# Molding of Reprocessed Thermoplastics with Preplastication Injection Molding

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*Received 22 February 2000; accepted 20 February 2001*

**ABSTRACT:** The injection molding of reprocessed plastics with a preplastication plunger injection-molding machine was investigated with a focus on the processing conditions. The process of the filling of the resin into the mold is much better controlled with preplastication than with processing in a conventional injection-molding machine. Reprocessing of the resin leads to a reduction in molecular weight due to drastic changes in the resin morphology, thereby causing a reduction in melt viscosity. Direct experimental evidence for reduced viscosity was obtained from measurements of the filling pressure recorded on the machine and also with a melt-flow indexer. The results of this study provide a practical solution for reducing the resin temperature when reprocessed resin is used in the injection molding of plastics. © 2001 John Wiley & Sons, Inc. J Appl Polym Sci 82: 1455–1461, 2001

**Key words:** injection molding; viscosity; recycling

## INTRODUCTION

Injection molding (IM) is a highly popular and commercially successful process for manufacturing plastic parts in a variety of shapes and sizes. Besides its suitability for mass production, it is also preferred because the manufacture of complex parts can be more accurately controlled with IM than any other process. As a practical matter, IM requires few or no finishing operations, thereby making the process very economical. The fact that plastics have a lower melting point than most engineering metallic alloys is used in the design of IM machines.

The use of thermoplastics in IM is far more widespread than the use of either thermosets or elastomers because of their reprocessability. As plastic parts find greater and greater use, their recycling and reprocessing is an environmental issue of critical concern. Plastic-component recycling in IM machines requires a machine stable enough to inject the resin under constant molding conditions, a situation not easy to achieve in conventional IM machines. It has been reported that the screw preplastication plunger IM machine,[1] which uses a new control system, maintains its stability regardless of the resin condition and other external variances. This new system uses a full software, closed-loop servocontrol (neuro-fuzzy control) and displays a perfectly deterministic behavior.

The advantage of the additional stability and accuracy of control of the screw preplastication plunger injection-type molding machine can be used to advantage to determine the effects of reprocessing on the optimum molding conditions for a given resin and mold geometry. This can lead to a solution for restoring the optimum molding conditions, even when the resin is reprocessed. Because of the large number of resins that can be

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Journal of Applied Polymer Science, Vol. 82, 1455–1461 (2001)

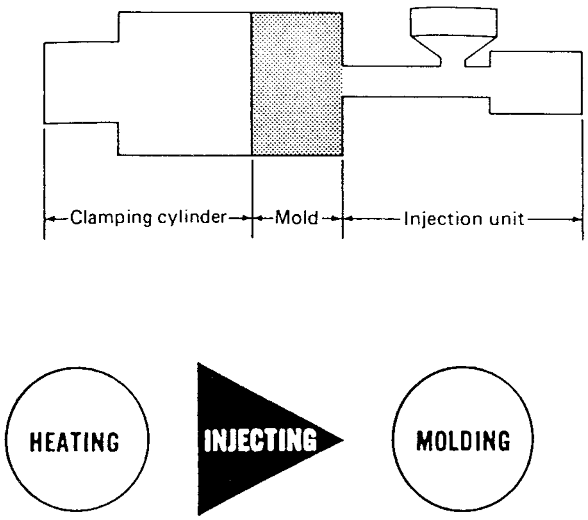


**Figure 1** Schematic sketch of the IM process showing the process steps.

used for manufacturing end products by the IM process, it is very difficult to obtain an exact quantitative solution to compensate for the resin degradation caused by reprocessing.

The aims of this work were to experimentally evaluate the reprocessing of a plastic resin in a screw preplastication IM machine and to investigate the flow properties and morphology of the resin in relation to the molding conditions and mold quality. A major goal of the work was to arrive at a practical set of processing parameters and molding conditions for use with reprocessed thermoplastics.

