Design Issues on Living Hinges

Living hinges (also known as integral hinges) in a plastic part can be defined as thin, flexible webs that connect two relatively rigid adjacent wall sections. They can be injection molded, extruded or produced downstream via machining or stamping. The most durable of the three types by far is hinges produced by injection molding.

A living hinge is formed when partially oriented polypropylene is cold drawn and flexed for the first time, resulting in stretching ratios as high as 2 or 3 to 1. A tremendous increase in tensile strength is then produced. Well-oriented webs have virtually unlimited fold endurance, assuming the appropriate part design, resin, and molding conditions are utilized. Furthermore, they do not stress-crack unless chemically attacked. Severe oxidizing environments (including direct sunlight exposure) will degrade the service life of a polypropylene living hinge.

No test has ever worn out a properly designed and molded hinge of homo-polymer polypropylene. In most cases, the testing was simply terminated after approximately a million flexes. One hinge unit molded of a 4 melt flow rate homopolymer was flexed at 75℉ (23℃) over a 180° angle 300,000 times, then at -20℉ (-28℃) for another 300,000 cycles, and finally at 75℉ for 300,000 cycles, all without failure.

Fillers and reinforcements compounded into polypropylene will adversely affect hinge quality. As the elongation (at yield) of the compounded product is reduced, hinge quality is sacrificed. Consequently, high aspect ratio fillers and reinforcements including talc, mica, glass fibers can yield very poor hinge life. Lower aspect ratio, treated calcium carbonate, on the other hand, may be used if the hinge is properly designed and the expected number of flexes is limited.

The key to a good molded hinge lies in the ability to freeze polymer orientation during molding prior to cold drawing. Upon flexing, the following polymer variables will affect the amount of frozen orientation:

1. <u>Molecular Weight</u>: High molecular weight is very desirable. The lower the MFR, the better. Lower melt flow rate resins make for more difficult molding.
2. <u>Molecular Weight Distribution</u>: A broad range of molecular weight distribution is important. Longer chains cannot relax so easily as short chains. Reactor grades are better than their controlled rheology counterparts.
3. <u>Nucleation</u>: By helping freeze orientation, nucleation will enhance hinge quality, especially where thicker hinges (0.0 15 in./0.38mm) are concerned. However if there is melt flow hesitation, nucleation may actually hamper quality.
4. <u>Homopolymer</u> and Random Copolymers versus impact Copolymers Thanks to their higher starting tensile strength and low blushing characteristics, homopolymer and random copolymer polypropylene grades will produce better hinges. However, for cold temperature applications where the part requires impact resistance, impact copolymers are recommended.
5. <u>Chemical Stability</u>: The web is a relatively thin area, especially after cold drawing. a situation which makes polymers more vulnerable to UV-induced degradation and stabilizer extraction. Consequently, living hinge parts that are required to withstand exposure to UV light and or hot and wet environments must be specially stabilized for long hinge life, and tested to ensure suitability.

2. Injection Molding

2.1 Hinge Design

Figure 1 is a cross-section sketch of a proper hinge design. Note the use of radii to improve melt flow and reduce notch sensitivity in the hinge area. Consider, too, the suggested use of a radiused restriction. This will ensure bending at the thinnest point on a straight line along the web centerline.

Figure 1 also indicates that shoulders on the two main bodies may be used to offset any curvature of these parts on the perpendicular plane. These shoulders will also help when both parts of the molding are quite deep. It is not possible to develop a web hinge along a curved centerline.

