Available online at www.sciencedirect.com
ScienceDirect
Procedia Materials Science 6 (2014) 361 – 367
Procedia Materials Science
www.elsevier.com/locate/procedia

3rd International Conference on Materials Processing and Characterisation (ICMPC 2014)

Investigation of Melt Flow Index and Impact Strength of Foamed LLDPE for Rotational Moulding Process

PL.Ramkumar[a*], D.M.Kulkarni[b], V.V.R Abhijit[c], Aditya Cherukumudi[d]

[a,b] *Faculty, Department of Mechanical Engineering, Bits Pilani-Goa Campus, Zuari Nagar, Goa -403726, India*

[c,d] *Students, Department of Mechanical Engineering, Bits Pilani-Goa Campus, Zuari Nagar, Goa -403726, India*

Abstract

Rotational molding of foamed polyethylene has increasingly become an important process in industry because of its thicker walls, low sound transfer, high stiffness and good thermal insulation. However, the foaming process of polyethylene during rotational molding has not been well studied. The focus of thisarticle is to assess the rotomoldability of foamed polyethylene and to investigate how LLDPE foam influence the process of rotational molding and the final product quality. Rotational molding experiments are carriedout in a laboratory scale biaxial machine. Impact tests and melt flow property are performed on the rotationally molded parts. It is found that the MFI and impact strength of rotomoulded product increases as the foam percentage increases up to 6% after which both decreases. Therefore it is concluded that 6% of foam is the optimum level to obtain sufficient melt flow index and better impact strength.

Selection and peer review under responsibility of the Gokaraju Rangaraju Institute of Engineering and Technology (GRIET)

Keywords: Melt Flow Index; Impact strength; Foamed LLDPE; Rotational Moulding

1. Introduction

Rotational moulding is one of the fastest growing polymer processes when compared with other techniques in the plastic industries. The products obtained from rotational moulding find wide applications in various fields like agriculture, storage tanks, industrial equipments, medical devices, material handling, road/highways, automobiles, etc. Different resins like plastisols, polyethylene, polycarbonate, acetate butyrate, polyamide, elastomers, polyurethane, polypropylene, ethylene vinyl acetate, fluorocarbons even nylon can be rotomoulded, LLDPE has been found by Crawford and James (2002) to have the largest consumption in rotational moulding industry. It is due

* Corresponding author. Tel.:
E-mail address: ramkumarpl@goa.bits-pilani.ac.in

Selection and peer review under responsibility of the Gokaraju Rangaraju Institute of Engineering and Technology (GRIET)
doi:10.1016/j.mspro.2014.07.046

to its unique melt flow property, broader processing window, excellent thermal stability and good mechanical properties.

The rotational molding technique has been developed for more than three decades. However, the research efforts in rotational molding have been relatively few, when compared to other polymer processing methods such as injection molding and extrusion (Tadmor and Gogos, 2006). An important contribution in the development of rotational moulding technology has been made by Crawford and James (2002), Crawford (1996) and Crawford (2003). Few researches like Antonio and Alfonso (2004), Olinek et al., (2005), Spence and Crawford (1996) and Laws (2004) have focused on powder properties in rotational moulding process. Mechanical properties of the rotomoulded parts have been largely investigated by Van et al., (2001), Pick and Harkin-Jones (2003) and Pick et al., (2003). Powder process sintering was observed by Liu (1998) and heat transfer modelling of rotational moulding process was deeply investigated by Crawford (1989) and Nugent et al (1992). As a subsequent improvement in rotational moulding process, Spence and Crawford (1996) have shown that a low viscosity material produces products in which bubbles or surface pores are not observed. Also overheating can reduce the bubbles, but it may tend to have an adverse effect on the mechanical strength of the product as they are greatly reduced because of thermal degradation as well as overheating results in longer cycle times reducing the efficiency of the process. According to Bharat InduChaudhary et al (2001) the weight percentages of the low molecular additives like mineral oil, glycerol monostearate are added to polyethylene as sintering enhancers which results in decreased melt viscosity and elasticity at low shear rate.