## BACKGROUND

The IM process can be described as a process in which the molten plastic is forced under pressure into an appropriately shaped cavity inside a mold and then is allowed to solidify to produce the required component.[1] Figures 1 and 2 show the construction of a conventional IM mechanism and an inline, screw-type molding machine mechanism. The production cycle involved in the manufacture of a plastic component or part consists of the following main stages:

1. Melting of the resin.
2. Injection or filling of the resin melt into the mold.
3. Packing and holding of the molten plastic inside the mold.
4. Cooling of the mold (solidification of the molten plastic).
5. Ejection of the part after complete solidification.

In conventional IM machines, the melting, plastication, and injection are carried out in a single cylinder, the screw cylinder. The screw functions both as a melting and plasticating unit in the initial part of the process and as a plunger in the latter part (filling).

The main difference in the preplastication plunger IM machine is that there are two separate cylinders, the screw cylinder and injection cylinder, which incorporate the screw and plunger, respectively. The process is shown in Figure 3(a–d). The filling of the plastic into the mold cavity is carried out under velocity control. At a relatively larger cross section inside the cavity, a larger volume of plastic per unit of time needs to be forced into the cavity to maintain a constant speed of the resin flow front.

This means that, although the plastication and melting phase is an important part of the injection process, the phase that needs to be controlled precisely for maintaining process stability of the injection process is the resin filling. The preplastication plunger IM machine separates these two phases, thereby allowing additional control of the filling process, because in this case the component whose velocity needs to be controlled is the lightweight plunger rather than the heavy screw. This, in addition to the neuro-fuzzy control mechanism mentioned earlier, imparts a highly deterministic performance and stability to the machine with respect to conventional machines.

## RESULTS AND DISCUSSION

The reprocessed resin terminology used in this article refers to a resin that has been injected as