Fig. 1 ***Typical polypropylene hinge design***

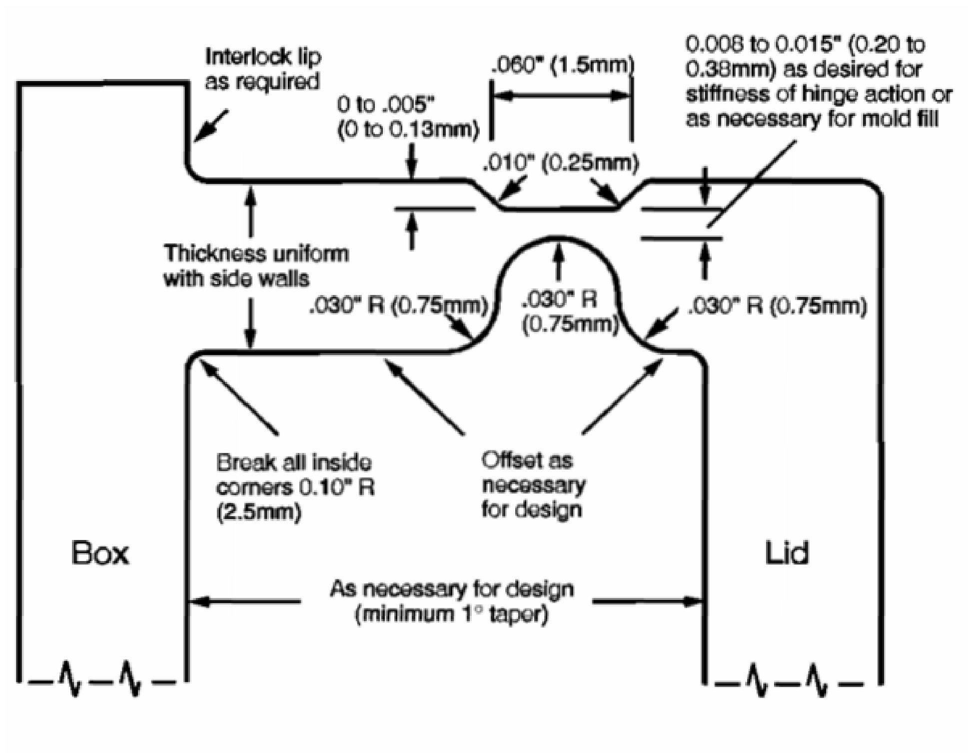
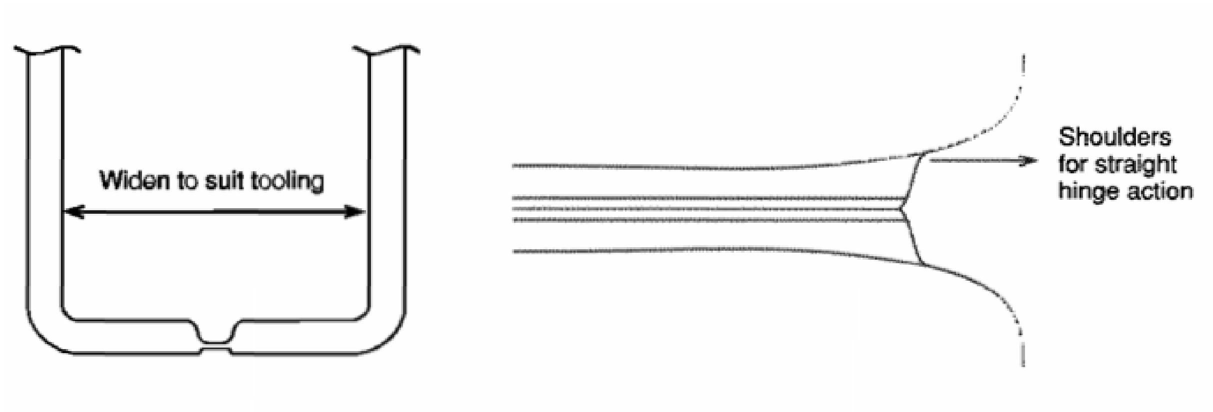


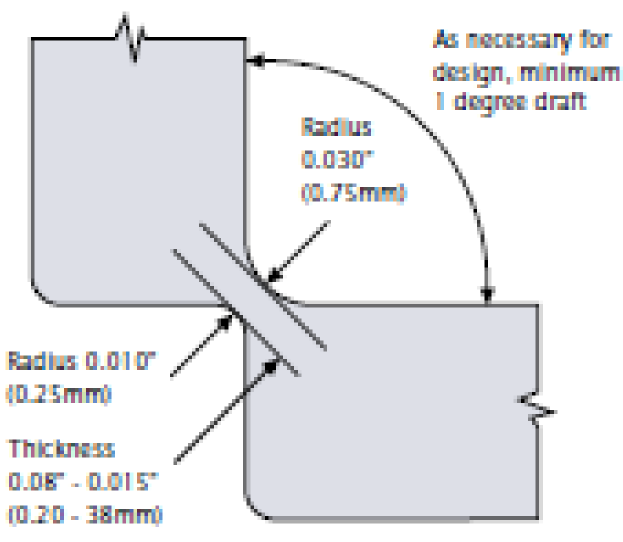
Fig. 2 ***Shoulder for deep moldings/straight hinge action***