Rotational molding of foamed polyethylene has increasingly become an important process in industry. It has been used to produce parts in various applications such as furniture, toys and novelties, and flotation and drink containers (Klempner and Frisch, 1991). Foamed structures provide several advantages in thermoplastic products, including: a lightweight, excellent strength–weight ratio, superior insulation abilities; and energy absorbing performance (shock, vibration, and sound).

Few works has been conducted in knowing the mechanisms and property of foams. Guobin et al (2004) has studied the mechanisms of foaming using LLDPE foams in rotational moulding. A similar study has been conducted by Remon et al (2008) on the foaming mechanism of polyethylene blown by chemical blowing agent under ambient pressure. Archer et al (2002) has studied the foaming characteristics of mettalocene-catalyzed LLDPE for rotational moulding. He observed that metallocene based polyethylene produces foam with lower density than conventional polyethylene. A study on the effect of crystallinity and morphology on microcellular foam structure was carried by Saeed et al (1996). Author varied crystallization and morphology by controlling the cooling rate. He predicted that polybutylene (PB), polypropylene (PP) and polyethylene terphalate (PET) has a higher crystallinity at a lower cooling rate.

From the literature survey, one can understand the importance of melt characteristics and final product quality in rotational moulding. Available research greatly emphases on the foaming mechanism and effect of addition of endothermic bellowing agent on the base thermoplastic materials in terms of its properties. But the melt characteristics and impact property of the final foamed rotomoulded product are also an important parameter which should be equally investigated for ease of processing and strength of the product. In this study the melt flow indexand impact strength investigation of foamed LLDPE where performed for various foam percentage ranging from 2 % to 10 % (2, 4, 6, 8&10%).

2. Experimental work

2.1 Material

The resin used in this study was linear low density polyethylene of grade R350 A 42 having density of 935 Kg/cm^3 supplied by GAIL india limited. The above mentioned grade is recommended for manufacturing of water storage tanks, automobile parts, and boats etc. The foam used is linear low density polyethylene foam. Before the experiments are done the foam powder is first blended with the linear low density polyethylene by a dry mixer.

2.2 Equipment used

2.2.1 Melt Flow Indexer

Melt flow index of the LLDPE foam mixer has been checked with dynisco melt flow indexer as per ASTM D 1238. Melt Flow Index is the output rate (flow) in grammas that occurs in 10 minutes through a standard die of

2.0955 ± 0.0051 mm diameter and 8.000 ± 0.025mm in length when a fixed pressure is applied to the melt via a piston and a load of total mass of 2.16 kg at a temperature of 190°C. Melt flow index is an assessment of average molecular mass and is an inverse measure of the melt viscosity; in other words, the higher a MFI, the more polymer flows under test conditions. Knowing the MFI of a polymer is vital for anticipating and controlling its processing. Three samples of LLDPE foam mixture (2, 4, 6, 8&10%) was tested for its melt flow property and recorded. Fig 1 gives the details of experimental setup.

Fig. 1.Dynisco Melt Flow Indexer

2.2.2 Rotational Moulding Machine

Rotationally moulded products are produced on a lab scale electrically heated biaxial rotational moulding machine as shown in Fig 2 (a) using an stainless hollow mould having square cross-section with polished internal surface as shown in Fig 2 (b). Powder weight of 160 g mixed with required weight percentage of LLDPE foam is used to produce rotational moulding product.

Fig. 2.(a) Biaxial Rotational Moulding Machine; (b)Stainless Steel Hallow Mould

2.2.3 Impact Testing Machine

Moulds were subjected to impact testing to know the effect foam percentage on impact strength of the rotomoulded product. impact test specimens are made as per the ASTM standard D 256. The specimen dimension being 63 x 3 x 12.7 mm for impact. Tests are conducted under normal condition in a bench impact testing machine as shown in Fig 3.

Fig. 3.Izod Impact Testing Machine

2.3 Experimental Procedure

Before the experiments are done, Pre weighted quantity of 160g of LLDPE powder is blended with 6 wt % of LLDPE foam by a dry mixer. The internal mould surface of the mild steel mould is coated with a silicon oil based mould release agent. The different process variables are set for different run orders. LLDPE foam mixer is then placed inside the mould. The mould is then bolted in to the oven where it underwent a biaxial rotation which makes the powder to spread in the internal surface of the mould. After certain temperature the thermoplastic powder and foam mixer melts and sticks to the wall of the mould. The process is continued till the required thickness of the plastic part is obtained. After getting the required thickness, mould is cooled and demoulded. From the rotomoulded products, the impact test specimens are prepared as per ASTM standard D256. Impact tests were performed in an izod impact testing machine. 4 J pendulum was used to evaluate their ability of energy absorption.