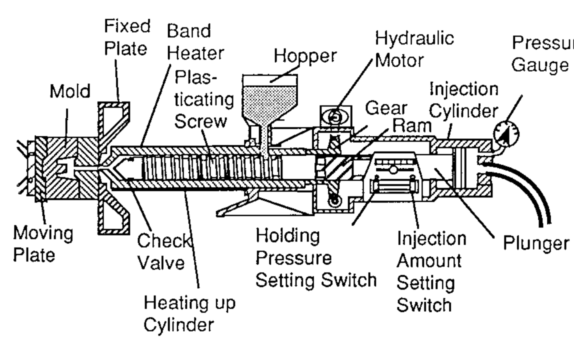


**Figure 2** Inline, screw-type IM machine mechanism.[4]

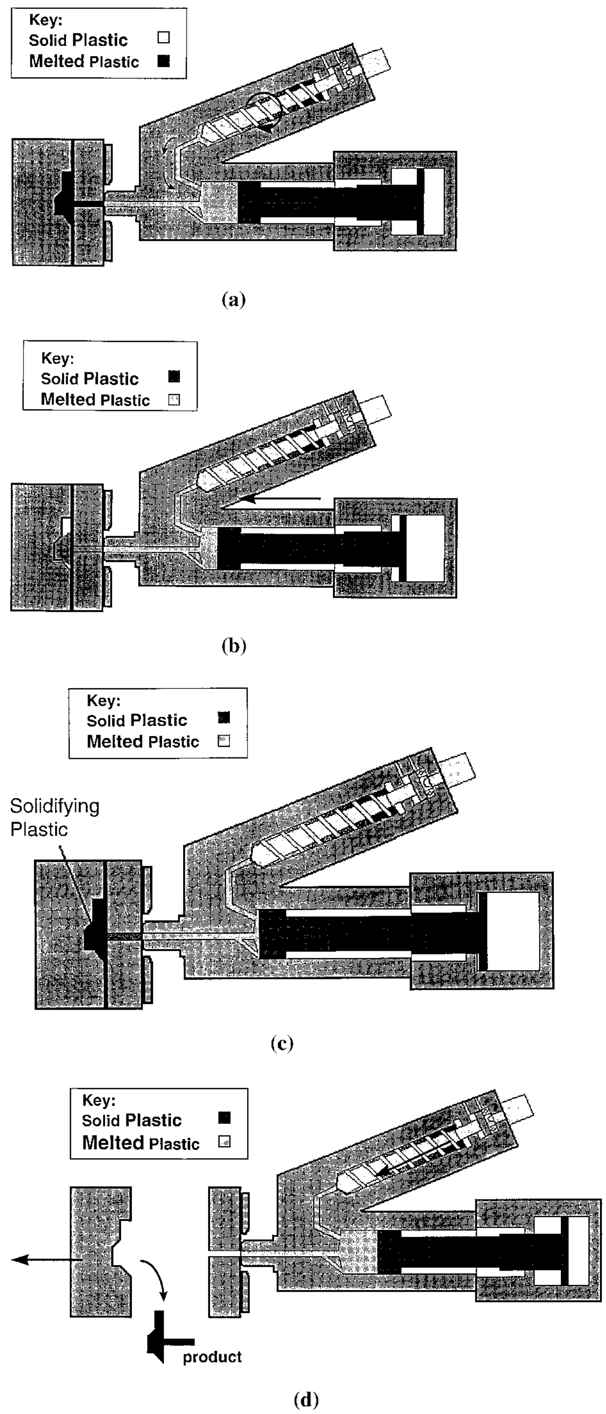


**Figure 3** Preplastication IM machine process showing (a) the plasticizing and charging phase, (b) the filling phase, (c) the holding phase, and (d) the sealing and ejection phase.

a part of a molding at least once. There is a need for injecting reprocessed resin because a large amount of the resin that is injected cannot be used in the form of the final product. For high-end resins employed in the manufacturing of products used in medical and electronic applications, as much as 30% of the injected resin can be wasted in the form of spruce, runner, and products not fulfilling quality requirements.

Previous work in the literature[2–4] has shown that the morphology of a resin changes drastically after it has undergone injection. This means that even though these resins are thermoplastics, there should be some permanent changes in the polymer chemistry. The high shear stresses that the resin encounters because of the combined action of plastication in the screw cylinder and flow through the reduced0diameter gate and through the cavity results in a change in the microstructure. Higher and higher shear stresses lead to more and more crystallinity in the polymer. The polymer chains are aligned parallel. The interchain distances correspond to bond distances, forming a three-dimensional periodic array.[5] This reorientation is bound to cause certain permanent chemical changes in the polymer molecular weight and weight distribution. As can be seen in Figure 4,[6] there is a drop in the viscosity with a reduction in the molecular weight.

All the experiments were carried out on a screw preplastication plunger injection-type (noninline) IM machine (model TR80S2) manufactured by Sodick Plastech Co., Ltd. (Kaga, Ish-

