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Processing and characterization of HDPE and MDPE processed by rotational moulding

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ABSTRACT

Rotational moulding otherwise called as roto moulding is a process used to produce hollow plastic products with nearly stress free objects with the help of a bi axial rotational moulding machine which rotates the mould in two axes with minimum speed of rotation. Plastic granules pulverized into fine powders are used to produce hollow parts such as water tanks, fuel tanks, kayak boats, refrigerated panel etc. The present work investigates the mouldability of High Density Poly Ethylene (HDPE) and Medium Density Poly Ethylene (MDPE) powders by rotational moulding process. A lab model roto moulding machine has been fabricated. There are two rotating frames – an inner and an outer frame – both rotating about two mutually perpendicular axes. The driving torque is given by a motor. The machine was designed to accommodate a rectangular shape stainless steel mould. Both MDPE and HDPE were processed at three different internal air temperature and the mechanical properties were estimated as per ASTM standards. Both tensile and impact strength were observed to be improved by the increase in internal air temperature. Hardness values observed shows no significant effect on internal air temperature. The MDPE products showed higher impact strength while HDPE products showed higher tensile strength. The morphology of the MDPE and HDPE powders and the microstructure of the products were studied under optical microscope.

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1. Introduction

Rotation moulding is an innovation in the field of polymer processing techniques since it is the only process which produce zero stress products and ultimately the process find its application in the manufacturing of the most complicated closed structure without any attachment in between. The most significant limitation is the shortage of materials that are amenable to rotational moulding. In theory it should be possible to rotomould any plastic that melts when heated, and goes solid when cooled. In practice, most plastics degrade during rotational moulding. This is mainly due to the adverse needs placed on the polymer due to the prolonged periods at high temperatures. The present work investigates the rotomouldability of MDPE and HDPE at different processing conditions with the help of a handmade lab model rotomoulding machine fabricated to meet the required processing conditions. The previous works in the field of rotational moulding recommends that if the formation of bubbles in the rotomoulded parts are predominant, that will directly affect the surface finish and this can be eliminated to some extend by pressurised moulding techniques in which inner mould surface is pressurised by external means [1–6]. It was also published that the internal mould pressurization can reduce the overall heating time and hence reduces the overall processing time in rotational moulding [13]. The heating time in the cycle was determined experimentally and simulated with COSMOL for a product thickness of 5 mm and was found to be 24.5 minutes. The studies suggested that the same methodology can be adopted for the different product thickness and could be re calculated as such as per the needs [7]. The use of anti oxidants in rotomoulding powder grades can modulate the degradation process and this can maintain the recrystallization process for an enhanced range of heating schedule which results in obtaining finer structures and enhanced impact properties [8,9]. Studies on the incorporation of natural fibers in rotomoulded parts have been initiated from different parts of the world and the results shows a significant improvement in mechanical properties on addition of natural fibers. But the bubble formation and surface roughness

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are the difficulties in commercial production of natural fiber reinforced polymer composite rotomoulded products [11,12].

2. Materials and methods

2.1. Experimental setup

A Bi-axial type lab model rotational moulding machine was fabricated to conduct experiments. The machine was made with hollow mild steels rods. There are two rotating frames – an inner and an outer frame – both rotating about two mutually perpendicular axes. The driving torque is given by a motor, first to the outer rotating frame via a chain link that connects the motor axis to the machine axis. Then from outer frame, torque is transferred to the inner rotating frame by a chain and bevel gear arrangement. Roller bearings are provided wherever necessary to reduce the friction during rotation. The bevel gears have a speed ratio of 4:1which is most suitable for cuboidal moulds. All the sprockets connecting the chain have same number of teeth. So they do not give any speed reductions. A 12 V 7Amps DC battery is the source of power for the machine. The mould is clamped at the center of the inner frame by a G – Clamp. The speed of rotation can be adjusted between 30–50 rpm. The mould is heated in a hot air oven with sufficient temperature. Once heated, the mould is transferred immediately to the machine and the rotation process begins till the plastic solidifies and cools to room temperature. Heating temperature is varied from 220 °C to 240 °C and cooling time is fixed as 30 minutes.

