Design Of Injection Mold For Specimens With Intentional Weld Line

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***Abstract*— This paper presents actual state of art of mold used for preparing of samples for tensile test with forced appearance of weld line. Two most common types of cavities with adjacent flow weld lines and opposite flow weld lines. Both types of cavities produce samples with perpendicular position of weld line to test load. Designed and produced new type of cavity allows producing samples for tensile test with rotated weld line to direction of load force. This mold will be used for production of polymer composite samples for further research. Weld lines are likely to occur in molded products, they must be taken into account during the mechanical and technological design processes. The weld lines become more critical when particulate fillers are compounded with the polymer.**

***Keywords*— weld line, mold cavity, polymer composites**

I. Introduction

Injection molding is one of the most productive processes used to form plastic parts. The effectiveness of the method depends on the quality of the product, which can be hindered by inadequate process settings or mold construction causing various deficiencies. Many kind of defect such as weld lines, warpage, jetting or sink marks can reduce the quality of the injection molded parts, worsening productivity. The occurrence of a weld line means a significant problem both aesthetically and mechanically in the design of injection molded parts.

The product quality of injection molded plastic parts is the result of a complex combination of the material used, the part and mold designs and the process conditions used to manufacture them. For injection molding processors
the weld line, also called knit line, is always a quality issue. Weld lines form when plastic melt splits, then recombines at some downstream location in the mold cavity during the injection process. This is inevitable when molding complex parts which have core inserts, variable wall thickness with the part, or runner branching for multigated parts.

In many injection molded parts, when two melt streams meet each other during the processing, a weld line is formed. When the meeting involving two flows coming from opposite sides is frontal and without additional flow, a cold or butt weld line is formed with lower mechanical strength. If the stream meeting is lateral and the fronts still have some time to flow together and under pressure, the resulting hot or streaming weld line is stronger than the previous one [I].

A weld line is a region of low mechanical strength of the part because of:

- unfavorable molecular or fiber orientation,
- insufficient bonding (incomplete molecular entanglement or diffusion)
- formation of a V-notch that works as a stress concentrator at the weld
- presence of contamination or micro voids at the weld interface

In the case of composites, the presence of a weld line is more critical, because the fillers tend to be oriented in the weak plane of the weld line. In cold weld lines, the molecular entanglement is worse, and the filler orientation in the weld-line plane is perpendicular to the direction of mechanical loading of the part. Even with lamellar fillers such as talc, which have a low aspect ratio, there is also a preferential orientation in the plane of the weld line.

Upon changing the processing parameters, it is possible to improve the weldline resistance. This improvement can be achieved through the improvement of the molecular cohesion in the weldline region, the rise of the molecular or filler orientation in the direction of mechanical loading, or the development of a favorable crystalline structure [2].

In composite materials the molding morphology and the subsequent mechanical performance are influenced by the presence of the filler. The properties of a material in a part are directly related to the morphology that develops during processing. The morphology is determined by the intrinsic characteristics of the material and the processing setup. It is well known that during the injection molding, and because of the developed stress rate and velocity profiles, a skin-core structure is formed across the thickness of the part. The skin is the highly oriented structure developed near the mold surfaces, where the shear rate is higher. The core of the molding, away from the cold mold surfaces, is a non-oriented spherulitic region. The degree of crystallinity, the skin/core ratio, and the overall structure are influenced by the processing conditions [3]. In the presence of a weld line, which is a macro-defect inside the molding and is also affected by the processing parameters, additional aspects concerning the mechanical behavior of the part must be considered.

Weld lines are formed when two melt fronts come in contact with each other. In a part with multiple gates, variable wall thicknesses, holes or cores form separate melt fronts during mold filling and the separated melt fronts create weld lines, causing numerous troubles in the part [4]. It not only worsens the local mechanical properties, but creates optical imperfections, especially when using high gloss materials. The surface marks of weld lines can be eliminated by the application of induction heating in surface temperature control, which was investigated on ABS tensile bars by Chen et al. [5].

Many parameters have an effect on the properties of a weld line and these factors have been investigated from many aspects. As regards mechanical properties, analysis of weld line strength and modulus was performed and showed that the weld line did not have a significant effect on tensile modulus [6]. Several researchers [7] used the weld line factor (WL-factor), defined as: strength of specimens with weld line/strength of specimens without weld line, to evaluate their experiments. Highest WL factors were obtained for unfilled materials and using high melt temperature, high holding pressure and low mold temperature. Weld lines were studied using laser extensometer and acoustic emission, and the conclusion was that a weld line is not a simple discontinuity in the material, but a locally extended disturbance of the stress and strain distribution [8].

