Causes and Cures of Problems During Rotomoulding

by R. J. Crawford

This article will form part of a series in which the causes of problems during rotational moulding will be explained and possible cures will be identified. For many years rotational moulding was regarded as a black art which relied heavily on the skill and expertise of the moulder. While these attributes are still very necessary, it is a fact that today, there is a much better understanding of what is happening during the rotational moulding process.

MOULDING CYCLE

The sequence of events which occur during rotational moulding is illustrated in Fig. 1. In this case, the oven temperature control has been set at approximately 300°C (572°F). When the cycle begins and the rotating mould moves into the oven, the environment within the oven close to the mould increases in temperature quite quickly, but it rarely reaches the set temperature. It may be seen that the oven environment temperature goes through a series of oscillation perhaps because of hot/cool spots within the oven. The temperature of the outside of the mould increases more slowly than the air within the oven, and the temperature of the inside surface of the mould lags behind this by 10-15°C at all times.

What is particularly interesting and most informative in Fig. 1 is the temperature of the air inside the mould. At the very beginning, this shows hardly any change in temperature because it takes a finite time for the heat to penetrate the metal mould. Then the internal air starts to increase in temperature at a steady rate. Up to point A, the powder is tumbling in-

side the mould and none of it is sticking to the mould because the temperature of the latter is insufficiently high. At point A, which corresponds to a temperature of about 120°C at the inner surface of the mould, the plastic powder starts to melt
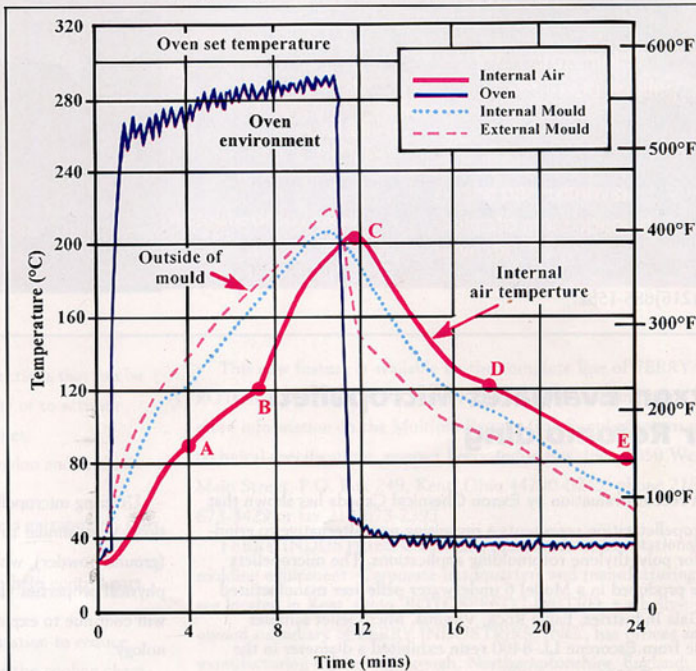

Fig. 1. Temperature Variations During Rotational Moulding

and form a thin film of melt on the inside surface of the mould. If MOLD-IN GRAPHICS are being used, then it is at this point that they have been sealed on and the speeds/speed ratios can be increased. Once the plastic powder starts to melt, it absorbs a large amount of the heat being input to the mould. Hence, the temperature of the internal air rises less sharply during the melting region A-B. However, once all the powder has melted (point B), the internal air temperature starts to rise more steeply again.

Immediately after point B, all the powder has adhered to the mould and there is no free powder tumbling inside the mould. However, the structure of the plastic close to the mould is very loose, porous, and in-

elapse, these bubbles would also disappear. However, by this point, it is likely that degradation would have started to occur. Hence, in most cases it is preferable to retain a small number of bubbles within the structure of the moulding to avoid overcooking. For most polyethylenes, this optimum cure condition occurs when the temperature of the internal air reaches about 200°C (392°F).

It should be noted that the degradation of rotomoulded products begins at the inner, free surface. Although the temperature of the material here is less than at the surface close to the metal mould, the presence of oxygen at the inner surface initiates the degradation processes. Generally a thin layer of degraded material

the dimensions and properties of the end-product. The plastic solidifies at the region D which is characterized by a reduction in the rate of temperature decrease of the air inside the mould. The change in rate occurs because there is a release of thermal energy when the plastic solidifies, and so the internal air cannot decrease in temperature as quickly as before. Once the plastic has solidified, its structure has been formed and the cooling rate is less critical to the properties or dimensions of the moulding. Hence, the use of fast cooling, as caused by water spray, will have little effect on the properties of the moulding.

CRYSTALLINITY

The word "crystallinity" refers to an ordered structure of molecular chains within a plastic. Conversely, "amorphous" refers to a situation where there is no regular arrangement of molecules. Since the long molecular chains in polymers are complex in shape, it is not practical for them to become arranged into a totally regular structure.

