The Molding Area Diagram

The Processing Window

Background

The Molding Area Diagram (MAD) is a simple and economical method to quantitatively analyze several characteristics of the injection molding process. The MAD was originally developed to measure the robustness of an injection molding process in the early stages of mold debugging so as to assist technicians in identifying problems and determining the effects of process and tool changes in a quantitative and objective manner. The procedure consists of determining the molding pressure latitudes (ranges) at two or three different melt temperature levels and charting the results. Unfortunately, this technique cannot be accomplished with some of the newer velocity-controlled machines since a molding latitude requires determining the process limits by changing the injection pressure while holding the injection time fixed. Many newer injection molding machines do not have a "manual" option to allow this approach.

The basic MAD plot, shown in Figure 1, depicts a typical graphic analysis of the entire processing range for the mold/machine combination. It is typically a tilted geometric figure having four boundaries; two related to temperature and two related to pressure. These boundaries are gross attribute failures - points beyond which the process cannot exist. Four process characteristics become quantifiable when these boundaries are reached: the range of the molding latitude, the area, tilt and rate of decay of the MAD.

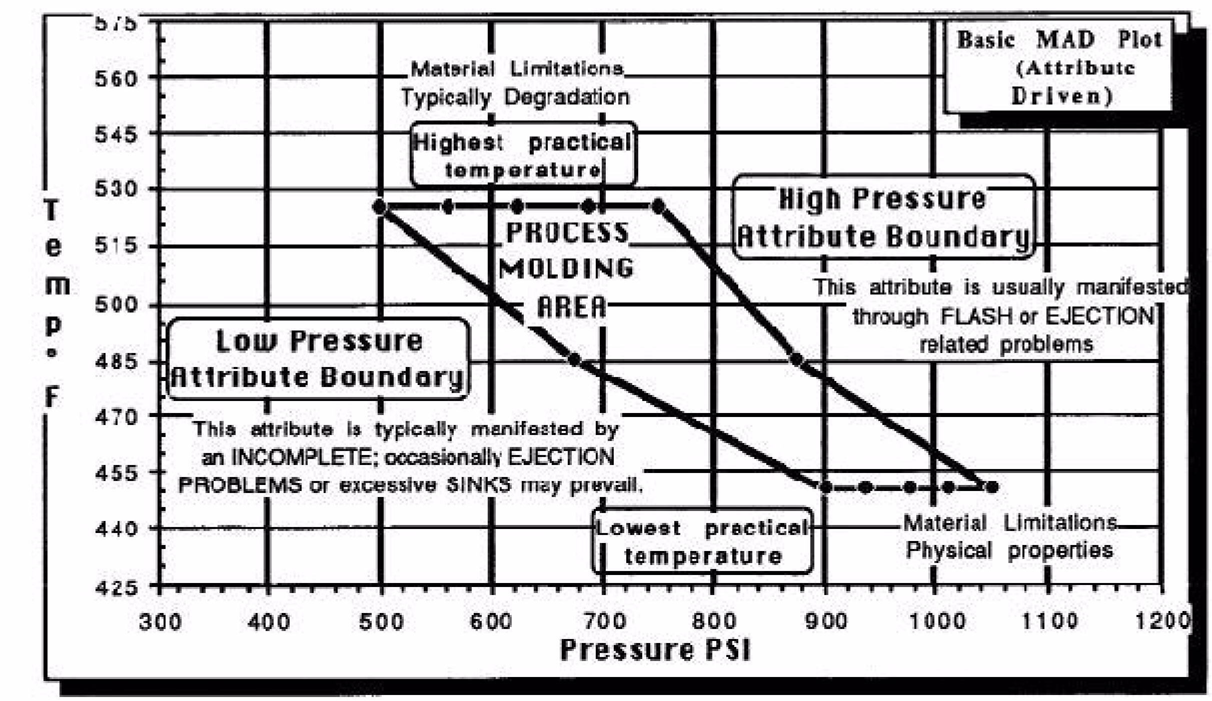

Figure 1 - Structure of the Molding Area Diagram

The nature of the process failure at the low- and high-pressure limits of the molding latitude is the key for process improvement. Molding latitude limits are primarily the result of mold cavity filling unbalance. The more unbalanced the filling pattern of a mold is, the smaller, and therefore less robust, the molding latitude will be. In multicavity molds, each cavity of the mold fills at a different time. This is the result of minor differences in flow paths, temperature, and gating/rheological effects. The pressure exerted on the plastic at the end of the filling process is time dependent, which means that, since each cavity fills at a different time, each final pressure will be different. Since plastic shrinkage is a linear function of cavity pressure, each cavity will shrink differently depending on when it filled. This effect is verified by the part weights of the various cavities. In a typical multicavity mold with "identical" cavities, the weight from each cavity will be different and the resulting pattern is similar to the cavity filling sequence pattern.