3. Result and Discussion

3.1 Melt Flow Index

The melt flow index is one of the most common parameters specified when describing a polymer. It is convenient method for expressing important flow characteristics of polymer, which clarifies the way in which the polymer can be processed.

As observed from Table 1that the MFI value increases as the foam percentage increases up to 6% after which MFI value decreases. As observed the maximum value of melt flow index is obtained at 6% of foam mixed with LLDPE. High melt flow index at 6% indicates ease of melting and easy to process. But, the material with this behavior would have shorter chains and therefore low molecular weight and lower viscosity.

As the foam % is increased further from 6% to 8% (or) 10% the MFI value decreases as shown in Fig 2. The decrease in MFI value increases the molecular weight. This intern may affect some of the key physical and mechanical properties of the polymer such as tensile strength, creep resistance and liquid temperature etc. The reason is primarily due to intermolecular interactions. The two most common of these interactions are entanglement and secondary bonding. Entanglement is simply the mutual wrapping of polymer chains around each other. Higher molecular weight implies longer polymer chain and longer polymer chain implies more entanglement. When the polymers are highly entangled, they resist sliding over each other. More additional energy must be put in to system to cause the molecules to move relative to each other. The additional energy is seen as a higher softening temperature and higher mechanical property. Secondary bonding has much the same effect as entanglement of the polymer. The underlying purpose of determining melt index is to estimate the ease of melting of polymer. Therefore, attention of moulder lie on selecting optimum value of MFI which leads to optimum mechanical property and processability. When the foam percentage is increased beyond 6% (or) below 6% the processability is greatly affected with the improvement in mechanical property. The selection of MFI in this case greatly depends up on the moulders requirement and the percentage of improvement in mechanical property that is obtained when foam percentage is increased.

Table 1. Melt Flow Index for Varied Foam Percentage.

Foam Percentage	Average Weight (g)	Average Melt Flow Index(g/10min)
2%	0.1481	4.443
4%	0.1508	4.524
6%	0.1563	4.8
8%	0.1527	4.58
10%	0.1491	4.47

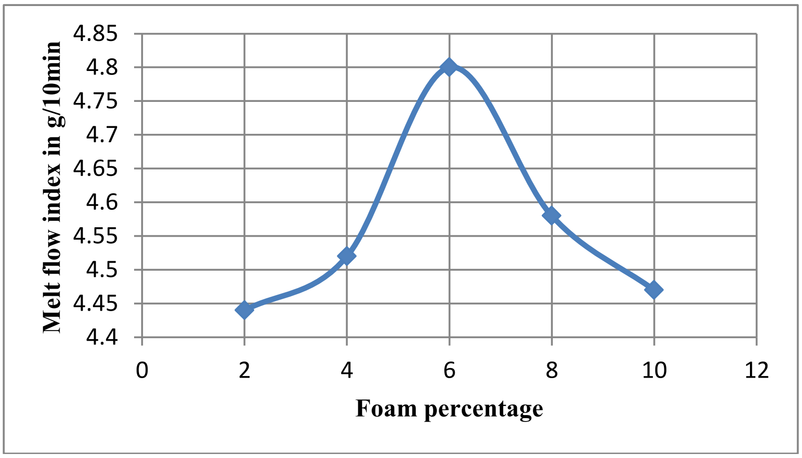

Fig. 4. Variation of Melt Flow Index with Respect to Percentage of Foam in LLDPE

3.2 Impact Strength

Impact tests were performed at room temperature on rotomolded parts in order to evaluate their ability to absorb energy. Impact specimens are prepared as per the ASTM D256. The specimen dimension being 63 x 3 x 12.7 mm for impact.Impact tests were performed in typical Izod impact testing machine. A pendulum of maximum energy capacity of 4 J was used to evaluate the energy absorption ability of the material. To account for process variability during experimentation, three replications were taken for each experimental run. Thus three samples of impact specimens were cut and subjected to testing.

