Cycle Time Reduction in Rotational Moulding of LLDPE - FS Nanocomposites

GIRISH CHANDRAN V,
MECHANICAL ENGINEERING,
NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE,
Pampady, Thrissur, Kerala, INDIA
girishchandran@ncerc.ac.in

Abstract: Rotational moulding (RM) is a low shear polymer processing method that uses centrifugal force in a heated chamber to produce hollow seamless products. The availability of materials, large cycle time and process monitoring are few of the challenges faced by both industrialists and researchers in RM. The overall cycle time of a rotational moulding process involves times required for heating as well as cooling of the part. In case of LLDPE the moulders use a typical demoulding temperature of 50°C to demould the part. At this temperature LLDPE shrinks and detaches itself from the mould inner wall. Any attempt to demould the part above this temperature results in damaging the part due to the strong adhesion of the part with the mould. This in turn increases the cooling cycle times. To address this issue, an attempt has been made to demould the part made of LLDPE - FS nanocomposites at temperatures higher than common demoulding temperature. As there is no quantitative method to measure the adhesive force between the mould and LLDPE - FS nanocomposites an innovative method was designed to measure the same

Keywords: Rotational moulding, Cycle time, LLDPE, Fumed silica Pulling force measurement

I. INTRODUCTION

Unlike other polymer processing technologies, RM uses no pressure, resulting in products with no residual stress[1]. Rotationally moulded products are used in different domestic and engineering applications like storage tanks, underground septic tanks, fuel tanks and many other exotic and engineered products. The existence of an optimum sintering temperature had been predicted at which the density of the sintered product was maximum for a good quality rotationally moulded product [2]. Use of reinforced plastic composites has been accomplished by researchers and industrialists for RM, providing materials with much improved properties over pure polymers [3-6].

Rotational moulding suffers from a relatively longer cycle time for the removal of entrapped gasses (bubble) and ineffective heating/cooling of mould. The importance of internal cooling of mould was emphasized by Tan [7] and suggested rapid and symmetrical cooling across the mould for smaller spherulite size, increased the mechanical properties and less potential warpage or distortion in mouldings. The existence of an optimum sintering temperature had been predicted at which the density of the sintered product was maximum for a good quality rotationally moulded product [8]. Along with the improvements in materials used for RM, the RM industry has seen rapid technological advances in the past few decades in process control and cycle time reduction. Until recently, the RM process was relying on both trial and error and the experience of the operator to judge the curing of product and hence product quality. This imposed a serious quality control issue when automotive and industrial products were moulded. The monitoring of internal air temperature (IAT) in the mould provided a better control of the process eliminating much of the guess work from the process. Monitoring the IAT and pressure in moulds has provided significant improvements in product quality and repeatability [9] Since, the monitoring of IAT in a bi-axially rotating closed mould in an oven imposed practical difficulties, wireless temperature monitoring systems like ROTOLOG™, TEMPLOGGER, K-PAQ™ were developed.

The design of moulds and choice of mould material along with internal mould coating [1] for quick release of parts ensured reduced cycle time for the RM process. The quality of polymer powder and aesthetics were improved by the use of mixing colorants in sophisticated pulveriser to obtain the proper powder size and shape. The use of improved process control and adopting variations in materials by use of micro scale and nano scale reinforcements for desired properties make the RM process one of the most important polymer processing method.