As shown in figure 2, the inclusion of shoulders allows for an increase in the thickness of the section of the mold where the hinge is to be formed, thus preventing any bowing or breaking of the steel insert.

A typical land length is 0.060 in.(1.5mm). A land that is too short will cause insufficient back pressure, leading to non-uniform melt flow through the hinge and excessive stress on bending. A land that is too long will result in high pressure drops, underpacking across the hinge and a poor fit.

Fig. 3 ***Right Angle Hinge Design***



A slightly different hinge design is shown in Figure 3. Although not as efficient as the basic design shown in Figure 1 and with a more limited angular movement, this design will allow the hinge to be molded at an angle to the tool parting plane.

To make a tool steel-safe, it is advisable to start with a thin hinge (0.008 to 0.010 in. (0.20 to 0.25mm) and adjust upwards if necessary, to a maximum of 0.0 15 in. (0.38mm) Although thicker hinge sections may be employed where the required angular movement is small, these cannot be considered as true living hinges because they result in a lower degree of polymer orientation which may result in lower flex life.

Hinge sections below 0.008 in. (0.20mm) will cause excessive pressure drop, which may, in turn, create excessive local shear, excessive shear heat buildup and under-packed parts or short shots.

A well designed hinge will maximize molecular orientation — and orientation gives strength. In the same context, sharp corners must be avoided because they will act as stress risers (see Figures 1 and 2). Gates need to be positioned to ensure that the melt will flow perpendicularly to the hinge. Gate positioning will be discussed further in subsection 2.4. Hinges longer than 6 inches should be designed in 2 or more sections with small gaps or breaks between sections, this improves hinge life and reduces tool flexing.

For better hinge life, parts need to be flexed a few times immediately after molding (cold drawing) while they are still warm. This will allow for the web to elongate well beyond its yield point without breakage.

2.2 Tool Cooling

Proper cooling is an essential requirement in order to preserve the initial molecular orientation achieved during the mold filling stage. The importance of proper cooling can never be overstated, although coolant channel layout is frequently a secondary concern and depends on the amount of space left over in the tool after knock-out pins and other mold components have been designed. Ideally, cooling channels should run parallel and as close as possible to both sides of the binge (see Figure 4) to reduce the effect of shear heat buildup at the hinge land.

• Increasing hinge torque resistance

In addition to the living hinge angular movement, twisting forces may also occur. This is often the case with snap-on latches, lids, etc., where maximum stress develops at both ends of the hinge. The following approaches may prevent the hinge from tearing along the crease:

1.Increase hinge thickness at both ends, e.g.– from 0.010 to 0.020 in (0.25 to 0.50mm), over a length of 0.020 to 0.040 in (0.50 to 1.0mm), then blend in the two different thickness settings.

2.Add a 0.005 in (0.13mm) film at both ends of the hinge, parallel to the plane of the hinge. This thinner web will stretch and orient when torque is applied, thus preventing crack initiation. This thinner web has been shown to increase the torque-to-failure ratio tenfold (See Figure 5a.).

3.Radius ends of hinge to improve tear resistance, as shown in Figure 5b.

4.Add thin film across the end of the hinge (on a line perpendicular to the hinge plane) by shaving off the two ends of the hinge-forming core. Once flexed for the first time, this thin web will become highly oriented, therefore preventing crack initiation and subsequent propagation to the hinge (see Figure 6).