Fig. 2. Stages in Structural Formation During Roto Moulding

deed powdery at the inside surface. Fig. 2 illustrates the stages during the formation of the structure during rotational moulding. In Fig 2(a), the individual particles stick together at their surfaces and form a loose porous mass. As time progresses and temperature increases, the irregular pockets of trapped air transform into spheres. This is occurring during the period B-C in Fig. 1. Close to the optimum cure condition, most of the trapped spherical bubbles will have disappeared. Those close to the mould surface will tend to have disappeared completely because they have been at an elevated temperature for a longer period of time. Those close to the free, inner surface will tend to be larger because they have had less time to facilitate their removal.

If sufficient time were allowed to

forms at the inner surface. This is brittle and if a crack is initiated in it, this crack will propagate very rapidly through the rest of the unaffected, tougher structure of the plastic.

It is also apparent from Fig. 1 that after the heating is stopped, the temperature of the air inside the mould continues to rise for a period. This will depend on the wall thickness of the plastic product. For the case shown in Fig. 1, the product had a thickness of 3 mm and the internal air continued to rise in temperature for about 1 minute. This needs to be taken into account if a precise peak temperature is sought for the internal air - particularly when very thick products are being moulded.

Once the cooling stage (C-D) begins, the moulder has considerable control over

In some polymers, such as polystyrene and acrylic, the chains are so complex that they are not capable of crystallizing, and so they are always amorphous. Even those polymers which are regarded as being crystalline, such as polyethylene or nylon, are never purely crystalline. They tend to consist of both crystalline (regular) and amorphous (irregular) regions and the relative extents of each can be controlled during processing.

High density polyethylene (HDPE) is an almost perfectly linear polymer and can therefore be obtained in a highly crystalline state (approximately 80-85% crystalline). The higher the degree of crystallinity, the higher will be the density (because more material is packed into a
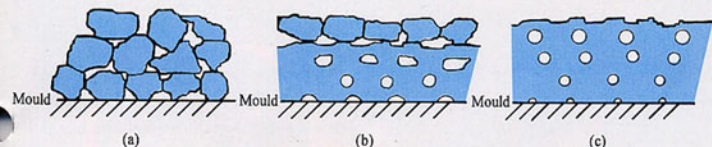
given volume) and the higher will be the melting temperature (because more energy is needed to separate the tightly packed molecular chains).

Low density polyethylene (LDPE) has a substantial number of side branches along the molecular chain and these make it difficult for the chains to pack together in a regular arrangement. Hence, LDPE is only capable of crystallinity levels of about 55%. It therefore has a lower density of about 920 kg/m³ (compared with 960 kg/m³ for HDPE) and a lower melting point of 110-115°C (compared with 133-135°C for HDPE).

In general, the following properties are affected by increasing the degree of crystallinity:

• strength and stiffness are increased;
• toughness is decreased;
• solubility and permeability are decreased;
• density is increased; and
• shrinkage is increased.

For a particular grade of polyethylene, the degree of crystallinity in the final product will be influenced by a number of factors during moulding:

• maximum temperature reached (point C in Fig. 1);
• rate of cooling (slope of C-D in Fig. 1);
• presence of nucleation additives in the plastic; and
• molecular or weight of the poly-mer.

These effects may be explained as follows:

First, a high molecular weight implies long molecular chains, and these have greater difficulty getting organized into a regular pattern. This can be important in the selection of the grade of plastic if some specific property is critical. For example, if shrinkage is to be minimized, then crystallinity should be minimized. All other things being equal, this would suggest that a high molecular weight grade should be chosen, i.e. a high viscosity (low Melt Index) grade.
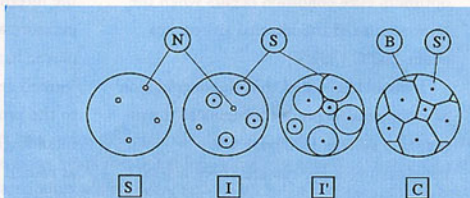
Fig. 3. Crystallization Process [S] Start; [I] First Intermediate Stage; [I'] Second Intermediate Stage; [C] Completion; [N] Nucleus; (S) Growing Spherulite; (S') Fully Grown Spherulite; (B) Interspherulitic Boundary

(From Charrier, J.M. "Polymeric Material, and Processes" Houser Publishers, Munich, 1990)

Fig. 4. Spherulitic Morphologies
[C] Coarse Morphology;
[F] Fine Morphology;
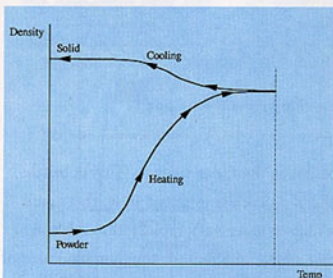(S) Large Spherulite;
(S') Small Spherulite

Fig. 5. Changes of Density With Temperature During Rotational Moulding

The effect of nucleating agents relates to the way in which the crystalline regions start to grow. Fig. 3 shows that as the plastic cools, nucleation sites become available and the crystalline regions spread out from these. Some additives act as nucleating agents and so will cause extra sites for crystal growth. This can be important because the number and size of crystalline regions affects the properties of the moulded product. A coarse structure in which there are few, large crystalline regions (spherulites) produces a stiffer but more brittle product. The converse is a fine morphology where there are many small spherulites as shown in Fig. 4.

