

STUDIES ON THERMOFORMING OF MEDIUM GAUGE HIPS SHEETS

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**CENTRE FOR POLYMER SCIENCE AND ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

MARCH 2015

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STUDIES ON THERMOFORMING OF MEDIUM GAUGE HIPS SHEETS

by

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Submitted

in fulfillment of the requirements of the degree of

Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

MARCH 2015

*Dedicated To My
Family*

CERTIFICATE

*This is to certify that the thesis entitled, “**Studies on Thermoforming of Medium Gauge HIPS sheets**” submitted by **Mr. Satish Kommoji** to the **Indian Institute of Technology Delhi**, for the fulfillment of award of the degree, **Doctor of Philosophy**, is a record of bonafide research work carried out by him under our supervision and guidance. This thesis has been prepared in conformity with the rules and regulations of the Indian Institute of Technology Delhi, New Delhi.*

The thesis, in our opinion, is worthy of consideration for award of the degree of Doctor of Philosophy in accordance with the regulations of the Institute. To the best of our knowledge, the results embodied in the thesis have not been submitted to any other University or Institute for the award of any other Degree or Diploma.

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Acknowledgements

A journey is easier and pleasant when you travel together. This thesis is the result of five years of work whereby I have been accompanied and supported by many people. It is a pleasant aspect that I have the opportunity to express my sincere gratitude to all of them.

I express my profound sense of gratitude and veneration to my supervisors, Prof. Anup K. Ghosh and Prof. Naresh Bhatnagar, for guiding me all the way during my PhD tenure. Their constant inspiration and encouragement have been a great motivation for me behind all the work I have conducted. I appreciate their cool composure, patience, enthusiasm, critical comments and generous co-operation throughout this investigation which helped me to tide over the difficult situations. I have learnt from them that failures in all doing should motivate one to work harder. They have always boosted me to put in extra efforts and I am indebted to them what I am today. I am also thankful to them for providing me opportunities to handle some short-term projects and assisting them in few industrial projects which enabled me to fortify my skills.

I express my deep sense of gratitude to my Student Research Committee (SRC) members, Prof. S. N. Maiti, Prof. B. L. Deopura and Prof. P.V. Madhu Sudan Rao, who have monitored my work and provided me the valuable suggestions. I am also thankful to Prof. V. Choudhary, Prof. A. K. Gupta, Dr. J. Jacob and Dr. B. Satapathy who inspite of their busy schedule have always made themselves available for valuable discussions and support.

I would like to extend my thanks to Prof. Bijwe, Industrial Tribology Machine Dynamics and Maintenance Engineering, IIT Delhi and Prof. D. Ravi Kumar, Mechanical Engineering Department, IIT Delhi for their kind support and providing necessary facilities to carry out hot tensile tests in their laboratory. I would like to convey my special thanks to Dr. Shashi Motilal for her support and encouragement.

This work would not be possible without the support and encouragement from my friends, seniors and juniors. My special thanks go to my friend Mr. Srinivas Reddy with whom this journey is pleasant and motivating. My special thanks also go to Dr. Dileep Kumar, Dr. Bala Murugan, Dr. Prakasan and Dr. Sangeetha Nandi who motivated me throughout this work. Also my special thanks goes to Mr. Saikat Banerjee, Dr. Mayank, Mr. Satpal Singh, Mr. Manash Jyoti Kashyap, Mr. Piyush Arant, Ms. Sneh Bharti, Ms. Shikha Jain, Mr. Sanjeev Kumar, Ms. Jutika Goswami, Ms. Priyanka Singh, Mr. Tahir Zafar, Ms. Priya Sonkar, Mr. Sabhapathi Sankar, Ms. Ritima Banarjee and Mr. Arnav Ghosh for their cooperation and moral support during my difficult situation. I would also like to thank Mr. Vineet Soni,

Mr. Amit Singh, Ms. Deeksha Gupta, Mr. Praveen Saini, Mr. Dibyendu Das, Mr. Suneel Kumar, Mr. Jaggi, Mr. Abhishek Gandhi and others, for their love and never ending support through the years.

I would like to thank my friends Suneetha Thota, Narayana Rao Gurram, Santosh Vulluri, Suresh Karusala, Krishna Pravin Nuguri, Chakravarti Chigurupati, Santosh Rayavarapu, Deepak, Janaki Ram and Sumant. I would also like to thank friends outside IIT Delhi Prasanna, Sagar, Gnana Kumari and others for their emotional support and care which has encouraged me immensely.

I owe thanks to laboratory staffs Mr. S. S. Bhatnagar, Mr. Surender Sharma, Mr. Shiv Kant, Mr. Ashok Kapoor, Mr. Devender Singh for their timely help and suggestions. I would also like to convey my thanks to Ms. Suchitra Singh, Ms. Rama Sharma, Ms. Aditi Vasishtha, Ms. Mamta Kumari and Mr. Narender Kumar for their all possible supports.

I wish to acknowledge Reliance Industries Limited, India for providing me financial assistance to carry out my research work smoothly.

I take this opportunity to express my deepest gratitude to my family members specially parents, brother and sisters, for their consistent encouragement, moral support and sacrifice in undertaking this PhD. The love from my parents has always given me the strength and confidence to overcome the difficulties and to accomplish the objectives in my life. They always stood by my side with their worldly wisdom and blessings.