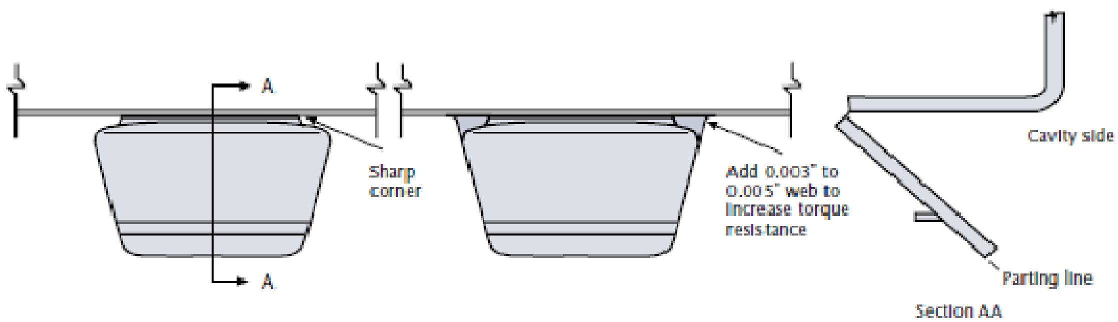


Fig. 5a. Improving hinge tear resistance

Fig. 5b. Improving hinge tear resistance

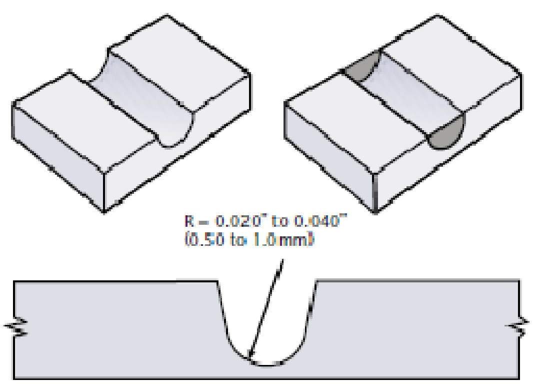


Fig. 6. Increasing tear resistance by adding thin web ends of the hinge

•Gate location

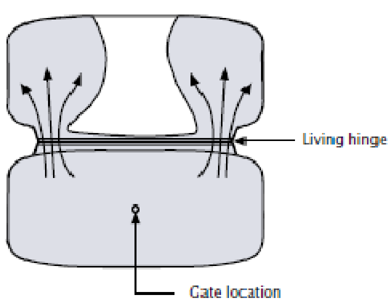
Gate location has a major impact on the amount of initial molecular orientation that exists across the hinge. Mold cavities must be filled perpendicular to the hinge plane so that once the melt front hits the hinge, it will continue flowing across without interruption until volumetric fill is reached. The gate(s) should be positioned so as to prevent weld line formation and/or air entrapment along the hinge area.

Figure 7 shows a long, narrow box and lid. If only one center drop is used, the flow will hit the hinge restriction before the gated cavity has filled. Because the hinge restriction represents a higher pressure drop, the melt will stop at the hinge until the extremes of the cavity are filled. At this point the pressure will rise, but because the center hinge area had already started to freeze, the material will flow across from both ends, creating a weld line along the hinge with possible air entrapment.

To avoid this situation, a design using multiple gates or a long flash gate is typically used, as shown in Figure 8.

Another suggestion is to break long hinges into two smaller ones with a gap in the center. The box in Figure 8 would then have two gates, one opposite each smaller hinge segment.

For a two-hinge construction (e.g. VCR cassette case, mop head, etc.), in order to avoid two flow restrictions in series, it is typical to multi-gate the part at the center section (see Figure 9). The center section should be slightly thicker than the adjacent walls by 20 to 30% to assist flow uniformity across the hinge.