Most of the research concerned the comparison of mechanical properties of specimens with/without weld lines molded by a dual-gated dog bone-shaped cavity. In this case, the weld line is formed by the head-on collision of the opposing flow fronts, and the flow immediately stops. How- ever, there are quite a few weld lines that are affected by an additional flow after the collision in practical injection moldings. For example, when an obstructive pin is located on the flow channel, the polymer melt is divided into two flow fronts by the pin, and then the flow fronts subsequently merge behind the pin. The merging polymer melt continues to flow until the flow channel is filled completely. There- fore, the influence of additional flow on the properties of the welded interface must be considered. We distinguish these kinds of weld lines, as adjacent flow weld lines, from those by the head-on collision, called opposite flow weld lines, as shown in Fig. I. Adjacent flow weld line is also called meld line or hot weld line.

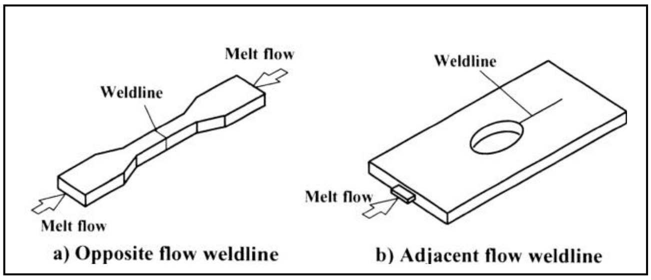

Fig. 1. *Types of weld lines*

Criens and Mosie pioneered the investigation of mechanical properties of adjacent flow weld line by measurement of tensile strength of injection molded plaques having two holes in tandem. However, they have not mentioned the influence of flow behavior after the collision. Research proves that the flexural strength of fiber-reinforced plastics varied scarcely along the weld line. Strength of some materials increased along the flow direction. The variation of strength along the flow direction means that the magnitude of the factors reducing weld line strength-V-notch at the surface, poor molecular entanglement across the interface, and molecular orientation along the weld line-varies along the flow direction. Therefore, in order to investigate the properties of adjacent flow weld line, it is important to clarify the effect of each factor. In particular, the structure of V-notch is considered to be the most important factor, being an obvious source of stress concentration that initiates fracture. This means that the effect of V-notch must be eliminated when the other factors except V-notch are investigated. Two techniques to accomplish this purpose are considered, i.e., removal of the V- notches using a milling machine, and application of a very keen crack into the weld line to deactivate relatively the V-notch.

II. MOLD CAVITIES WITH OPPOSITE FLOW WELD LINE

There are several types of mold cavities used to prepare samples for tensile test with weld line. Authors of case studies either follow selected standards or prepare own modification for special case. Koster [1] prepared tensile specimens from PS in mold according to ISO 8256 (fig.2).

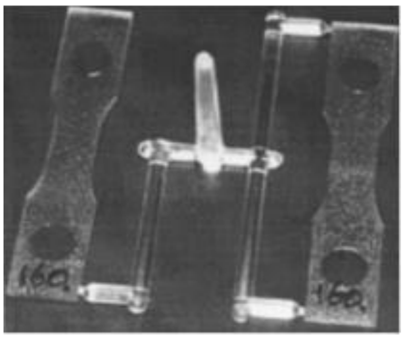

Fig. 2. *Single gated and weld line specimens according to ISO 8256*

Tung et al. used for sample made of nylon 6 congaing organically montmonirollite (organoclay) mold cavity as pictured in fig.3 [2]. Results show that nylon 6 has good resistance to weld line weakening.

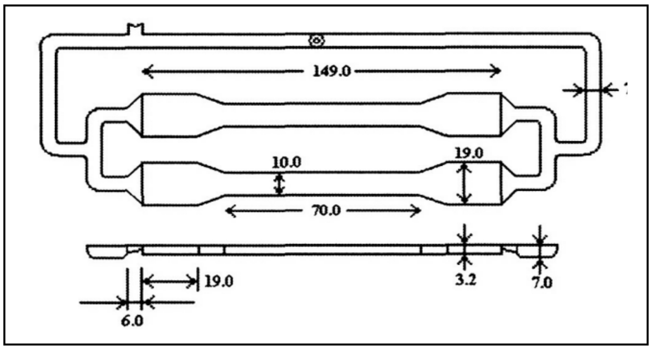

Fig. 3. *Mold cavity used for samples preparation from nylon6*

For the samples made from rubber a dumbbell mold cavity according to ISO 37-1997 E (fig.4) has to be used. For the dumbbell specimens, weld line weakness was not clearly observed. The average breaking percentage at the weld line region is extremely low and weld line strength decreased as the viscosity of rubber compound increased and I or had a short scorch time. It was believed to be due to the high tack property of the rubber compound and the very small mold cavity [3]

