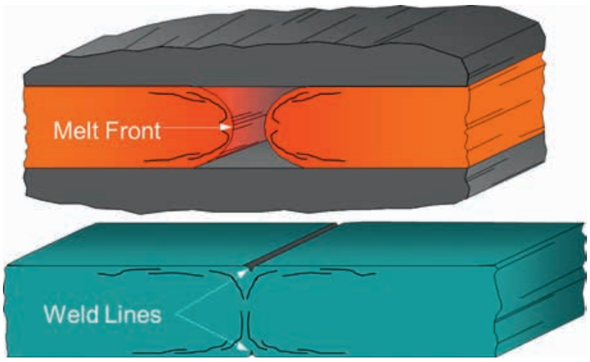
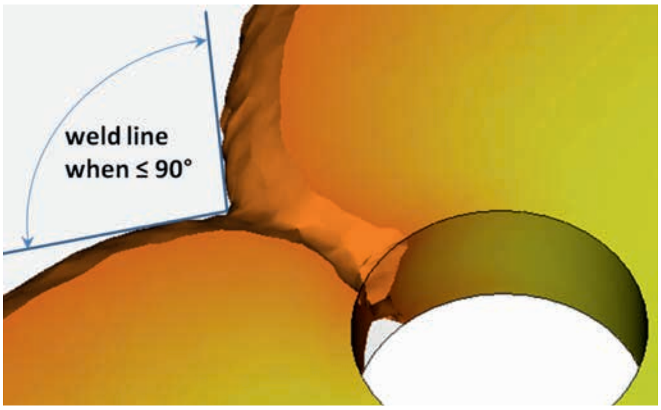
Understanding and Optimizing Weld Lines in Thermoplastic Molding

Weld lines (also called knit lines) are surface defects that form during mold filling when flow fronts come together at sufficiently small interface angles. This typically happens where flow fronts rejoin after holes or where flow fronts merge from two or more gates. In addition to being unsightly, weld lines can also be weaker than the surrounding area. For these reasons, it is important to understand how weld lines form, and how to optimize their appearance and strength.

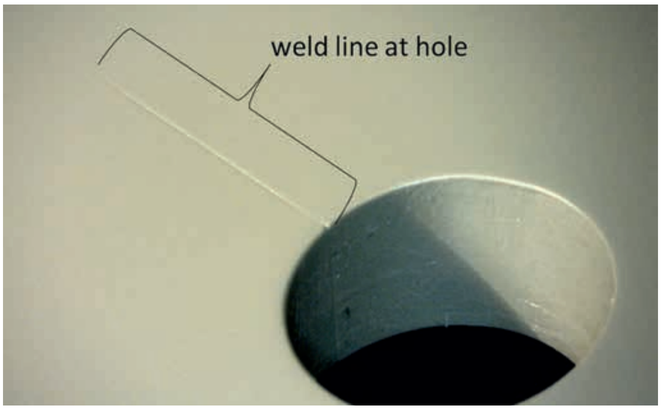
The flow of molten plastic in a mold does not progress in a turbulent manner as would a fast moving Newtonian fluid such as water. Nor does it slide along the walls of the mold cavity. Instead it moves forward by way of fountain flow. As the melt touches the much cooler mold surfaces, a skin of stationary plastic quickly forms. Portions of the long chain polymer molecules become lodged in the stationary and slow moving layers near the mold surface. This pulls plastic from the center, core region of the advancing flow front. Fresh melt exits the core and rolls out to the mold surface.



The resulting flow front has a rounded cross section with polymer chains laid out along the curved surface. When flow fronts meet head on as shown above, the rounded leading edges form a V-shaped groove along the interface. This "V" notch can act as a mechanical stress concentrator and reduce mechanical performance in properties such as impact strength and elongation to break. Reduced intermingling of the polymer chains across the interface is less than at other locations, which also reduces mechanical performance.



The preceding filling simulation plot shows how the flow front rejoins after splitting to pass around a hole in the plastic. A weld line will typically extend from the hole until the angle formed between the merging flow fronts exceeds about 90 degrees. The simulation was stopped at the instant when this occurred. The following image of a real part shows that the weld line does indeed extend to this location.