2.2. Materials used

Polymer material used for rotational moulding must possess certain characteristics. They must be capable of being produced economically as a free flowing powder. Secondly, as plastic is heated, it should transform from the solid state to molten state relatively quickly so as to avoid clumps being formed inside the rotating mould. Plastic melt must also have ability to coat the mould surface evenly. However plastic melt must not be of low viscosity or flow too freely in the melt form. It is also important that the thermal stability of the melt is such that it can withstand long times at elevated temperatures without degradation. Polyethylene is one such material which has all these properties needed for rotational moulding. In the present work, Medium Density Polyethylene (MDPE) and High Density Polyethylene (HDPE) are used for rotational moulding process. The Table 1 shows the various properties of MDPE and HDPE.

2.3. Mould release agent

During rotational moulding, the metal wall becomes hot and the surface of the powder particles becomes tacky and they stick to the mould wall and to each other. It is essential to apply mould releasing agent to the mould to prevent sticking of polymer to mould and thus helps in easy removal of the part. A silicon type mould releasing spray of make Stella was used for all experiments. The spray was applied from a distance of 12 inches for even coating. One pass evenly over the mould surface gives a film less than one micron thick and ensure penetration onto the deepest cavity.

2.4. Mould for rotational moulding

The mold for the rotational moulding was fabricated in such a way that samples conforming to the standards can be obtained for testing. Initially a CAD model of the mould was created according to the required dimensions in PTC Creo software. The mould is cuboidal in shape with bottom and top halves. They are tightened using 6 mm screws which are symmetrically spaced around mold. The exact dimensions of the mould are shown in Table 2. The mold is fabricated from 304 Grade stainless steel sheet with a gauge of 20. A 20 gauge sheet has a thickness of 0.952 mm. Stainless steel material was chosen to prevent corrosion of the mold in long run. Since stainless steel has low thermal conductivity, the thickness was kept small.

2.5. Experimental procedure

The shape of the product made by rotational moulding depends on the coalescence and sintering of the granular particles. During moulding, sufficiently high temperature must be applied for long time to achieve correct viscous and elasto – rheological characteristics to promote coalescence. But polymers are characterised by relatively low thermal stability. To get successful rotational moulded part, an acceptable compromise between the two is needed. Several trials were preformed initially to find the suitable range of process parameters. After that experiment was conducted in this range of values and the products were developed. Three levels of temperatures were chosen and the heating time was kept constant as shown in Table 3. The quantity of the powder required for 3 mm wall thickness was estimated as per standard formulae. The objective of the first step in rotational moulding is to elevate the polymer to temperatures where the powder particles can stick together and adhere to mould wall. For this purpose mould is kept in an electric oven for the set time and temperature.

3. Results and discussions

3.1. Morphological characterisation

The micrograph of the MDPE and HDPE powders used for the rotational moulding was taken with an optical microscope at varying magnification to the study the influence of particle shape and size on the moulded part. The microscope is of make OLYMPUS, having magnifications of 50 X, 100 X and 500 X. In order to get the powder micrograph, the powder was placed over a paper covered with an OHP sheet. Fig. 1(a & b) shows the morphology of the MDPE and HDPE powders used for the moulding process. From these images, it is observed that the powder particles possess irregular shape and size. The rotationally moulded specimen is also analyzed inorder to get the size of pores and surface cracks.

Pores are visible on the surface of all the products. These are formed when the air trapped in the melt move to the surface

Table 1
Properties of MDPE and HDPE materials.

Properties	MDPE	HDPE
Melting temperature	120 – 125 °C	126–135 °C
Glass transition temperature	110 °C	110 °C
Density	0.935 g/cm^3	0.96 g/cm^3
Melt flow index	4 g/10 min	2.6 g/10 min

Table 2
Specifications of the mould.