Rotational moulding suffers a disadvantage of longer cycle times as compared with the other polymer processing methods like blow moulding, injection moulding, etc. Hence, any decrease in cycle time is considered beneficial. This helps in improving the productivity of the process. The overall cycle time of a rotational moulding process involves times required for heating as well as cooling of the part. In case of LLDPE the moulders use a typical demoulding temperature of 50°C to demould the part. At this temperature LLDPE shrinks and detaches itself from the mould inner wall. Any attempt to demould the part above this temperature results in damaging the part due to the strong adhesion of the part with the mould. This in turn increases the cooling cycle times. To address this issue, an attempt has been made to demould the part made of LLDPE - FS nanocomposites at temperatures higher than common demoulding temperature. As there is no quantitative method to measure the adhesive force between the mould and LLDPE - FS nanocomposites an innovative method was designed to measure the same

II. PULLING FORCE MEASUREMENT

In this study material used was rotationally mouldable grade of LLDPE (R35A042) and Hydrophilic FS of grade Aerosil-200 supplied by Evonik industries. A test specimen of 100 x 40 x 3 mm was made using natural LLDPE and LLDPE - FS blends. To study the adhesion of LLDPE and LLDPE - FS nanocomposites to mould surface, a fixture was designed for using with UTM. The fixture was provided with a heating chamber to melt the polymer. One end of the fixture was mounted on the fixed end of UTM while the other end was fixed on the movable jaw of UTM with the load cell. With this arrangement the pulling force required for separating the product could be accurately measured. The fixture along with its installation on standard UTM is shown in Fig 1 & 2.

Fig 1: Fixture set up

Fig 2: Installation of fixture and experimental set up

The mould along with the top plate was made of both Aluminium and Steel to study the effect of mould material in demoulding LLDPE - FS nanocomposites. Thermocouples were used to measure the temperatures of heating chamber, mould and the polymer melt. The polymer melt temperature was used to control the process of heating, moulding, cooling and demoulding. A fan was used to cool the mould during cooling cycle. This simulates the condition of forced air circulation during cooling of a typical rotationally moulded product. The powder was heated in the fixture and was compressed by UTM by applying a force of 500 N. The powder was heated to 200C and was allowed to cool down. Forced air cooling was done with the help of a pedestal fan. The pulling force was measured by UTM in tensile mode at temperatures of 80C, 65C and 50C. These temperatures can be regarded as common demoulding temperatures in RM machine. The experiment was done for both aluminium (grade 2024) and steel (grade S275) which are used as mould materials. The effect of pulling force on cross head speed was also monitored at 5, 25 and 100 mm/min to study the mould ejection rates.

III. RESULTS AND DISCUSSIONS

During rotational moulding the polymer melt coats the mould inner surface and adheres to it, forming the shape of the mould. During the removal of the product from the mould, the adhesive forces between part and mould become significant. The factors affecting the pulling force are the presence of mould release agents, type of polymer, temperature, pulling rate, mould material along with its surface finish and the product design. No mould release agents were used during the experiments. The variation of pulling force with changes in temperature and pulling rate on steel and aluminium mould are shown in Fig 3.