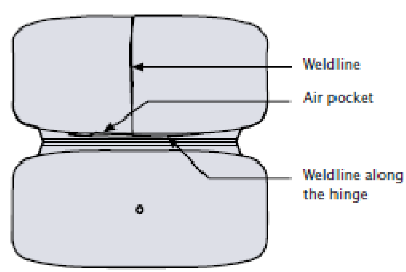


Fig. 7. Unfavorable gate location

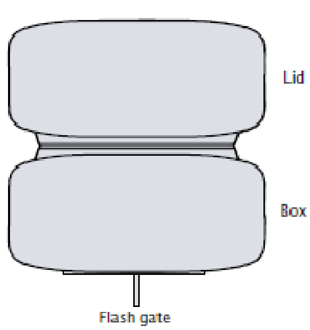


Fig. 8. Improved gating

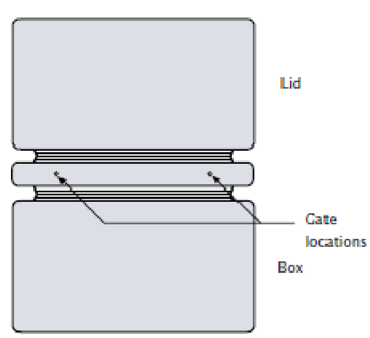


Fig. 9. Gating of a multiple hinge part (video-cassette case)

For square or slightly rectangular shallow boxes, the gate should be located on the bottom of the heavier cavity. It should be positioned beyond the cavity centerline, away from the hinge (as shown in Fig. 10). This type of design will assist the gated cavity to fill thoroughly before the melt starts flowing across the hinge restriction. Once it starts flowing across, there will be no flow hesitation.

For deep boxes, the gate may be positioned at the center line (See Figure 11). If walls are thinner than 0.040 in (1.0mm) or very large parts are to be molded with relatively tight tolerances underpacking on the non-gated cavity may be unacceptable due to the inevitable pressure drop across the hinge restriction. In this case, both cavities may need to be gated. In order to prevent the formation of a weldline along the hinge, the following approaches may be considered:

1.Both box and lid are gated on the center bottom. However, gates should be of different diameters, starting small and progressively making them larger while monitoring weld line formation via short shots. The knitline should be slightly away from the hinge. If hot drops are used, fine tuning may be carried out by adjusting tip temperatures independently.

2.Valve gates with sequential opening should be used. Timing should be adjusted by monitoring short shots and moving the knitline away from the hinge area.

3.The weld can sometimes be displaced from the hinge area by offsetting the gate on the smaller cavity beyond the centerline and away from the hinge. Gate sizes will have to be established by trial and error via short-shot analysis (Figure 12).