Finally and above all, I would like to thank the Almighty God. It would not have been possible for me to reach at this stage of academic pursuit without his grace.

(Satish Kommoji)

Abstract

Thermoforming is a process in which hot plastic sheet is converted into desired shape by air pressure, vacuum and/or mechanical means such as plugs. During this process the sheet comes in contact with the mold wall progressively and touches the mold wall at various positions at different times. As a result the thickness of the formed parts is not same throughout the formed part from top to the bottom giving a thickness profile. The quality of the formed part also depends on formability of the material. Forming of the sheet is carried out in their rubbery region of the plastic sheets. In this region the modulus of the sheet will be low and allows stretching of the sheet to higher elongations. The broadness of the rubbery plateau determines the forming temperature window and the uniformity of the stretching during forming determines the uniformity of wall thickness distribution. The ability of the plastic sheet that can be stretched uniformly in their softening temperature range depends on its molecular structure and varies from polymer to polymer. Amorphous polymers have broad temperature window and are better thermoformable than crystalline polymers. The crystalline polymers enter in to liquid state from a rigid or solid phase in a very narrow forming temperature range. Due to this crystalline polymers are difficult to thermoform compared to amorphous polymers. However, the formability of the polymers can be improved by the addition of fillers, blending of polymers or by modification of the molecular structure of the polymers.

In this work we used Dynamic Mechanical Analysis and Hot tensile tests to identify the forming temperature range for HIPS-M1 and HIPS-M2. As the thermoforming of amorphous polymers is carried out above the softening temperature, the T_g of the samples was measured from dynamic

mechanical analysis data. The breadth of the rubbery region in the storage modulus curve was taken as the forming temperature for the samples.

Thermoforming conditions such as sheet temperature, possible draw depth and the mold/plug speed were simulated using the hot tensile tests. Oven temperature was correlated with the sheet temperature, mold/plug speed with the strain rate and draw depth was correlated with the highest possible elongation. The variation of elastic modulus and uniformity in draw ratios distribution were considered in selecting the sheet temperature and forming temperature range. The draw ratios were measured from the stretched samples. It was found that the draw ratios shown broad and shallow shaped curve at temperature range of 110 to 130°C for HIPS-M1 and 120 and 130 for HIPS-M2. At a oven temperature of 140°C, the inverted “V” shaped curve was observed for both the materials indicating above this temperature the thickness distribution may be non-uniform.

In the investigation of thermoforming performance of the sheets, the sheets were thermoformed at sheet temperatures of 120, 130 and 140°C. The molds used were of depth of draw of 70, 110 and 165mm at constant draft angle of 6° and variation of draft angles of 3, 6 and 9° at constant draw depth of 110mm. The effect of sheet temperature, draft angle and depth of draw was studied. The measured wall thickness was analysed through dimensionless thickness distribution, average thickness and thickness variation coefficient.

The results indicate that sheet temperature has not much influence on dimensionless thickness distribution. However, the sheet temperature coupled with draft angle has influence on dimensionless thickness distribution in the slant length of the mold. With the change in draft angle of the mold the dimensionless thickness distribution profile is changing due to the

difference in the forming sequence especially in the slant length region. Constant thickness regions were found with the increase of draft angle from 3 to 9°.

Study of the effect of draw depth showed that the difference in dimensionless thickness is increasing from a position before the corner to the position immediately after the corner i.e. at the beginning of the slant length. The values were found to be 0.10, 0.28 and 0.39 respectively for 70, 110 and 165mm. This is an indicative of thinning of the product at the top of the slant length and forms discontinuity between the base and the side wall. The corner thickness values for these molds were 0.69, 0.64 and 0.76. The increase in corner thickness for 165A6 is due to the drawing of the material towards corner from the base during forming. Minimum thickness occurred for these molds at bottom corner for 70 and 110mm but for 165mm was at the beginning of the slant length. The minimum thickness values were 0.74, 0.53 and 0.27 respectively for draw depths of 70, 110 and 165mm.

Sheets were successfully thermoformed up to the draw depth of 165mm with draft angle of 6°. With the increase of the depth of draw the dimensionless thickness decreased significantly.

With increase of temperature and draft angle, improvement in average thickness and decrease in thickness variation coefficient can be observed for HIPS-M1 which is beneficial for thermoformed products. But with the increase of draw depth decrease in average thickness and increase in thickness variation coefficient can be found. Similar results were also observed for HIPS-M2.

To study the intermediate stages of vacuum forming, the vacuum time was varied keeping the sheet temperature and vacuum level constant at 150°C and 10mmHg respectively for different mold configurations. The depth of draw and the top diameter of the mold was kept constant but varied the draft angle. The depth of draw used was 110 mm and the draft angles used were of, no

draft angle (cylinder), 3, 6 and 12°. The local wall thickness at various positions was measured and plotted against the position from centre. The results were analysed using the wall thickness distribution and variation of local wall thickness, such as minimum thickness, thickness difference between the corner and immediately after the corner, corner thickness and base average thickness.

The results indicated that with the increase of vacuum time the draw depth is increasing for all the molds and with the increase of draft angle the uniformity of wall thickness distribution is increasing. At lower draft angles and at lower vacuum times, mold mark was observed which is discontinuity in the wall thickness from the base and the slant length. With the increase of draft angle the mold mark was found to disappear due to better material distribution.

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