Example

The best way to understand this concept is through a practical example. Figure 2 shows the results and analysis of a simple 48 cavity hot runner mold using high density polyethylene (HDPE). Special MAD characterization metrics develop when the process is charted. These four characteristics -- Molding Latitude, Mad Area, Viscosensitivity, and Viscodecay -- are measured and their importance described. Formulas for all these characteristics can be easily derived and incorporated into a standard computer spreadsheet.

48 CAVITY PRODUCTION MOLD

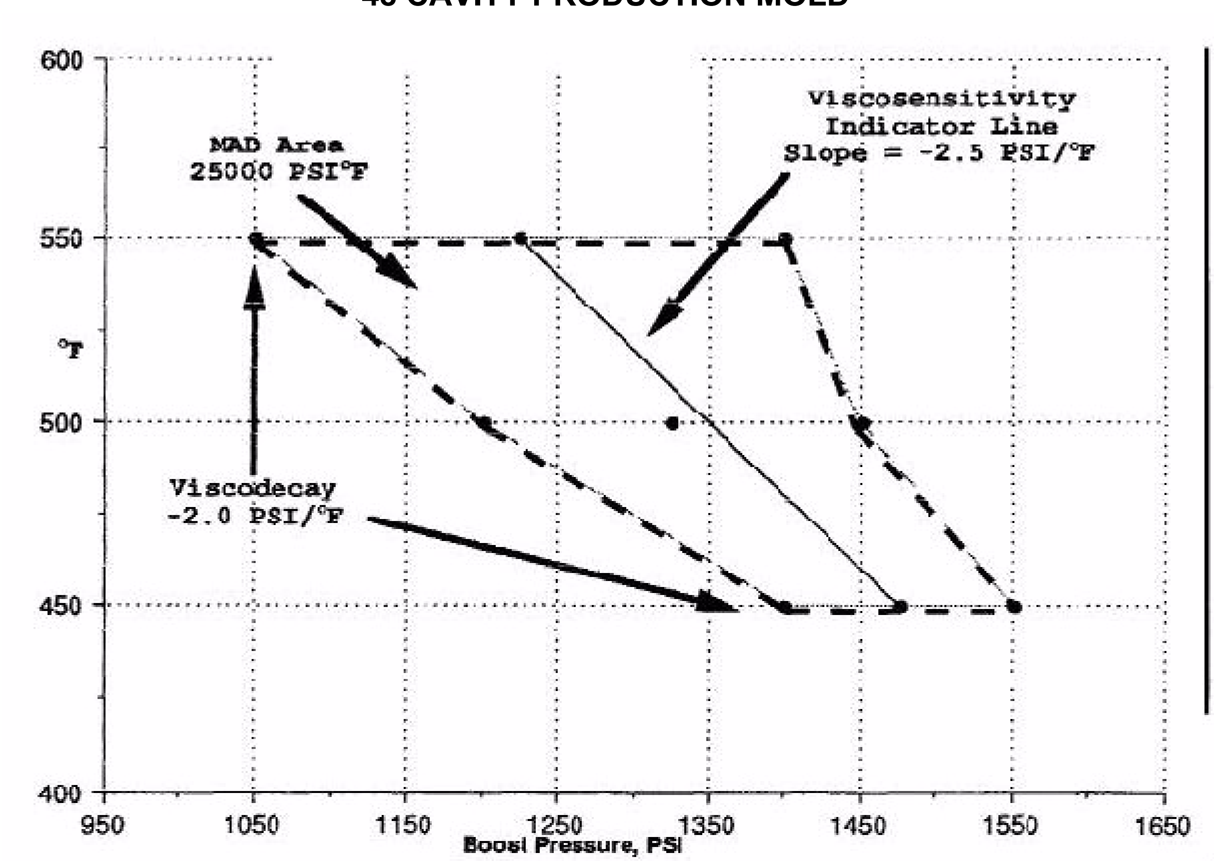

Figure 2 - Example of typical MAD with analysis

MOLDING LATITUDE - This is the pressure range within the attribute boundary limits of the process. For this example, the range at 450°F is 150 PSI, at 500°F, it is

250 PSI and at 550°F, it is 350 PSI. A typical minimum range for a production process is 100 PSI. In this case, all three temperature ranges are acceptable. For the final selection, the highest temperature was felt to be simply too hot and might cause some operating problems. The lowest temperature is at a point where the product performance might be affected due to excessive orientation levels causing cracking in normal use. This was a thin-walled part having a thickness of slightly over 1 mm. Experience had shown that molded parts with thickness in this range and below were quite susceptible to high levels of retained molded in orientation which significantly reduced useful impact resistance. The middle temperature was the final selection for the production process.