Specifications	Value/Number
Material	Stainless Steel 304
Chamber Length	17 cm
Chamber Breadth	8 cm
Chamber Height	3 cm
Screws	6 mm

Table 3
Process parameters used for experiment.

Material	Temperature(°C)	Heating time(min)	Powder quantity(g)
MDPE	220	20	112
MDPE	230	20	112
MDPE	240	20	112
HDPE	220	20	132
HDPE	230	20	132
HDPE	240	20	132

during the moulding process. It is possible to conclude that the pores are formed in large number due to irregular particle shape of polymer powder used for molding. The irregular shape of powder leaves many vacant spaces for the air particles which creates bubbles in the melt during heating. Some of these vacant spaces are filled by polymer melt by capillary action. Some of them remain and these bubbles appear as pores on the surface. Pores are visible on the product surface processed at all temperatures. But the pores are comparatively smaller in HDPE products. This can be due to the difference in material characteristics like melting point, melt flow index and viscosity. The pores on the surface affect the surface texture while bubbles inside the part affect the mechanical properties.

3.2. Mechanical characterization

Mechanical characterization tests were performed on products as per ASTM standards to find out tensile strength, impact strength, hardness and density. The test specimens were taken from the top and bottom surface of the cuboidal product. For each property, five samples were tested and the average value was considered for comparison.

Density is measured according to ASTM D792 standard. Two samples were taken from each product and the results are averaged. The measured value of density of each component is shown in the Fig. 2. The density is calculated according to the formulae.

Density = [a / (a + w − b)] * 0.9975 g/cc

a – apparent mass of specimen, without wire or sinker, in air, b - apparent mass of specimen completely immersed and of the wire partially immersed in liquid.

w – apparent mass of totally immersed sinker and of partially immersed wire.

At higher temperature, the voids and bubbles are completely filled by the polymer melt during the densification. Increased temperature aids in densification process as seen in Fig. 2. HDPE products show higher density because, the HDPE molecules have lesser branching which helps in better packing in the molecular level.

Shore D scale has been used to measure hardness as per ASTM D2240 standard. The durometer is a small apparatus with a needle at bottom. The shape and size of the needle depends on the scale chosen. The needle is pressed on the sample and a standard value of force is applied through needle on to sample. Then the device measures the hardness as a value between 0 and 100. Five samples were taken from each product and the results are averaged. The measured value of hardness of each component is shown in the Fig. 2. On an average, the crystallinity of HDPE is 75% and that of MDPE is 55%. So HDPE products showed higher hardness than the MDPE products. The hardness values are dependent on the material and are not much related to temperature.

The impact test was performed as per ASTM D256 standard. The notch is made at the midpoint of the sample with 45 degrees included angle. Two samples were taken from each product and the results are averaged. The measured value of impact strength of each component is shown in the Fig. 2.

From the Fig. 2 it is known that the impact strength of MDPE product is greater than the HDPE product. The melting point of MDPE is lesser than the HDPE. So MDPE undergo better densification compared to HDPE when subjected to same temperature. With increased densification, the number and size of bubbles in the