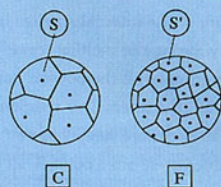The nature and size of the crystalline regions will also be dictated by the cooling rate (region C-D in Fig. 1). The formation of a regular crystalline structure in a polymer takes time, and if the plastic is cooled rapidly, then the crystalline structure does not have time to develop. This will tend to increase the proportion of amorphous material in the structure. The product will not be so strong and stiff, but it will probably have better toughness. Also, and perhaps more importantly, it will exhibit less shrinkage. However, as indicated later, it is likely to have greater warpage or distortion. Fast cooling usually results in a fine structure, i.e., a large number of small spherulites. Slow cooling usually results in a coarse structure, i.e., a small number of large spherulites (see Fig. 4).

SHRINKAGE

During rotational moulding, the plastic is undergoing quite large volume changes for a fixed mass of material. This is illus-

for a fixed mass of material. This is illustrated in Fig. 5. Initially the powder has a low bulk density and as the material is heated in the mould, it consolidates into a fairly uniform melt. At this stage, the material is in the molten state and, like all polymer melts, it is amorphous. As the material is cooled, its density increases further as the material contracts to take up a smaller volume for a fixed mass of material. If the final solid polymer is amorphous, then the amount of contraction during cooling is relatively small (see Fig 6[a]). If, on the other hand, the final solid polymer is a crystalline material, then it will undergo a large contraction on cooling.

The latter is what happens to polyethylene when it is cooled during rotational moulding. Hence, we normally expect a relatively large shrinkage because we are working with a crystalline material. However, from the earlier comments, it is apparent that we have some control over this by the choice of grade and/or the rate of cooling. Fast cooling will restrict the amount of crystallinity which can occur and will result in less shrinkage.

WARPAGE

Warpage commonly occurs in rotomoulded parts due to the nature of the process, i.e., cooling from one side of the plastic only. The effect is eas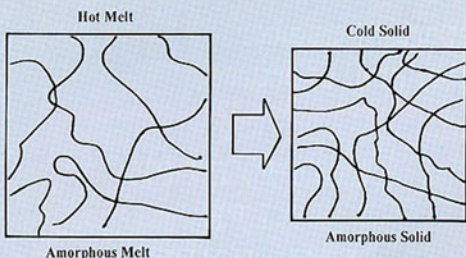ily demonstrated. Imagine a "pancake" of hot plastic placed on a flat, cold surface. The bottom surface will cool rapidly and have little crystallinity. The top half will, however, cool more slowly because the lower layer insulates it from the cold metal. The top half will therefore contain a higher degree of crystallinity and will shrink more than the bottom half as it cools. This will cause tensile stress at the interface, which will result in warpage of the plastic as illustrated in Fig. 7.

As a general rule, therefore, warped sections will curve towards the cooler surface. To alleviate this effect during rotational moulding, it would be desirable to cool the inner and outer surfaces of the plastic at the same rates. If this cannot be achieved, then it is preferable not to cool the metal mould too quickly because the inner surface will only be cooling slowly. As a further measure to avoid warpage, thick and thin sections should be avoided in the moulding. Thick sections will cool slower and be more crystalline. In achieving this state, the thick sections will tend to pull material from the thin areas and this causes warpage/distortion in the final product. This can also occur if there are hot spots or cold spots on the mould.
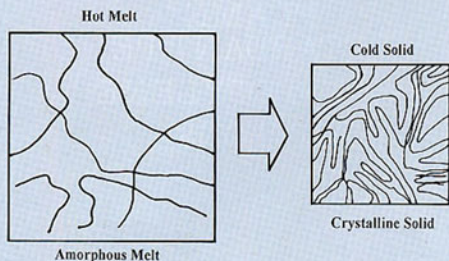
As a final point, it is also worth noting that any use of jigs to remove warpage or reduce shrinkage will set up residual stresses in the plastic. This is because the plastic is prevented from taking up the natural configuration which its structure prefers. When stresses are moulded into a product or introduced shortly after moulding using jigs, the material will become more susceptible to environmental stress cracking (ESC).

See related article by Blair Graham on page 16 of ROTATION.

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(a) Amorphous Material

(b) Crystalline Material

Fig. 6. Contraction of Amorphous and Crystalline Plastics During Cooling
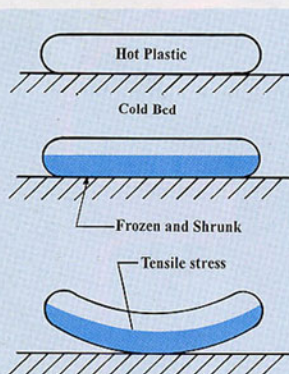

Fig. 7. Cause of Warpage in Plastics