Effect of Rotational Moulding Process Parameters in Blending of Virgin with Recycled PVC Tanks

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Abstract- To manufacture hollow plastic products rotational moulding technique is used. There is a growing concern over increasing usage of plastic products made of PVC. Recycling of plastics is the most important actions to focus. The present work focuses on rotational moulding process parameter optimization of blending recycled with virgin PVC. For this, L9 Taguchi orthogonal array method adopted. The experimental design was carried out with four process parameters (i.e., external mould temperature, mould speed, processing time, cooling time) with three levels is tested for the optimal combination of factors and levels in the rotational moulding process. The effects of processing parameters and the blending of recycled PVC in different compositions on the mechanical properties are investigated.

Keywords – Rotational moulding, Optimization, Virgin PVC, Recycled PVC

I. INTRODUCTION

Rotational moulding, known also as roto moulding or roto casting, is a process for manufacturing hollow plastic products. For certain types of liquid vinyls, the term slush moulding is also used. Although there is competition from blow moulding, thermoforming, and injection moulding for the manufacture of such products, rotational moulding has particular advantages in terms of relatively low levels of residual stresses and inexpensive moulds. Rotational moulding also has few competitors for the production of large (>2 m^3) hollow objects in one piece. Rotational moulding is best known for the manufacture of tanks but it can also be used to make complex medical products, toys, leisure craft, and highly aesthetic point-of-sale products.

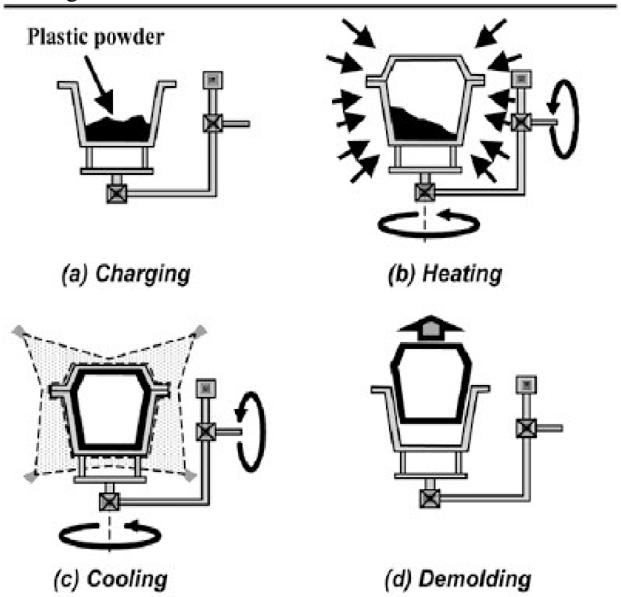
The rotational moulding process is a high-temperature, low-pressure plastic-forming process that uses heat and biaxial rotation (i.e., angular rotation on two axes) to produce hollow, one-piece parts. Critics of the process point to its long cycle times—only one or two cycles an hour can typically occur, as opposed to other processes such as injection moulding, where parts can be made in a few seconds. The process does have distinct advantages. Manufacturing large, hollow parts such as oil tanks is much easier by rotational moulding than any other method. Rotational moulds are significantly cheaper than other types of mould. Very little material is wasted using this process, and excess material can often be re-used, making it a very economically and environmentally viable manufacturing process.

The rotational moulding process consists of four distinct phases:

- Loading a measured quantity of polymer (usually in powder form) into the mould.
- Heating the mould in an oven while it rotates, until all the polymer has melted and adhered to the mould wall. The hollow part should be rotated through two or more axes, rotating at different speeds, in order to avoid the accumulation of polymer powder. The length of time the mould spends in the oven is critical: too long and the polymer will degrade, reducing impact strength. If the mould spends too little time in the oven, the polymer melt may be incomplete. The polymer grains will not have time to fully melt and coalesce on the mould wall, resulting in large bubbles in the polymer. This has an adverse effect on the mechanical properties of the finished product.
- Cooling the mould, usually by fan. This stage of the cycle can be quite lengthy. The polymer must be cooled so that it solidifies and can be handled safely by the operator. This typically takes tens of minutes. The part will shrink on cooling, coming away from the mould, and facilitating easy removal of the part. The cooling rate must be kept within a certain range. Very rapid cooling (for example, water spray) would result in cooling and shrinking at an uncontrolled rate, producing a warped part.
- Removal of the part.