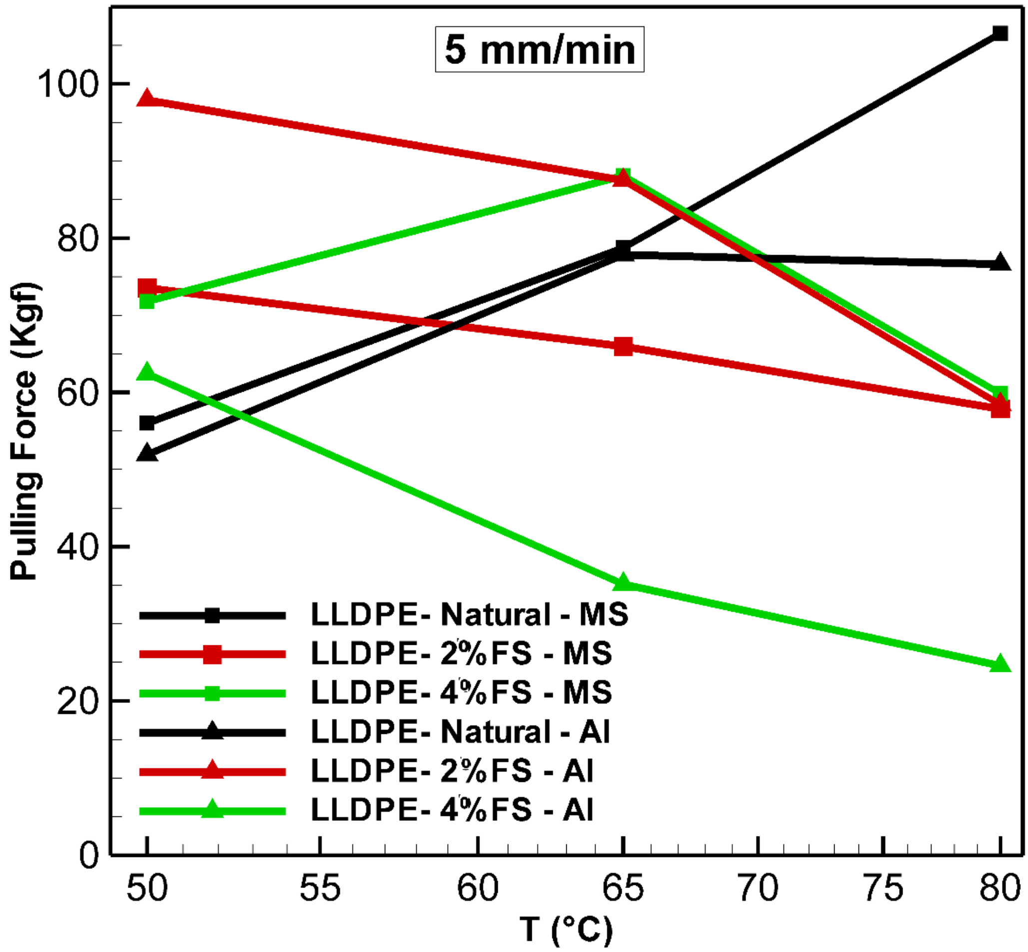

Fig 3. Variation of Pulling force at cross head speed of 5mm/min

It can be observed that the pulling force needed to remove the product from mould reduces with addition of FS both mild steel and aluminium moulds at higher temperatures. The pulling force variation may be due to the reduction of friction between nano composite and mould with the addition of FS. With the addition of FS, there exists a reduction in pulling force with increasing temperatures. The anomalous behaviour of increase in pulling force with 4% FS (MS mould) may be due to inadequate dispersion of FS in LLDPE matrix. The minimum pulling force for LLDPE -FS blends was observed at 80°C and thus it can be considered ideal temperature to remove the product from mould. However, natural LLDPE showed lower pulling force at 50°C than at 80°C. The reduction in pulling force denotes the lower adhesion of polymer to the inner mould surface. This can facilitate easier product removal and possible reduction in cycle time. Along with the reduction in pulling force, there can be a reduction in cycle time if the product is removed at 80°C instead of 50°C. A typical IAT curve for LLDPE - 4% FS from the industrial trials are shown in Fig 4.