MAD AREA - This is the area within the boundaries of the trapezoid. To calculate this value, the formula for area, as well as the formulas for the other two characteristics, should be set up using a typical computer spreadsheet. This way a plot can be generated at the same time. The process is simple enough though, and manual calculating and plotting can be easily accomplished. The resulting area is an excellent comparison metric for materials evaluation studies and mold quality rating. A typical use of this calculation would be to compare "identical" molds for robustness or as a reference for the same mold when major tool changes have been incorporated in the mold. Material evaluations and comparisons can now be accomplished in an unambiguous and objective manner through the use of this parameter.

VISCOSENSITIVITY - The tilt of the figure yields another useful value to help the molder characterize both the robustness and potential problems with his process. This characteristic value is the slope of the line joining the midpoints of the molding latitudes that compose the high and low temperature boundaries. This value provides us with a sensitivity index related to the viscosity of the molten polymer. It reflects the combination of the effect of the material viscosity and the geometry of the mold.

This factor has significant bearing on the robustness of the process; the lower the tilt, the less sensitive the process will be to viscosity changes caused by temperature and material variations. The slope of the tilt for this example is -2.5 PSI/°F. This is within the normal range of observed values for this characteristic. It will always tilt to the left yielding a negative slope although, occasionally, very robust processes have been observed with practically no tilt over the temperature range evaluated. Processes having tilt values in excess of -10 PSI/°F usually exhibit very difficult operating histories.

VISCODECAY - A notable aspect of the typical MAD plot is the shrinkage of the molding latitude as the melt temperature decreases. If the MAD geometry is considered as an inverted, truncated pyramid, the rate of decrease of the molding latitude can be estimated by a simple linear calculation. (There may be some curvature in these boundaries - but in a typical molding process, these molding latitude boundaries are fuzzy and can be assumed to be linear for all practical purposes.)

For this example, the decay rate is -2.0 PSI/°F. This value is another indicator of processing stability and robustness. Its value is typical of many products and may approach zero on some very robust products. The molding area diagrams shown in textbooks usually show a decrease in width as the temperature increases but these are usually not based on practical production molds. Textbook examples are usually generated from simple single cavity molds and are run in machines with excess clamp tonnage available. With most production molds, melt-temperature problems, such as poor ejection or excessive runner curling occur long before such a zone is encountered.

An interesting byproduct of the Viscodecay value is the ability to calculate the temperature at which the process will vanish! For this example, the molding latitude at 450°F is 150 PSI. Using the calculated decay rate, the molding latitude will become zero at 375°F. At this point, the molded part will simultaneously exhibit both incomplete and flash attributes.

Procedure

MOLDING LATITUDES -- The machine holding pressure should be at a low level such that the screw is stable at the inject/hold transition and does not allow any filling of the cavity to take place. The overall machine cycle should be the normal production time. When adjusting the injection pressure to develop the attribute failure limits, the limit selected should be just inside the failure point. If parts are incomplete, or ejecting poorly, etc., the limits have been exceeded and the data is unusable. Limits tend to be "fuzzy" due to slight normal variations in the process. Back off from the extremes slightly when determining the limit. A few PSI does not make a significant difference in the final result.

TEMPERATURE -- The minimum difference between the high and low temperatures needed to develop useful process information is about 25°F. A temperature difference of 50°F is quite adequate and usually achievable. Selection of the maximum and minimum temperatures is the first step in the process of developing a molding area diagram. The difficulty with this step is that determining these temperatures is a subjective process, particularly in the selection of the low-temperature limit, and depends greatly on the judgement and experience of the technician. The high-temperature limit is usually (and easily) determined by process problems.

The low-temperature limit is typically characterized by excessive injection pressures and/or physical property degradation. Every technician has his own opinion on what is considered a "comfortable" maximum injection pressure. The physical property response of the polymer to melt temperature is another characteristic that should be strongly considered. Many processes have sufficient processing latitude to allow parts to be molded far below the temperature at which sufficient physical properties are developed. The most common property failure is poor impact strength. Molding at too low a melt temperature yields parts with excessive levels of retained orientation which results in poor impact performance. An example of this is HIPS (High Impact Polystyrene). When polymer temperatures are at or below 450°F, the practical impact strength is at an unacceptably low value -- often barely above crystal polystyrene.

The high-temperature limit is typically characterized by material degradation or molding problems due to unreliable part, or runner, ejection from the mold. These failure modes are easily identified.

During the experiment, plan to run a latitude at the midpoint of the two temperature extremes. This provides a more reliable picture of the process. When running the molding machine, it must be well stabilized at each temperature and is usually achieved by running "on cycle" for one hour. When performing a MAD procedure, start at the low temperature. In practice, molding machine barrel temperatures can only be raised! A molding machine takes 3-6 times longer to go down in temperature than to increase it by the same amount.

Careful planning and discipline are needed to develop high quality information with this procedure.
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