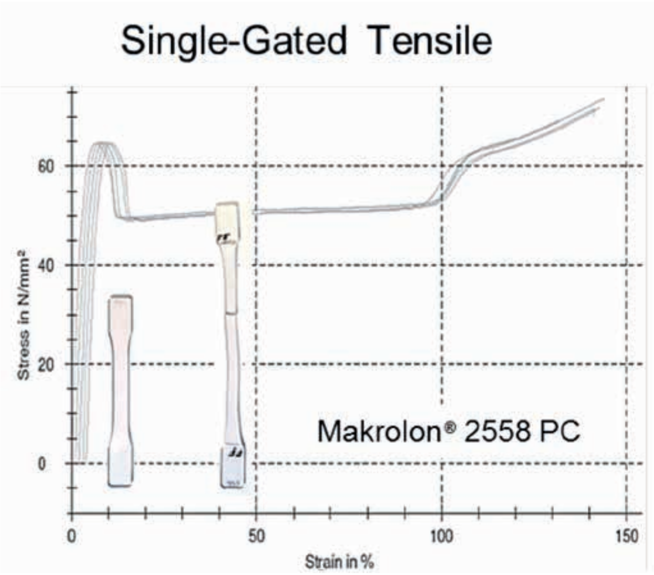


The flow front interface immediately beyond the visible weld line is called the meld line. The intermingling of polymer chains becomes increasingly improved as the meld line progresses away from the weld line until it is indistinguishable from normal flow.

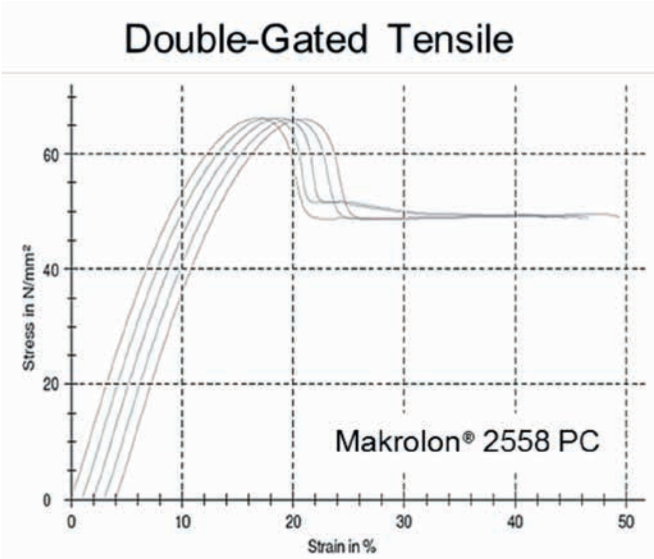
In glass-filled materials, the effect of the meld line on material performance may extend more than twice the length of the visible weld line. Meld lines typically have little or no effect on the performance of unfilled PC.

Plastics vary in how much weld lines diminish mechanical performance. One way to test the inherent weld line strength of plastics is to conduct tensile testing on standard dog bone tensile bars which were gated on both ends. These double-gated tensile bars have a severe, head-on weld line in the middle of each bar. Tensile testing on these bars can be compared to the same bars gated on just one end (no weld line) to see how tensile properties were affected.

The following tensile stress-strain curves show the typical performance for single gated (no weld line) tensile bars molded out of a common medical grade PC. Note that the peak at about 15 % strain shows the tensile strength at yield. Beyond this strain, the tensile bar goes through high levels of permanent deformation and thinning. Stretching continues until the part breaks at about 140 % strain.