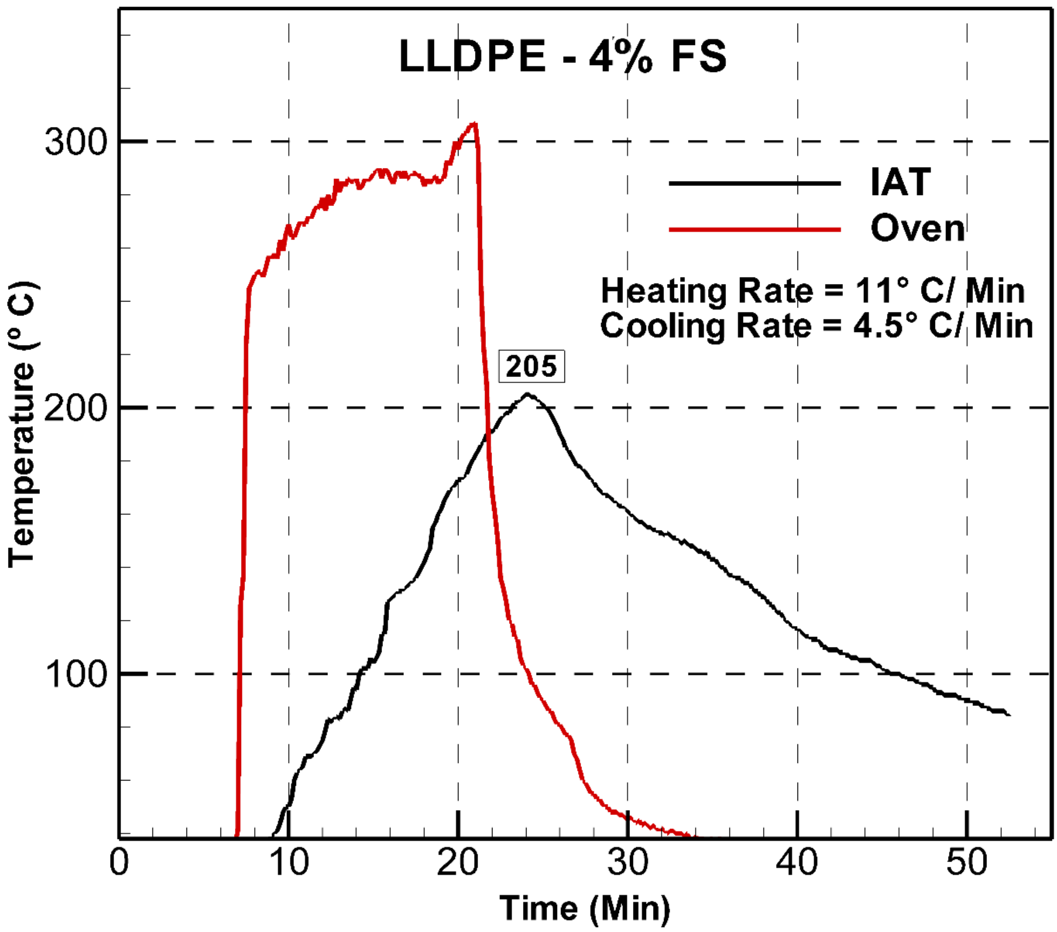

Fig 4. Heating/Cooling curve for LLDPE-4% Fs nano composite

It can be seen that a heating rate of 11°C/min and a cooling rate of 4.5°C/min is observed while moulding the product. Thus, if the product is removed at 80°C instead of 50°C, 6.7 minutes can be saved. The application of mould release agents can further reduce the adhesive forces between polymer and mould and needs separate investigations.

The rate of pulling, varies with the part ejection method used. Smaller pulling rates were observed during manual product removal while higher pulling rates can be seen with mechanical or pneumatic aids. The variation in pulling force at 80°C for different pulling rates are shown in Fig 5. It can be seen that the pulling force increased with the increase in pulling rate. The increase in pulling force was not significant above cross head speed of 25 mm/min. Both aluminium and steel moulds showed the similar trend. It can be observed that the blends with LLDPE - 4%FS showed the lowest pulling force even at higher pull rates. Thus LLDPE - 4% FS blends can be considered to reduce the adhesion with the mould during cooling and facilitates easy and quick part removal. This in turn results in reduction of cycle time during RM.