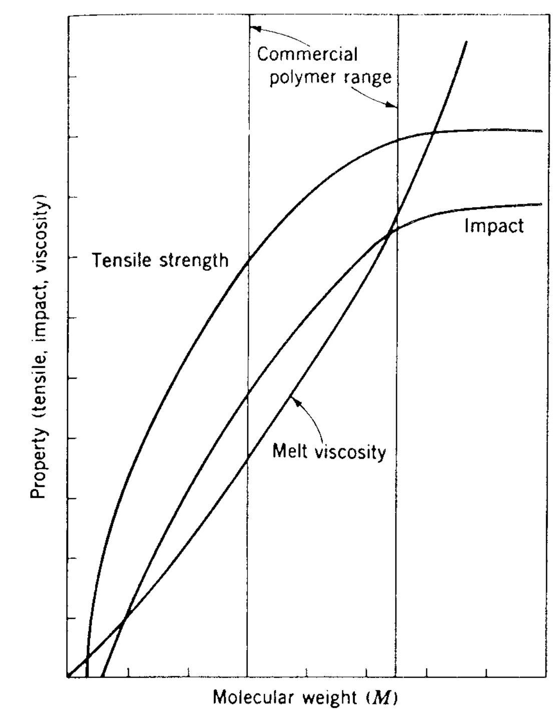


**Figure 4** Graph showing the effect of molecular weight on polymer properties.[6]

**Table I Specifications for the Injection Molding Machine TR80S2**

| Item | Unit | |
|---|---|---|
| Clamping unit | | |
| Clamping system | | Direct-pressure type |
| Maximum clamping force | kN | 785 |
| Day light | mm | 670 |
| Ejection system | | Hydraulic 5 point |
| Ejector force | kN | 32.4 |
| Ejector stroke | mm | 80 |
| Plasticization and injection unit | | |
| Screw diameter | mm | 32 |
| Plunger diameter | mm | 32 |
| Maximum injection pressure | psi | 2310 |
| Plasticizing capacity | kg/h | 50 |
| Injection rate | oz/s | 214 |
| Plunger stroke | mm | 135 |
| Maximum screw rpm | rpm | 350 |
| Screw torque | Nm | 38 |
| Number of temperature control zones | | 8 |
| Hydraulic system | | |
| Motor capacity for hydraulic pump | kW | 15 |
| Hydraulic circuit pressure | kg/m$^2$ | 170 |
| Tank capacity | L | 140 |
| Machine | | |
| Machine dimension | m | 3.4 × 1.1 × 1.6 |
| Machine weight | kg | 4100 |

ikawa, Japan). Table I gives the machine specifications for the different IM machine models manufactured by Sodick Plastech. The machine had a direct-pressure clamping system with a maximum clamping force of 80 tons, that is, 785 kN. The screw had a 32-mm diameter. The plunger also had a diameter of 32 mm and could inject resin into the cavity at a maximum rate of 114 cc/s. Most of the experiments carried out made use of injection-pressure readings available from the pressure transducer near the injection plunger along with values of the resin temperature and filling pressure. In addition, some experiments also made use of cavity-pressure measurements, with the setup consisting of pressure transducers mounted inside the cavity. An elaborate experimental setup consisting of pressure transducers, a signal converter, and CA realizer software (developed by Computer Associates, Slandia, NY) to display a plot of the real-time inner cavity pressure versus time was created and used for this purpose. Similarly, four thermocouples mounted in the cavity were used for obtaining an estimate of the temperature variations within the cavity during the mold-filling process. They were also mounted in 1-mm-diameter holes in the front plate of the cavity made by electrodischarge machining.

Figure 5 shows the positions within the cavity at which the pressure measurements for inner cavity pressures were made. Series 5 is the reading from the transducer fitted inside the injection