The basic steps of water tank manufacturing in rotational moulding divide into main four main steps as following;

1. Material preparation and Mould charging
2. Mould heating and rotating
3. Mould cooling
4. Part ejection or demoulding



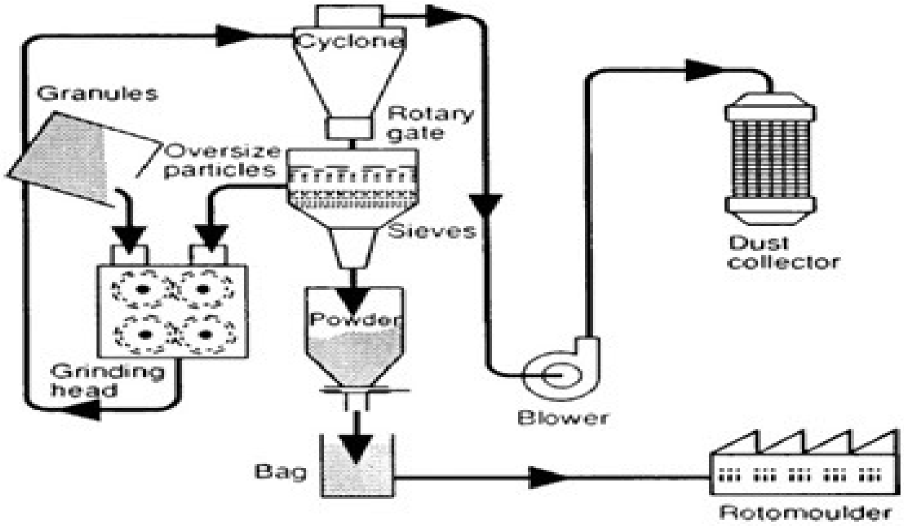
MATERIAL PREPARATION AND MOULD CHARGING

Material preparation

The raw material (LLDPE) or granules which receive for the manufacturing process are not ready to use. The material undergoes to main steps.

- Grinding the material.
- Mixing with concentrators.

The grinding process is visualized below.



General process parameters of rotational moulding are

- Rotational Mould speed : 3- 21 rpm
- Mould heating Time : 10 -15Min (depends on size of mould)
- Rotational moulding processing Time : 15-30Min (depends on size)
- Rotational moulding cooling Time : 10-12Min (depends on size)
- External mould Temperature during process : 180-210℃.
- External mould Temperature after cooling : 40-45℃.

II. Rotational Moulding Parameters

An L9 OA with four columns and 9 rows was selected and the experiments were performed according to L9. Table 3.5 (a) shows the L9 Orthogonal Array (OA) with the process parameter and their levels. Table 3.5(b) shows the composition of virgin PVC and recycled PVC scraps with sample codes (V: virgin PVC, R: recycled PVC.)

Table 2.1(a): L9 orthogonal array with the parameters and their levels

Trial	External mould Temperature	Mould speed	Processing time	Cooling time
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 2.2(b) The composition of virgin PVC and recycled PVC scraps with sample codes V: virgin PVC, R: recycled PVC)

Sample code	V100R0	V75R25	V60R40
Virgin PVC [wt%]	100	75	60
Recycled PVC [wt%]	0	25	40

III. Experiment and Result

The quality of the PVC TANK was assessed by testing three mechanical properties i.e. tensile test, compression test, Hydrostatic pressure Test, Flattening test and Hot air oven test. Each of these tests was performed on PVC TANKS which were produced with different parameter settings according to L9 OA.

Figure 3: PVC Water Tanks

The virgin PVC resins are listed as follows: melt flow rate of 18g/10 min, density of 952 kg/m3, melting temperature of 185 °C. Both, virgin and recycled, PVC pellets were transferred into OMEGA Rotational moulding to produce the PVC TANK according to L9 OA. The test specimen was obtained by removing the sides of the PIPE TANK and the base was cut into 2 specimens in dimension of diameter 90mm x thickness 2.1mm.