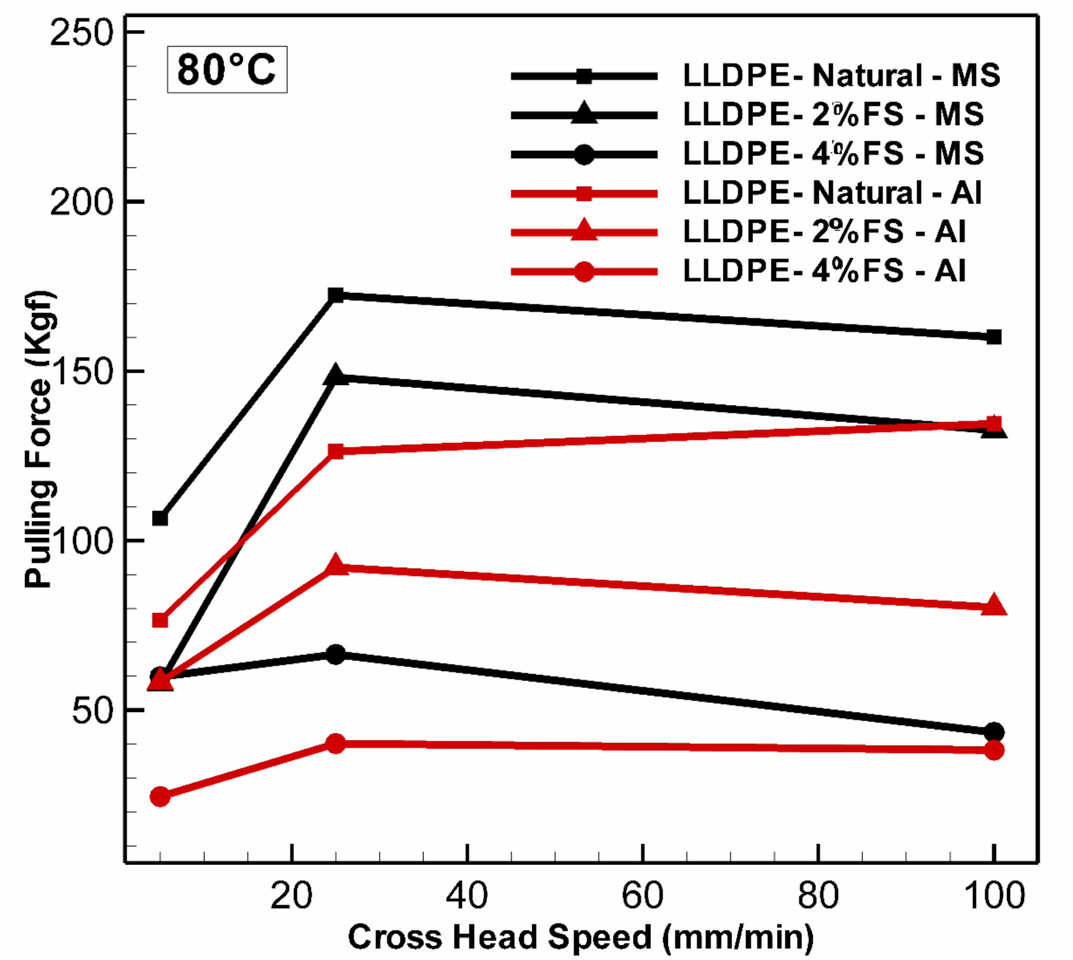

Fig 5. Variation of pulling force at 80°C

IV. CONCLUSION

Successful part removal is a crucial step in rotational moulding. The adhesion of part to mould surface after solidification is highly undesirable as it may damage the part. In industry this problem is avoided by the use of mould release agents. However, additional time is required for applying mould release agents to the mould. Use of non-stick coating is expensive and calls for additional care in mould handling. The LLDPE - 4% FS blends used in this study, tend to reduce the pulling force needed for the part removal at higher temperatures. The parts can be demoulded at 80°C with ease which is difficult for LLDPE alone. Also, for a typical cooling rate of 4.5°C/min a savings of 6.7 min can be obtained by removing the part at 80°C instead of 50°C. This can provide possible reduction in cycle time of rotational moulding process. Hence it can be noted that LLDPE - FS nanocomposites provide enhanced mechanical properties with good melt characteristics without adversely affecting the cycle time of rotational moulding process.

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