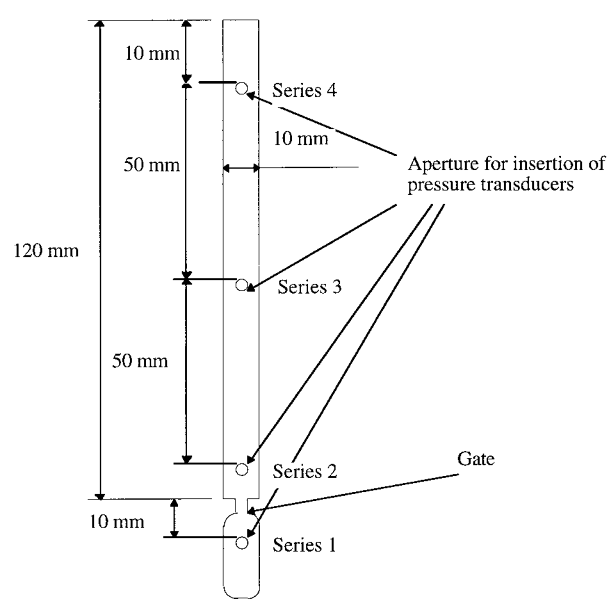


**Figure 5** Sketch showing the pressure transducer positions in the test mold cavity used in this experimental work.

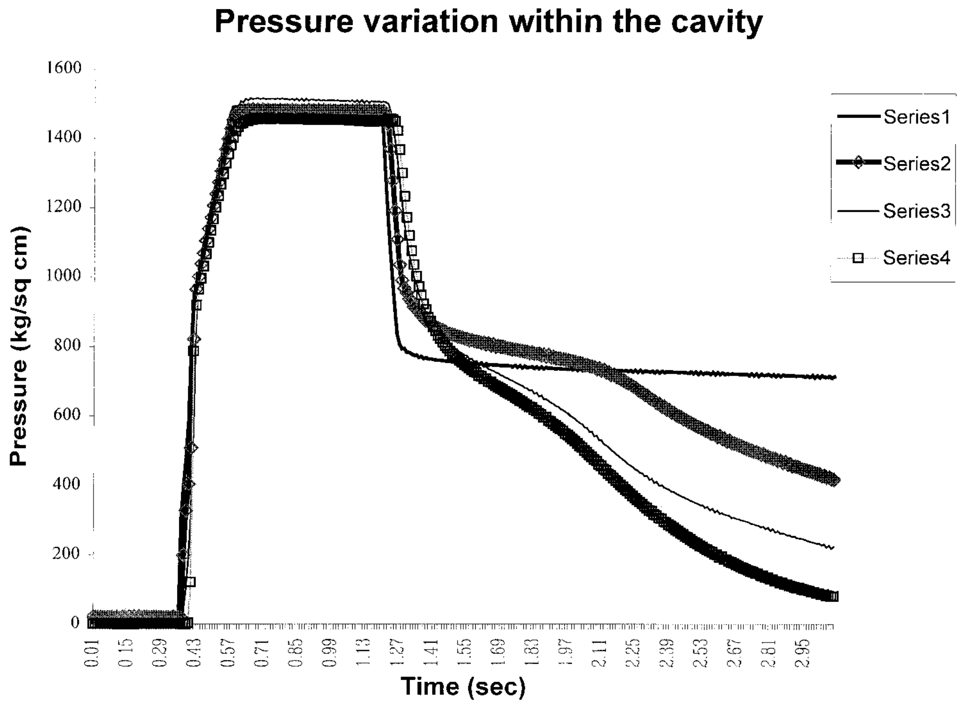


**Figure 6** Experimental data obtained from the transducers during the holding and filling phases.

cylinder that, therefore, measures the filling pressure, that is, the pressure that is actually exerted on the resin by the injection plunger to force it into the cavity through the gate. Series 1–4 represent the pressure readings obtained from transducers fitted along the flow path, with series 4 being from the transducer located near the end of the flow path and series 1 being from the transducer located almost at the start of the flow path, even before the gate section. The molding conditions, including the filling and holding pressures and velocities, were recorded. Figure 6 shows plots of the inner cavity pressure versus time, showing the inner cavity-pressure variation at different locations inside the cavity throughout the resin injection.

The software and hardware had the capacity to record both the inner cavity pressure and temperature at intervals of 0.01 s; therefore, an almost continuous plot of pressure and temperature at a specific position inside the mold cavity against time was obtained. Plots of the inner cavity temperature versus time and the inner cavity pressure versus time for all four positions inside the cavity provide a means of visualizing the mold-filling process.

Using this setup, we were able to record the change in pressure as the resin filled the cavity. Because the cavity geometry used in this study had a constant cross-section area along the flow path, it could be safely assumed that a constant velocity of the injection plunger should result in a constant velocity of the resin flow front during filling. A constant resin flow front velocity during mold filling is a necessary but not sufficient condition for establishing optimum molding conditions so that the best possible molding quality is obtained. Therefore, throughout the study, care was taken to maintain the same filling velocity, leading to a constant flow front velocity. The filling velocity is controlled by the movement of the plunger inside the filling cylinder. The reason the filling velocity needs to be varied when there is a change from virgin resin to recycled resin is that there is a reduction in the resin viscosity on reprocessing, as discussed later, which means that the optimum value of the filling speed required is reduced. This is because it is easier to inject a lower viscosity resin than virgin resin because it offers a lower resistance to flow.