The results of impact testing are as shown in Fig 5. These results reveal that impact strength gradually increase as the foam percentage is increased from 2% to 6 % and falls after 6%. A closer look into the process gives more insight into this phenomenon. The increase in impact strength as the foam percentage is increased from 2 to 6 may be attributed to two different facts. The one being, as the foam percentage is increased the thickness of the part increases, the ticker walls of the product resists the impact force. The other being, in the foaming as the foam disperse densely and many tiny bubbles have popped up and shrunk after a short period of time. Once the temporary equilibrium has been reached, the gas molecules inside the tiny bubble will not diffuse in to surrounding polymer. The high pressure gas in the nuclei causes the cells to expand, while a certain amount of gas tends to dissolve in the polymer matrix because of the pressure difference. The rate at which the cells grow is limited by the rate of gas generation from the foaming agents, the rate of gas diffusion to the polymer matrix, and the stiffness of theviscoelastic polymer matrix. In case of addition of foam percentage from 2 to 6 %, the gas generated is not sufficient enough to support the cell growth due to which foams with a smaller cell size and a narrow size distribution accompanied by a uniform foam structure is formed, which ultimately results in increase in impact strength.

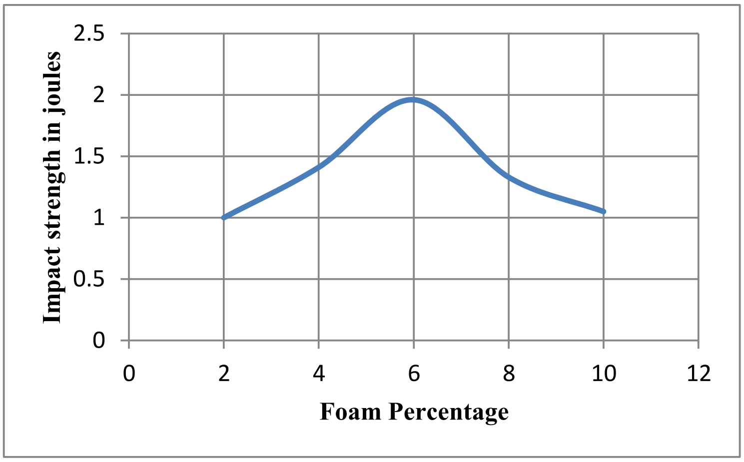

Fig. 5. Variation of Impact Strength with Respect to Percentage of Foam in LLDPE

As the foaming percentage is increased from 6 to 10 the impact strength reduces this reduction in impact strength can be attributed to two different facts. The first one being, the developed finer cells get destroyed because of increase in foaming content. Since the foam percentage is more, the amount of gas dissolved increases resulting in a cell growth. Adjacent cells will be in contact with each other eventually. These neighboring cells will first share a common wall in a polyhedral shape of cells and the thickness of the wall will decrease as the void fraction increases. In other words, the drainage of the polymer in the wall occurs as the foam density decreases. With the polymer drainage in the cell wall, the instability of the cells to coalesce increases because the strength of the cell wall decreases. This increased amount of dissolved foam induces a greater thermodynamic instability resulting a courser and non uniform foam structure. This ultimately reduces the impact strength of the product. The other reason being, since the density of foamed parts decreases and cell sizeincreases with increased foaming content. Large size cells supported by thin cell walls collapse as they aresubjected to external impact forces. The impact energy that foamed parts could absorb therefore decreased (Klempner and Frisch, 1991).

4. Conclusion

This article has assessed the rotomouldability of polyethylene foams and investigated the effect of foam content on melt flow index and impact strength of rotationally moulded parts. Based on the experimental results, the following conclusions may be drawn:

1. Melt flow index increases with increase in foaming content until 6%, after which it decreases.
2. Higher melt flow index at 6% indicates ease of melting and easy to process. But the material with this behavior would have shorter chains and therefore low molecular weight and lower viscosity.

3. Impact strength increases with increase in foaming content until an optimal foaming content is reached, where the impact strength is maximum after which it reduceses.
4. Using the experimental results it is predicted that 6% of foam was the optimum level to obtain sufficient melt flow and better impact strength.

