polyamide 66: Experimental Study and Fatigue Damage Modeling," Periodica Polytechnica Mechanical Engineering, 2016

[65] Arash Shahin, "Quality Function Deployment: A Comprehensive Review," University of Isfahan, Iran, 2019

[66] Jia N., Kagan V.A., "Effects of time and temperature on the tension-tension fatigue behaviour of short fiber reinforced polyamides," *Polymer Composites,* 1998

[67] D. Kazmer, Injection, Injection Mold Design Engineering, Carl Hanser Verlag, Munich, 2007

[68] G. Erhard, "Designing with Plastics," Hanser Gardner Publications, 2006

[69] Engineering Plastics, Engineered Materials Handbook, Vol. 2, ASM International, Metals Park OH, 1988

[70] Lundgren, J. and Gudmundson, P., "A Model for Moisture Absorption in Cross-Ply Composites Laminates with Cracks, *Juornal of Composite Materials,* 1998

[71] Lundgren, J. and Gudmundson, P., "Moisture Absorption in Glass-Fibre/ Epoxy Laminates with Transverse Matrix Cracks, *Composites Science and Technology,*Elsevier Science Ltd., 1991

BIODATA OF STUDENT

Ir. Abdul Azim is Professional Engineer registered under Board of Engineer Malaysia (BEM) with over 17 years of experience in Product Research, Design and Development. He experienced in designing products, components, parts & system in various industries e.g. Electronics, Automotive, Office Furniture and Manufacturing System. Ir. Abdul Azim started his career with Shimano Components (M) Sdn. Bhd. designing high end crank shaft and gear system for bicycle. He then worked with SONY EMCS Malaysia Sdn. Bhd. for over 6 years in Mechanical R&D TV/LCD division. He is one of the innovators for TV with woofer system. He is also pioneer group in designing LCD for SONY. Currently he works with Steelcase Office Solution as Asia Pacific Product Engineering Manager leading in High End Office Seating from design, development to launching, and life-cycle of furniture and seating category in Asia. He has experienced working around the world, America, Japan, China, India, France, Italy, Taiwan, Vietnam, Korea and Singapore. Hold 6 patents from USA & Malaysia. Ir. Abdul Azim graduated in Mechanical Engineering majoring in Automotive from University Technology PETRONAS. He is a committee member of Mechanical Technical Division, The Institution of Engineers, Malaysia. He is also a Malaysia Industry Standards Committee on Plastics & Plastic Products.

LIST OF PUBLICATIONS

Journal:

Abdul Azim A. A, "New Method on accelerating conditioned condition of Nylon with Glass Filled 30%," *Journal of Materials Processing Technology (Submitted and received with corrections on 7th Feb 19), IF: Q1*

Patents:

Abdul Azim Abdul Rahman, Mohd Khairol ANuar Mohd Ariffin, Mohd Sapuan Salit, Faial Mustapha, "Post Conditioning Machine." Perbadanan Harta Intelek Malaysia, PI 2015702194, issued 6th Julai 2015.

Malaysian Patent Application PI 2015702194, "Post Conditioning Machine" in the name of Universiti Putra Malaysia, International PCT//MY2016/050037, issued 13th June 2016.