Therefore, to further study the effect of resin reprocessing, we had to measure the change in resin viscosity that it causes. This was done with a melt-flow indexer. This device (Mfr. by M & L Testing Equipment, Dundas, Canada) which is simple to use and very rapidly compares the viscosity of different resins, is most commonly used in an industrial setting. The melt-flow indexer

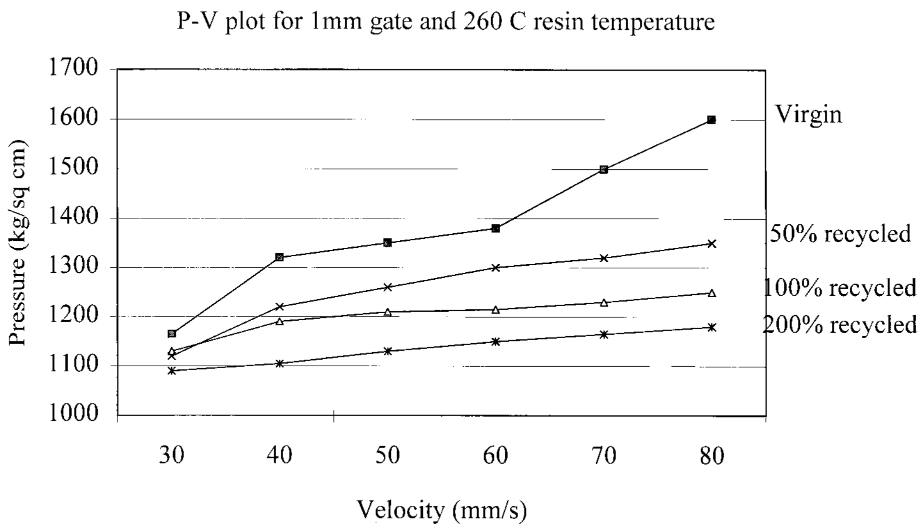


**Figure 7** Pressure–velocity data showing the effect of recycling on resin flow.

consists of a piston cylinder arrangement. The cylinder has a narrow capillary at one end. It can be heated to a given temperature by the heater coils surrounding the cylinder.

During the actual measurement, the resin is heated to the temperature at which it is to be injected into the mold. A certain fixed pressure is applied on the resin through the plunger with a dead weight placed on it. This forces the resin through the capillary. The time for a fixed quantity of resin to flow through the capillary is measured. This gives a direct means of comparison between the virgin and reprocessed resin in terms of ease of flow.

The viscosity measurements were carried out with the widely used melt-flow indexer method. To determine the effect of the use of reprocessed resin on IM, we measured the following parameters and then related them to the effect of reprocessing the resin:

1. Resin temperature. The reduction in resin temperature leads to an increase in resin viscosity and, therefore, an increase in the filling pressure due to the extra resistance to flow offered by the resin.
2. Filling velocity. The filling velocity is an externally controlled variable, but it tends to increase when recycled resin is used because of the lower viscosity of the reprocessed resin.
3. Molding mass. A reduction in the viscosity of the resin due to reprocessing makes the resin spurt while entering the mold cavity through the narrow cross-section gate. This leads to entrapment of minute air bubbles in the cooling resin, leading to a reduction in the molding mass.
4. Filling pressure exerted by the plunger. A reduced filling pressure is needed for pushing the resin inside the mold cavity when reprocessed resin is used because of the reduced viscosity of the reprocessed resin.
5. Filling pressure at various positions inside the cavity. An effect similar to that mentioned in the previous paragraph is observed.

Therefore, to observe the effects of this recycling on the process parameters, we injection-molded plastic once (100% recycled) and twice (200% recycled) along with a mixture of 100% recycled and virgin plastic, and we collected specimens for each condition. Figure 7 shows the relation between the maximum pressure during the filling and the velocity for different amounts of recycled resin. The gate size and resin temperature were kept constant.

Therefore, in this experiment the relation between maximum pressure and velocity during filling was obtained, with only one parameter (resin reprocessing) changed and the others kept constant. The pressure–velocity relation, with the gate size and resin temperature kept constant and with resins with different amounts of recycled resin used, was found and analyzed. At the same velocity, the maximum pressure was recorded for the virgin material.