References

Antonio Greco, Alfonso Maffezzoli, 2004. Powder-Shape Analysis and Sintering Behavior of High-Density Polyethylene Powders for Rotational Molding. Journal of Applied Polymer Science 92, 449–460.

Archer, E., Harkin-Jones, E., Kearns, MP., Crawford, RJ., Fatnes, AM., 2002. An Investigation of the Rotational Moulding of Foamed MetallocenePolyethylenes. Rotation 11, 27–29.

Bharat InduChaudhary, Elizabeth Takacs, John Vlachopoulos, 2001. Processing Enhancers for Rotational Molding of Polyethylene. Journal of Polymer Engineering and Science 41, 1731–1742.

Crawford, RJ., 1996. Recent Advances in the Manufacture of Plastic Products by Rotomoulding. Journal of Material Processing and Technology 56, 263–271.

Crawford, RJ., 2003. Vision 2020 through 2002. Rotation 12, 16-19.

Crawford, RJ., James, LT., 2002. "Rotational Molding Technology", Crawford, R.J (Ed.). William Andrew Publishing, Norwich, England.

Crawford, RJ., Nugent, P., 1989. Computer Simulation of the Rotational Moulding Process for Plastics. Journal of Plastics and Rubber Processing and Application 11, 107-124.

D.Klempner, K.C.Frisch, 1991. "Handbook of Polymeric Foams and Foam Technology", Klempner, D. (Ed.). Hanser, New York.

Guobin Liu, Chul Park, John Lefas, 2004. Rotational Moulding of Low Density LLDPE Foams. Journal of Polymer Engineering and Science 38, 1997–2009.

Klempner, D., Frisch, KC., 1991. "Handbook of Polymeric Foams and Foam Technology", Klempner. Hanser, New York.

Laws, RD., 2004. An in-Depth Look at the Influential Factors of the Dry-Flow/Bulk-Density Test Used in the Rotomoulding Industry. Rotation 10, 12–14.

Liu, SJ., 1998. Sintering Rheology of Semi -Crystalline Polymer. Journal of International Polymer Processing 13, 88-90.

Nugent, P., Crawford, RJ., Liang, Xu., 1992. Computer Prediction of Cycle Times During Rotational Moulding of Plastics. Journal of Advanced Polymer Technology 11, 181-191.

Olinek, J., Anand, C., Bellehumeur, CT., 2005. Experimental Study on the Flow and Deposition of Powder Particles in Rotational Moulding. Journal of Polymer Engineering and Science 45, 62–73.

Pick, ELT., Harkin-Jones, 2003. Understanding the Impact Behavior of Rotomoulded Linear Low Density Polyethylene. Rotation 13, 26–30.

Pick, L., Harkin-Jones, E., Kearns, MP., Crawford, RJ., 2003. A Comparison between the Impact Performance of Rotationaly Moulded Linear Low Density Polyethylene with Metallocene polyethylene. Rotation 9, 21–25.

Remon Pop-Iliev, Ning Dong, Donglai, XU., Chul B Park, 2008. Visualization of the Foaming Mechanism of Polyethylene Blown by Chemical Blowing Agents under Ambient Pressure. Journal of Advanced Polymer Technology 26, 213-232.

Saeed Doroudiani, Chul B Park, Mark Kortschot, 1996. Effect of the Crystallinity and Morphology on the Microcellular Foam Structure of Semicrystalline Polymers. Journal of Polymers Engineering and science 36, 2645-2662.

Spence, AG., Crawford RJ., 1996. The Effect of Processing Variables on the Formation and Removal of Bubbles in Rotationally Moulded Products. Journal of Polymer Engineering and Science 36, 993–1009.

Spence, AG., Crawford, RJ., 1996. The Effect of Processing Variables on the Formation and Removal of Bubbles in Rotationally Moulded Products. Journal of Polymer Engineering and Science 36, 993–1009.

Tadmor, Z., Gogos, KC., 2006. "Principles of Polymer Processing", Zehev Tadmor (Ed.). 2nd Ed. John wiley and sons, New York, pp. 753.

Van Hooijdonk, JPF., Mark Kearns, P., Armstrong, CG., Crawford, RJ., 2001. Effect of Processing Conditions on the Properties of Rotationally Moulded Polypropylene. Rotation 6, 28–30.