PLASTICS CONSULTANCY NETWORK

Injection Moulding - Gates and Runners

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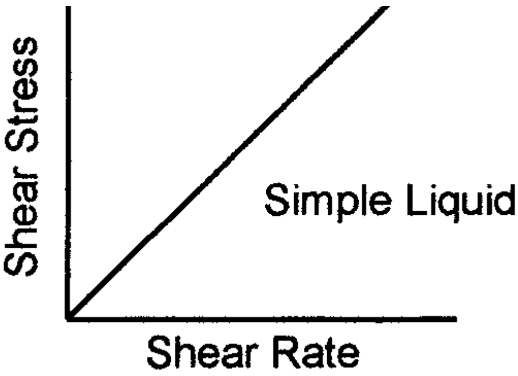
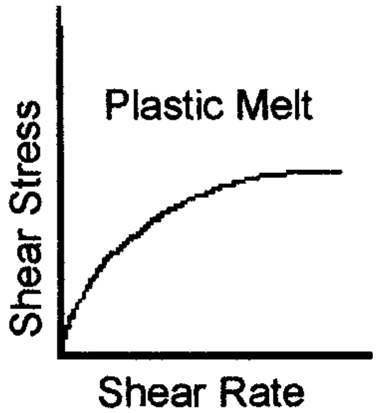
Shear Rate - Cause and Effect

It is very easy to forget that plastic melts are not thermally stable over long periods at, or above, melt temperature. Equally, it is as easy to forget that the molten mass is not impervious to the effects of shear. Plastic Melts are not Newtonian in their behaviour. That is, they do not react in a linear fashion when exposed to shearing of the melt or changes in temperature. A Newtonian melt would show a straight-line graph when plotted for shear rate vs. shear stress which reflects the consistency of the viscosity.

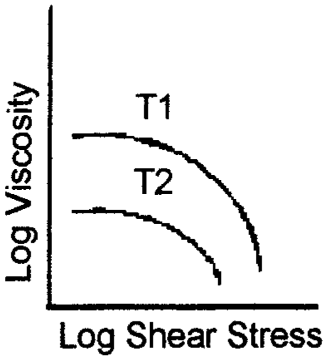


In the case of plastic melts, the shear rate does not change in proportion to the shear stress. This is another way of saying that the viscosity is not constant. The typical plot of shear stress vs. shear rate for a polymer melt shows that they are curves.



Graphs such as this are required to report the melt viscosity data of plastics. These curves are mathematically described so that a computer program may calculate a viscosity at any set of relevant conditions given. The most used form is the Power Curve as it is simple to use. Other forms include Carreau, Cross and Ellis interpolations.

As the shear rate and shear stress change, the viscosity changes. The typical plot of log shear stress vs. log viscosity shows the effect of shear at 2 differing temperatures.



There are now 2 factors which will affect performance - shear rate and temperature. The viscosity change may be as a result of a temperature increase in the melt temperature. It may also be induced as work heat arising from the pressure losses in the melt system.

So, having established that shear rate and shear stress affect the melt performance, it is now necessary to examine HOW they affect this performance.

Shear rate and temperature are easily seen as major factors. The one affects the other and in statistical terms are dependent variables. It could be assumed that by raising the shear rate sufficient heat can be added to the melt to allow processing with no additional external heat input. This is adiabatic performance and can be seen in certain injection moulding machines and extruders.

The cautionary note is now required. Every material has a critical shear rate. Above this rate, the polymer melt fractures and the molecular weight is reduced. This reduction will debase the material properties. In some cases, where the shear rate has been exceeded late in the process, such as at the gate, the effect may be very local and only in the area where the problem occurred.

The fact of exceeding the critical shear rate is well known in the extrusion process as melt fracture. There are, in most cases, visible evidence of its occurrence. The associated property loss is as well-known and steps are taken to avoid it. It is probably more easily identified in extrusion since the molecular weight of the polymers used in that process are very high and, are considerably more viscous than are usual with injection moulding. Melt viscosity is a very large factor in the incidence of critical shear rate.