Thus, with the same filling velocity profile maintained, it can be seen from the pressure–

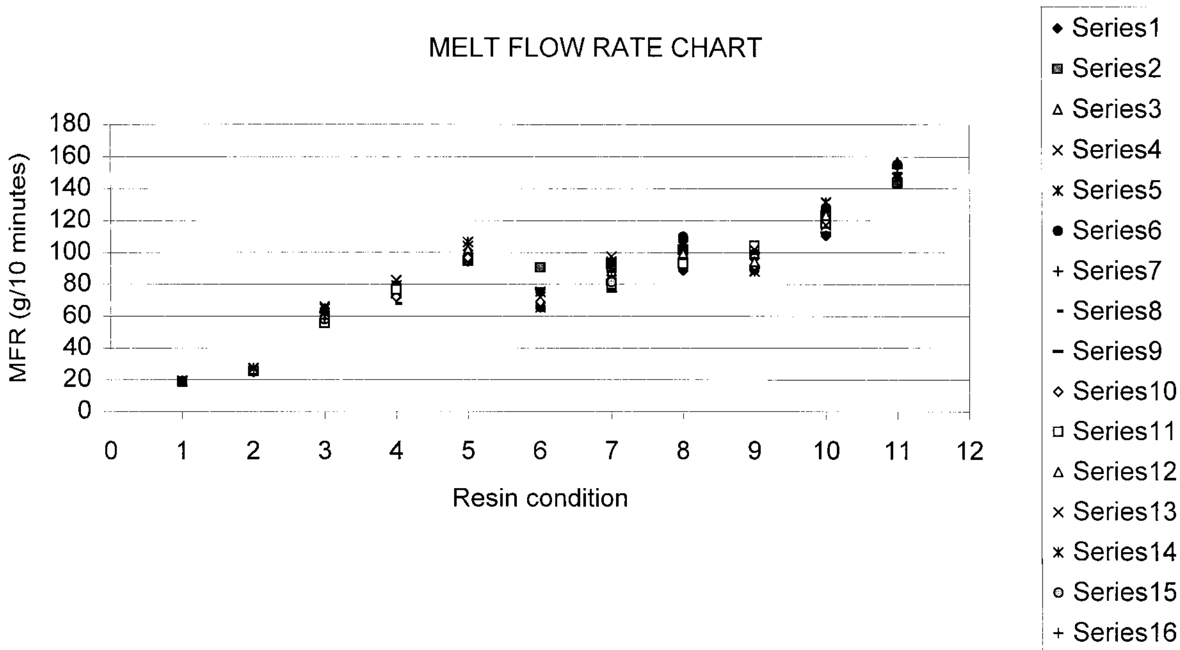


**Figure 8** Data showing the effect of resin temperature and recycling on the melt-flow rate.

velocity plot that a lower pressure needed to be exerted on the resin to force it through the gate to fill the cavity. This indicates that resin reprocessing affects the resistance of the resin to flow, that is, the viscosity of the resin.

We tested this hypothesis by carrying out the melt-flow index test and comparing the times required for the resin to flow for virgin resin and resin recycled to different levels. This can be seen in Figure 8. Also in Figure 8, we see that as the resin temperature increased, the melt-flow rate also increased. This backs up our hypothesis that the use of reprocessed resin will lead to a change in the optimum molding conditions for a specific mold geometry.

As explained before, although it is known that the resin viscosity is reduced because of reprocessing, it is almost impossible to determine a quantitative estimate of this reduction because of the large number of possibilities in terms of resins used and the amount of reprocessing they have already undergone.

## SUMMARY AND CONCLUSIONS

The experimental results obtained in this study lead to the conclusion that the use of reprocessed resin results in a reduction in viscosity during IM; the resin viscosity also decreases with increasing temperature. For most of the commonly used engineering resins, a reduction in the resin temperature will have a nullifying effect on the viscosity decrease because of reprocessing. Thus, the already established optimum molding conditions for a specific mold geometry need not be reestablished by trial and error if necessary changes in the resin temperature are made and the resin viscosity reduction due to reprocessing is appropriately accounted for.

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