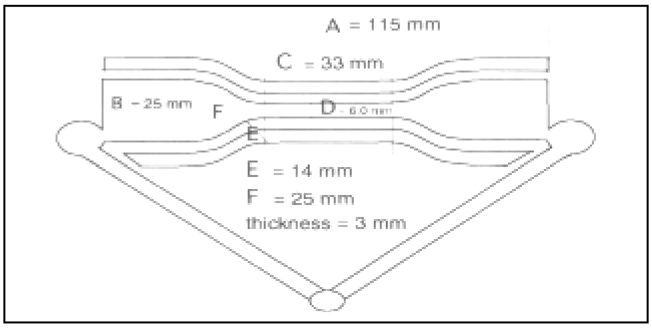

Fig. 4. *Dumbbell mold cavity used for samples preparation from nylon6*

For the case of micro-injection molding Xie and Ziegmann [9] used a mold cavity as presented in figure 5. Double-gated mold with this part cavity was designed and constructed. In order to avoid the short-shot of the micro cavity during injection molding process, a variotherm mold temperature control unit was integrated in.

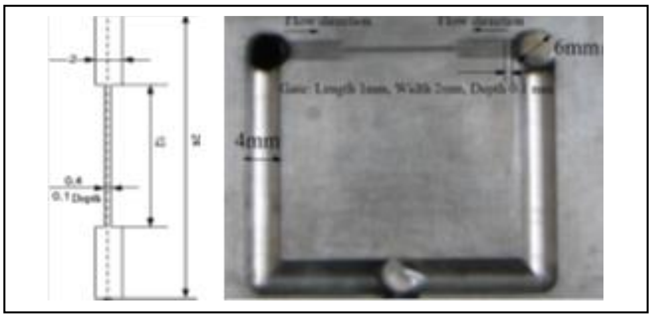

Fig. 5. *Dimension and geometry of the micro tensile sample (left). The cavity location and runner system arrangement in the real case.*

III. MOLD CAVITIES WITH ADJACENT FLOW WELD LINE

Samples for tensile test with adjacent flow weld line are commonly not produced in cavity with shape of tensile test bar. Molds for producing such samples have mostly square or rectangular shape of cavities. The cavities have either one or two gates. The one gated cavities have an obstacle placed in such way that they split the melt flow into two streams, which join again behind the obstacle and form a weld line (fig.6). The desired shape of tensile bar is then subsequently cut off from the plate.

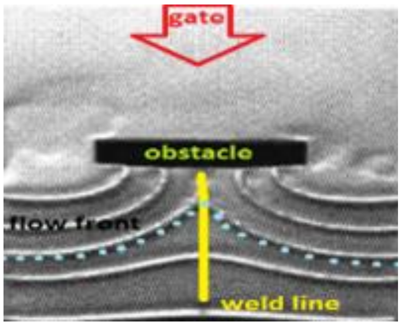

Fig. 6. *Melt flow front in single gated cavity with obstacle and position of the weld line .*

Ozcelik et al. [10] used a single gated cavity with various shapes of obstacles to produce weld line with various angles of flow front touch (fig.7).

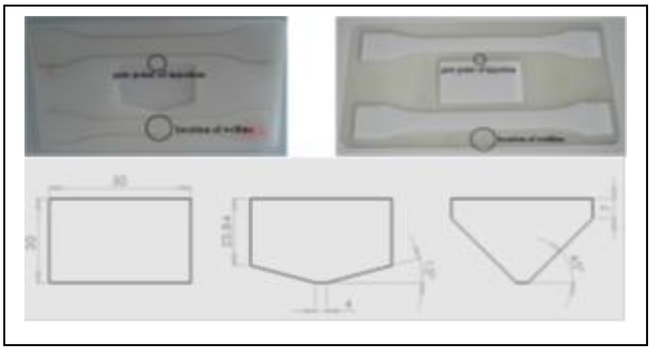

Fig. 7. *Design of mold cavity (up) and shapes of obstacles*

The shapes and dimensions of obstacles were verified via CAE simulation to obtain the desired flow front angles. With this mold effects of injection parameters and weld line on the mechanical properties of polypropylene (PP) moldings were studied. The tensile and impact strength of specimens having a weld line were lower than the values obtained from specimens without a weld line. The impact strength of specimens revealed more significant change than the tensile strength. The impact strength for the specimen without a weld line tended to increase as the packing pressure increased from 14 to 20 MPa. But, this result was not valid for the specimen with a weld line.

Another possibility to produce a sample for tensile test with adjacent flow weld line is use two gated solution. Kovács et al. [11] used a two gate mold cavity (fig.8). The gates in cavity are placed on the same side and distance between them determines the angle of weld line.