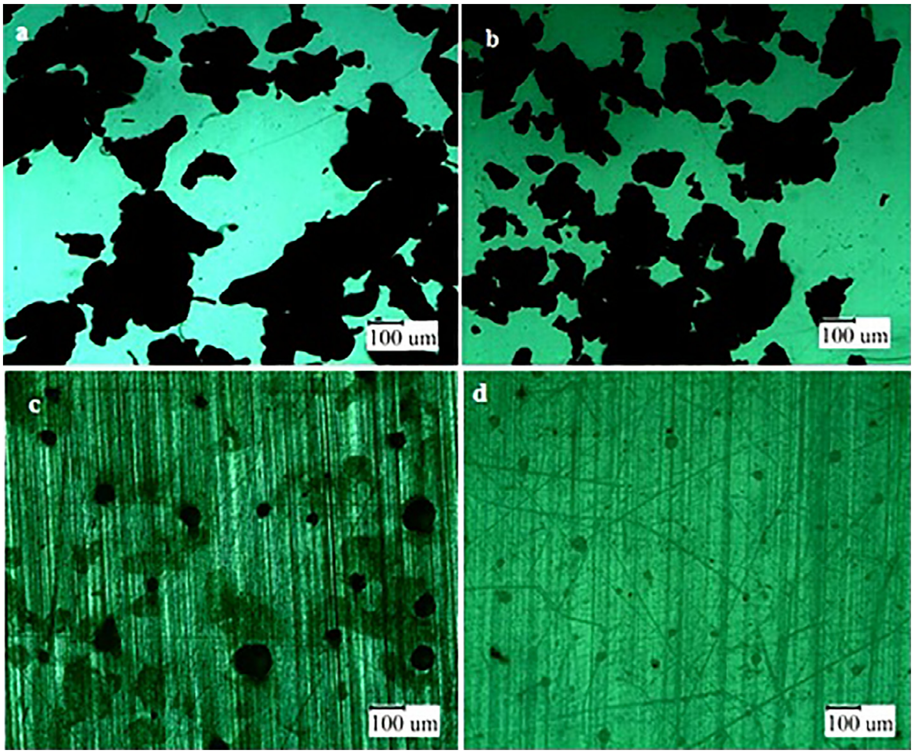

Fig. 1. Morphology of (a)MDPE powders (b) HDPE powders (c) MDPE rotomoulded surface (d) HDPE rotomoulded surface.

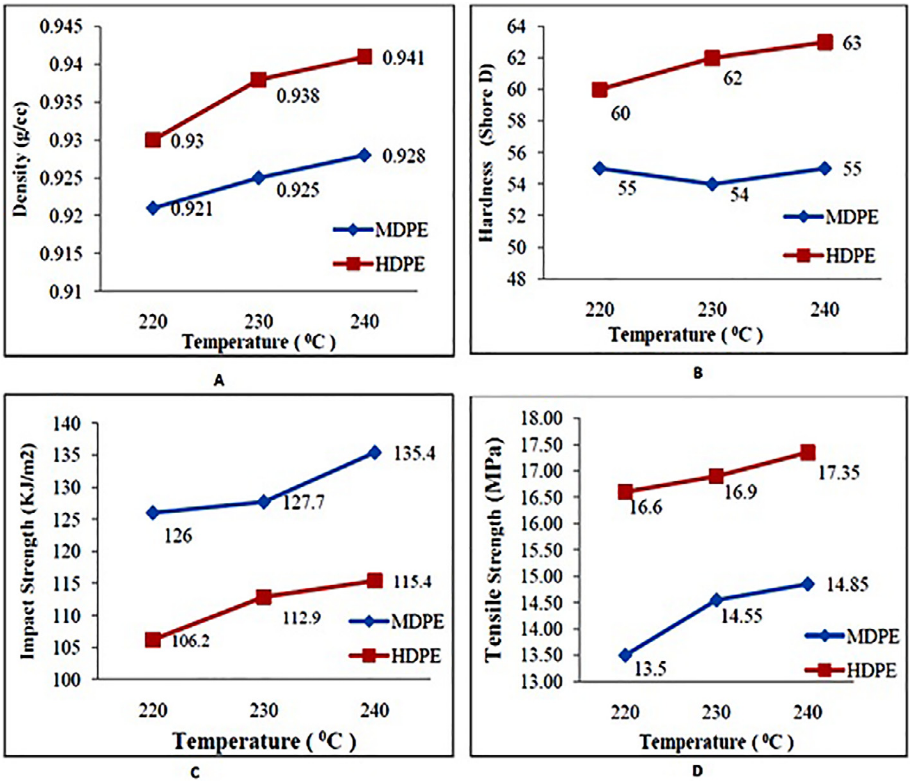

Fig. 2. Variation of A) Density, B) Hardness, C) Impact strength, D) Tensile strength versus Peak Internal Air Temperature.

component decreases. When there is less bubbles, the cross sectional area available to resist the impact load is more. Hence they show better impact strength compared to HDPE products.