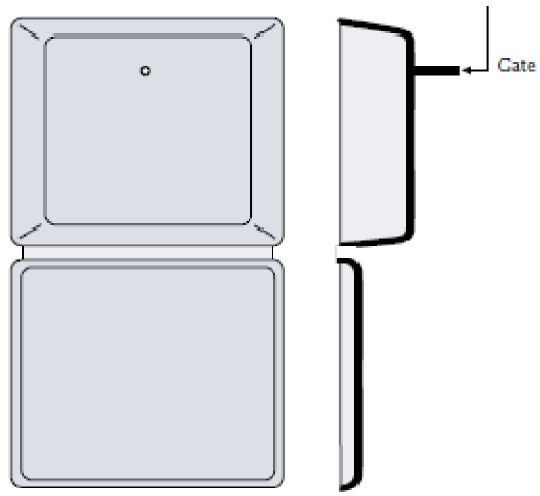


Fig. 10. Gating shallow boxes

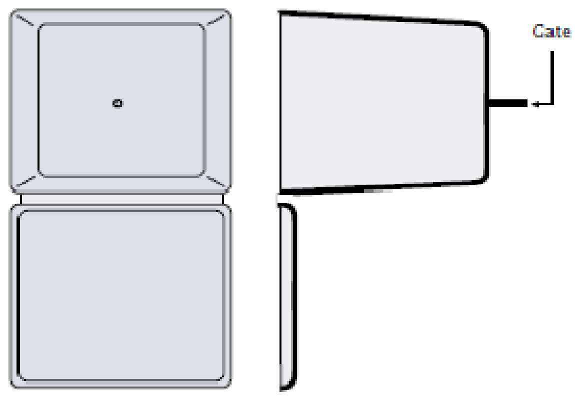


Fig. 11. Gating deep boxes

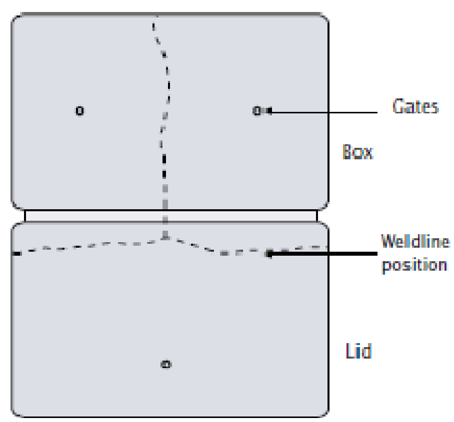


Fig. 12. Gating on both sides of hinge

Processing

To achieve favorable molecular orientation, it is important that the melt should flow uninterrupted through the hinge restriction, while full pressure is being applied until fill is achieved. The effect of gate positioning to maximize orientation and to prevent undesirable weld line formation and air entrapment has already been discussed.

The processing tips below will further contribute to hinge quality enhancement.

1. Cooling system

The cooling system should be checked (especially the cooling lines along the hinge) to make sure it is properly connected and functional.

2.The part

The part should be filled using medium to high injection rates without any step changes in velocity profile. Smoothly ramping up or down to suit specific tooling constraints presents no problem. Filling too slowly will likely cause flow hesitation which may lead to hinge delamination. Too low a melt temperature will cause similar problems. Excessively high mold temperature in the hinge area due to poor cooling may also lead to hinge weakness.

3.Mixing and plastication

Polypropylene pellets and pigment concentrates need to be fully melted and blended. If not properly plasticated, agglomerates may concentrate at the hinge, causing weak areas and eventual failure.

4.Venting

Because of the fast fill rate requirements, it is of paramount importance that the tool be properly vented. Clogged, insufficient or poorly placed vents represent additional problems which will cause flow restrictions and may lead to slow filling, air entrapment, burn marks and cosmetic defects.

Other manufacturing processes

In addition to injection molded hinges, polypropylene living hinges can also be made via stamping, blow molding, extrusion and machining.

• Stamping

Stamping is usually employed with extruded sheet. Hinges are produced when a forming die is used to apply heat and/or pressure to the sheet at moderate rates. High-speed stamping operations are not recommended as the polypropylene is not given time enough to flow and orient. In addition, roller dies are not recommended for this procedure due to the resulting unfavorable orientation.

Hinges formed by stamping should be approximately 0.020 in (0.50mm) thick. They are less durable in flexing but stronger in tear.

- Heated sheet/cold die: usually coupled with thermoforming. The die is cold since there is enough residual heat in the sheet.

- Cold sheet/heated die: this approach is more energy efficient if the sheet does not require pre-heating for other reasons. It also prevents distortion of the sheet, which occurs when highly stressed sheet stock is heated.

• Blow molding

Although more difficult to control, blow molding also allows for hinge incorporation. A 0.010 in (0.25mm) gap should be left at the pinch-off where the hinge is to be formed. In order to optimize hinge quality, the final mold closing speed has to be carefully adjusted.

•Extrusion

Although commercially practical, hinge quality is only fair for three reasons:

1.Molecular orientation is parallel to the hinge.

2.Extrudate cannot be flexed immediately after molding as it first has to go through the cooling line, haul-off and other downstream equipment to stabilize its shape.

3.Differential shrinkage due to uneven wall stock between the hinge and adjacent walls, leading to warpage. Warpage may be minimized if the shoulder thickness does not exceed 2 to 3 times hinge thickness.

•Machining

Hinges can be fabricated by machining extruded polypropylene sheet. Care should be taken to cut the hinge perpendicular to the extruded machine direction in the sheet stock. Machined hinges should have a similar design described for injection molded hinges.

Conventional cutting tools for wood and metal can be used to machine hinges. Because of the low heat conductivity of polypropylene in relation to metals, almost all friction-generated heat between the cutting tool and the polypropylene will be conducted to the metal tool. To minimize heat and friction, water-soluble oil or kerosene are recommended. Cutting speed should be the highest possible without overheating the tool. Heat build-up will tend to soften or melt the polymer, which will then be prone to sticking to the cutting tool.

Note: Machined or stamped hinges are sometimes used to manufacture working prototypes of polypropylene hinged parts.