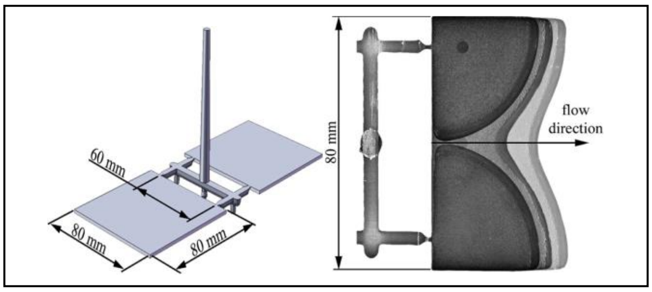

Fig. 8. *Design of double gated mold cavity (left) and melt flow front.*

IV. Design of mold cavity with opposite flow weld line with rotated weld line angle

For purpose of testing the influence of angle between weld line and load direction on tensile properties of composite polymers was a new shape of mold cavity designed. Proposed mold had two cavities, both double gated. In one cavity a classical sample can be molded, where the weld line is perpendicular to direction of load force. Second cavity had two gates placed in the middle of cavity on the opposite side. To be able produce a weld line with various angle of weld line, the distance between gates was changed and verified with CAE simulation in Autodesk Simulation Moldflow Insgiht [12,13].

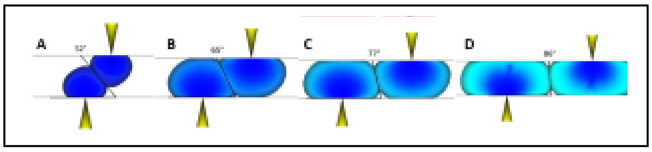

Fig. 9. *Distance between gates and obtained weld line angles (A=3mm, B=6mm, C=9mm, D=12mm)*

Based on results of injection molding simulation the obtained weld line angles were 52°, 65°, 77° and 86°. Increasing the distance between gates would lead to form the weld line perpendicular to loading force by tensile test, same as for sample from the first cavity.

Based on these result a cavity plate with runner and cooling system was proposed. The length of runner system was designed and verified via CAE simulation to gain the equal timing of melt flow through both gates in first and second cavity (fig.10). The runner system contains inserts that allows to change the cavity in which will be the sample produced and also allows the position change of gates in second cavity. Inserts were V-block shaped to achieve high accuracy and easy exchange. [14]

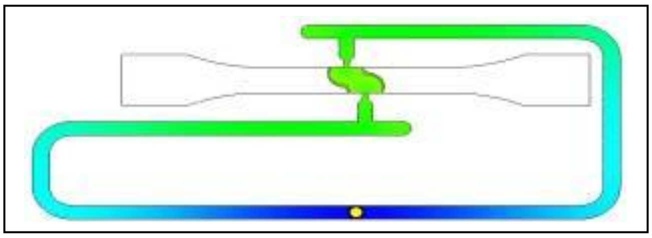

Fig. 10. *Designed runner system with balanced flow length, to obtain equal melt entry from both sides of cavity.*

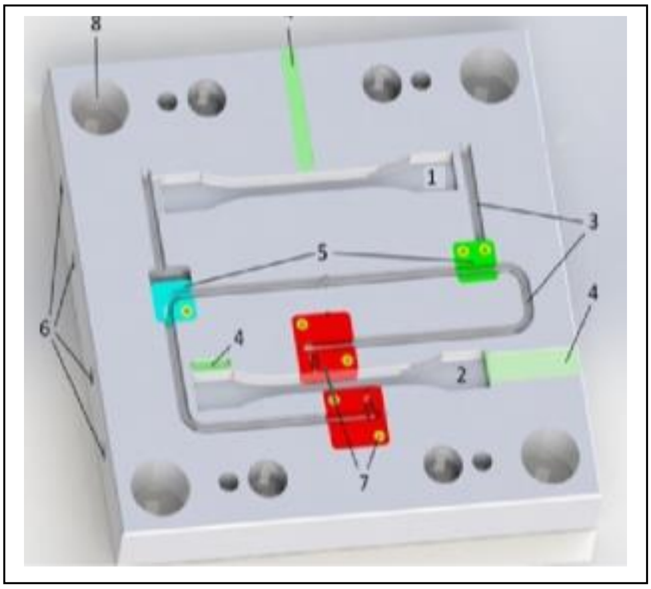

Fig. 11. *Cavity mold plate: 1-first cavity, 2- second cavity,3 –runner system, 4-venting, 5- runner system inserts for selecting cavity, 6 – cooling channels, 7-runner system inserts for changing of gate position, 8-holes.*

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