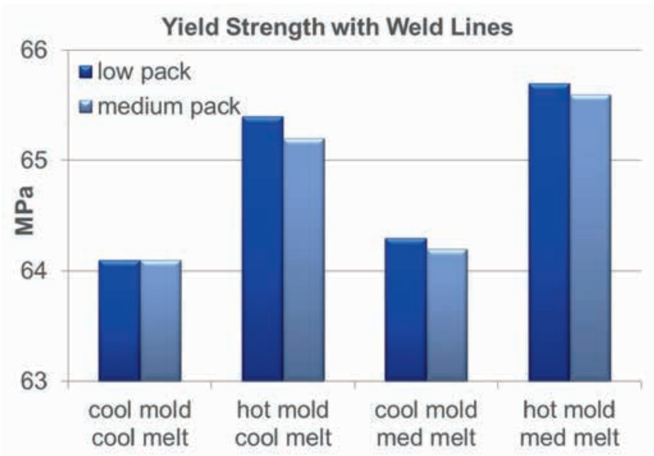


The following tensile stress-strain curves show similar results for double-gated tensile bars molded from the same material. The yield point is reached at about the same stress and strain as in the single-gated samples. After the yield point, these bars continue to undergo permanent deformation, despite the weld line, until they break at about 40 % strain, well beyond the brief static loading requirement of most applications. The drop in elongation-to-break reflects a vulnerability of weld lines to impact loads and stress cracking under excessive long-term loading. The “V” notch acts as a stress riser which can concentrate and focus stresses at the weld line and lead to premature mechanical failure.



The 3.2 mm thick PC tensile bars exhibited excellent retention of yield strength. Note that this testing is based on transparent Makrolon® PC resin. Fillers and certain opaque color packages, especially those with high levels of titanium dioxide or metal flake pigments, can substantially reduce mechanical performance.

Processing conditions can affect weld line performance. The following chart shows the results of a study that looked into the influence of mold temperature, melt temperature, and packing on Makrolon® polycarbonate weld line strength at yield. Of the three, a hot mold improved the strength the most. Elevated melt temperature had a smaller effect. Packing had very little influence. Note that the scale of the chart extends only from about 63 to 66 MPa, so strength at yield was quite good for these PC double-gated tensile bars at all of the conditions of the study.



The double-gated tensile bars used in these tests are relatively thick. Weld lines in parts with thin walls, long flow lengths and/or difficult-to-fill geometries may be significantly weaker. In unfilled PC and PC blends, it is safer to limit applied stress at weld lines to no more than 75 % of the published yield strength, less if the weld line area is particularly difficult to fill. For glass-filled versions of these materials, the allowable limit for weld lines drops to 50 % of the published tensile strength-at-break values. These guidelines are for briefly applied static loads. Guidelines for long-term loads call for a maximum applied strain of about 0.5 % for weld lines in most unfilled PC and PC blends. The actual stress or strain limits for a specific application need to be verified via thorough finished part testing.

Additional factors may affect weld lines in thin or difficult geometries. Some geometries may require a very fast filling speed to maintain a hot flow front and good bonding at the weld line. Undersized gates can limit the filling speed and reduce weld line strength. Inadequate venting at the weld line can trap air and impede bonding at the interface. Vents should be provided at critical weld lines, particularly if they are at the end of fill.

Gate placement and design are also important. When possible, position gates to avoid weld lines in areas subjected to impact or long-term loading, or in areas where a weld line would be cosmetically undesirable. Parts with center holes or openings, such as filter bowls, can be filled via a continuous diaphragm gate in the hole to avoid weld lines between gates.

Sequential valve gating can reduce or eliminate weld lines between gates in multi-gate applications. Hot runners for sequential valve gating are equipped with valves that can open and close the gates independently. Filling typically begins with one gate. Additional gates then open in sequence behind the advancing flow front, so weld lines are avoided. This process is most suited to parts with gates at intervals along their length.

Done properly, molding simulation can predict weld line locations, weld line severity and the flow front temperature at the weld line. It can predict if flow stops at the weld line or if flow continues in layers beneath the surface, thereby enhancing weld line strength. Simulation can also indicate if the gate is large enough to satisfy the filling speed needs without causing shear-related defects.

Rapid heat cycle molding (RHCM) is a relatively new processing technique in which selected areas of the cavity surface are rapidly heated for filling using hot oil, steam or heaters, and then rapidly cooled with water or cooler oil to solidify the part. This technique has been used in items such as TV bezels or automotive trim to enhance surface replication and to minimize or eliminate the appearance of weld lines. While RHCM has proven it can improve cosmetics, it is still unclear how much this surface-modifying process enhances weld line strength.

Weld lines are a normal part of injection molding and will appear in nearly any part with holes, openings, or multiple gates. While seldom a problem, they can be a source of weakness, particularly in parts subjected to impact or long-term stress, and their appearance can be objectionable in certain applications. It is therefore important to understand the techniques to optimize weld line appearance and performance as well as the ways to account for weld lines in the part design.

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