Visible signs of melt fracture are usually found when either small gates, high volume flow rates or the presence of sharp edges in the flow path. It is easy to find with some polymers, acetal and high density polyethylene for example. In both of these examples, it appears as "gate frost". With a general idea of the level of critical shear rate, it is fairly simple to calculate whether a gate size, coupled with cavity volume and fill rate will create a problem or not.

The point is that injection speed has to be balanced so that excessive shear does not take place in the gate area and, that too much lock force may be needed to withstand the shock impact from a fast flowing melt. Really, the speed should be matched with the gate size.

The critical dimensions for the gate are the gate width and the gate thickness or diameter. The smaller the thickness, the lower is the safety threshold for gate shear rate.

First, establish the volume flow rate (Q in most formulae).

Volume Flow Rate (Q) = One Cavity Volume / (Fill Time x No. of Gates/Cavity)

Apply this in either of the next formulae:

Shear Rate Rectangular Gate: 6 x Q / (gate width x gate thickness^2)

Shear Rate Round Gate: 32 x Q /(3.14159 x gate diameter^3)

Units:

- Cavity Volume in cubic centimetres
- Fill Time in seconds
- Dimensions in centimetres

critical SHEAR RATE x 1000 for various polymers	
ABS Acrylonitrile butadiene styrene	50
ABS Plating Grade	30
EVA Ethylene Vinyl Acetate	30
GPS Polystyrene GP	40
HIPS High Impact PS	40
LDPE Low Density Polyethylene	40
PA.6 Nylon 6	60
PA66 Nylon 66	60
PA612 Nylon 612	60
PA12 Nylon 12	60
PBT Polybutylene Terephthalate	50
PET Polyethylene Terephthalate	50
PC Polycarbonate	40
PES Polyethersulphone	50
PMMA Acrylic	40
POM Acetal	40
PPO Polyphenylene Oxide (Mod)	35

PPS Polyphenylene Sulphide	50
PP Polypropylene	100
PSU Polysulphone	50
PUR Polyurethane	40
FPVC Flexible Poly Vinyl Chloride	20
PVC-U Rigid PVC	20
SAN Styrene Acrylonitrile	40

An example using these formulae follows:

Remember, the higher the melt viscosity, the lower the critical shear rate. If a glass or mineral filler is present, halve the shear rate at least. If your calculation shows that you exceed the critical rate, try increasing the fill time or increase the gate thickness / diameter.

If you have only the part weight, divide this by the density of the part.

For example, a part weighing 35 grams in polystyrene should be divided by 1.06 which gives a volume of 33.02 cc.

If this was to be used through a gate of 0.11 cm diameter at 1.5 sec then

Shear rate=32 x 33.02 / (3.14159 x 1.5 x 0.11^3) = 168,464

This exceeds the 40000 rate for the material, slow the fill rate and open gate to cure:

Shear rate=32 x 33.02 / (3.14159 x 2 x 0.165^3) = 37,437

The gate has been increased to 1.65 mm (0.165 cm) and the fill time to 2 seconds.

Anything less than this will take the shear rate over the limit. The key is in the VOLUME which is too great to squeeze through a small gate quickly. The point is that small gates with a big cavity volume are not a good idea. In most cases it is best to use the fastest fill speed possible as this evens up the cavity fill pressures. However, as has just been shown, it must be within the limits prescribed by the material. Profiling the injection speed and pressure (the two are indivisible at high rates), will help to avoid over packing.

The other area where critical shear rate must be carefully avoided is that of screw rotational speed. All screws have clearance between the flight lands and the barrel wall. This is filled with a thin film of the polymer melt.

High screw RPM will destroy the film by shear alone. This degraded material will then gradually mix into the main stream of the melt and be injected into the mould.

Certain aspects of screw design also impinge on this area. The width of the flight land needs to kept to a minimum rather than to be "safely" engineered. There are a set of critical screw rotational speeds for the various materials which are given in metres / second. This is then calculated for the actual RPM based upon the barrel diameter.