Tensile strength was determined as per ASTM D638. Two samples were taken from each product and the results are averaged. The tensile strength of HDPE products was found to be higher than MDPE products. In case of polyethylene, with increase in density, the crystallinity also increases. Crystallinity reduces the degree of freedom for the molecular chains to move. Qualitatively speaking greater the crystallinity harder the polymer or greater the strength. The tensile strength values were found to increase with increase in temperature for both the material. It is mainly the result better densification of the polymers at higher temperature.

4. Conclusions

Rotational molding (RM) is a powder processing method used to produce hollow polymer/plastic parts. The main process parameters of this process are speed, temperature and heating time. In the present work, products were made by rotational moulding using Medium density polyethylene (MDPE) and High density polyethylene (HDPE) material. The properties such as density, hardness, impact strength, tensile strength were tested and compared. The mechanical properties showed improvement with increase in temperature for both materials. This improvement can be attributed to the densification process. The crystallinity of the polymer also plays a key role in the mechanical properties of the products. The MDPE products showed higher impact strength while HDPE products showed higher tensile strength. The morphology of the MDPE and HDPE powders and the microstructure of the products were studied under optical microscope. Bubble formation over the surface was observed to be more on MDPE compared with that of HDPE, leads to hike in mechanical properties of HDPE products.

References

[1] K.O. Ogila, M. Shao, W. Yang, J. Tan, Rotational molding: a review of the models and materials, Express Polym. Lett. 11 (10) (2017) 778–798, https://doi.org/10.3144/expresspolymlett.2017.75.

[2] S.-J. Liu, C.-Y. Ho, Factors affecting the warpage of rotationally molded parts, Adv. Polym. Tech. 18 (1999) 201–207.

[3] A.G. Spence, R. Crawford, J: The effect of processing variables on the formation and removal of bubbles in rotationally molded products, Polym. Eng. Sci. 36 (1996) 993–1009.

[4] A.G. Spence, R.J. Crawford, Removal of pinholes and bubbles from rotationally moulded products, Proceedings of the Institution of Mechanical Engineers Part B: J. Engg. Manufacture 210 (1996) 521–533

[5] R. Pop-Iliev, C.B. Park, K.H. Lee, The potentials for processing metallocene PE grades in rotational molding, in: Proceedings of PPS-18, International Conference of the Polymer Processing Society, 2002, p. 6.

[6] L. Xu, R.J. Crawford, Analysis of the formation and removal of gas bubbles in rotationally moulded thermoplastics, Polym. Eng. Sci. 28 (1993) 2067–2074.

[7] P.L. Ramkumar, Anuraag Ramesh, Param Prabhu Alvenkar, Neki Patel, Mater. Today proceedings2 (2015) 3212–3219.

[8] Lanlan Chen, Xiaojie Sun, Effects of thermo-oxidative aging on structure and low temperature impact performance of rotationally molded products, Polym. Degrad. Stab. 161 (2019) 150–156.

[9] S.J. Liu, K.M. Peng, Rotational molding of polycarbonate reinforced polyethylene composites: processing Parameters and Properties, Polym. Eng. Sci. 50 (7) (2010) 1457–1465.

[11] F.G. Torres, M. Aguirre, Rotational moulding and powder processing of natural fiber reinforced thermoplastics, Int. Polym. Proc. 18 (2) (2003) 204–210.

[12] F.G. Torres, C.L. Aragon, Final product testing of rotational moulded natural fibre-reinforced polyethylene, Polym. Test. 25 (4) (2006) 568–577.

[13] L.T. Pick, E Harkin Jones, Effect of mould pressurisation on impact strength of rotationally moulded polyethylenes, Plast., Rubber Compos. 35 (8) (2013) 324–330.

Further reading

[10] R.J. Crawford, A.G. Spence, M.C. Cramez, M.J. Oliveira, Mould pressure control in rotational moulding, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 218 (12) (2004) 1683–1693.