Figure 4: Rotational Moulding Machine

The Impact, Hydro static pressure test and flexural strengths of the virgin and recycled PVC TANK was measured on the INSTRON Table Mounted Universal Testing Machine Series 3367 at room temperature (23°C) and humidity (50%). The Impact strength test is conducted on Impact Testing machine(Fig 4.1) according to ISO 4985 standards with a weight of 1 kg, height 2 meters sample rate of 2 points/s, specimen gauge length (G.L.). The Hydro static pressure test was measured according to ISO 4985 standards with one end of ELBOW closed and applied hydraulic pressure from other end, sample rate of 2 points/s, both of specimens GL Initial temperature settings were set, and the machine operator found the right process variables to keep constant with virgin PVC while binary blends were being made. Each blend was a constant 83Kgs. Below are the Process Parameters shown:

External mould Temperature	**195(^{O} C) (varying based on blending percentage)**
Mould speed	12 RPM
Processing Time	34min
Cooling time	9Min

At each blend, temperature settings were adjusted to either low or high levels according to the experimental plan, with randomization, which meant that intermediate breaks, happened to let barrel and nozzle zones reach equilibrium states. In addition, many shots were made initially to heat up the mould since there were no hook-ups available. In all, 48 shots were retrieved, which contained two tensile strips each, were gathered although many more shots were taken as adjustments; so 96 data points could be presented.

RESULTS: Virgin PVC and recycled PVC show very similar molecular weight distributions. In this study, the effect of using pre-consumer PVC scraps (which can be collected during tank manufacturing process), as an alternative to post-consumer recycling, mixed with virgin grade PVC on static and long-term mechanical properties is studied. Samples were prepared by blending virgin PVC with various contents of recycled PVC.

Sample code	**V100R0**	**V75R25**	**V60R40**
Impact strength (JOULES)	19	18.32	16.34
Compression strength(Bar)	941.8	938.23	856.38
Softening point(^{O} C)	81	83	85
External mould Temperature (^{O} C)	210	195	185
Mould speed(rpm)	8	12	19
Processing Time(min)	25	32	38
Cooling time(min)	8min,30sc	9min,15sec	11min,20sec

The best solution (there are many solutions to gain these maximums) is rated as 0.556, responding with: 75% PVC and 25% RPVC as the best mixture, processed at 185°C at the mould, 195°C at die, The Impact strength is 18.32 J. It must be noted that maximizing both mechanical properties and the RPVC content creates a severe bias towards the recycled content, hence it must also be understood that optimizing without that parameter will always have a prediction saying 100% PVC is favored.

	Impact strength (J)	**Compression strength (Bar)**	**Softening point (^{O} C)**	**External mould Temperature (^{O} C)**	**Mould speed(rpm)**	**Processing Time(min)**	**Cooling time(min)**
V75R25	18.32	938.23	83	195	12	25	9min,15sec

IV.CONCLUSION

The above results conclude that, the Process parameters can be optimized for the better result by using modern technologies and methodologies. We found Taguchi Method is very helpful tool in such analysis. Time to time inspection of machines working and accordingly setting the process parameters will be helpful in increasing the productivity of organization. Recycling plastic can reduce consumption of energy, non-renewable fossil fuels use, as well as global emissions of carbon dioxide. The effect of recycled PVC and virgin PVC on impact strength optimal values of process parameters was analyzed. The optimal amounts of mixture components to produce recycled plastic products are determined. As the results of doing systematic experimentation, using mixture experiments, the quality of recycled plastic products can be improved and becomes more robust to variations at the optimal operating settings. The results have proven that the manufacturer can use these settings of recycled PVC and virgin PVC to produce quality products with low cost (quality depends on source as some recycled content qualities can be very high) and environmental impact reduction.

In this study, the effect of using pre-consumer PVC scraps (which can be collected during pipe fitting production process), as an alternative to post-consumer recycling, mixed with virgin pipe grade PVC on static and long-term mechanical properties is studied. Samples were prepared by blending virgin PVC with various contents of recycled PVC.

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