

OPTIMIZED MECHANICAL PERFORMANCE OF WELDED AND MOLDED BUTT JOINTS: *PART I – SIMILARITIES AND DIFFERENCES*

Abstract

Recent developments were oriented on the analysis of the mechanical performance at local (knit lines and welds) and bulk (molded part) areas, with the influence of molding and welding conditions. It has been found that for non-reinforced and reinforced nylon, the mechanical performance in the knit planes and welded areas are approximately equal to the mechanical performance of a base resin (matrix).

The observations on similarities and differences in the formation of knit and weld lines are presented in Part I of this paper.

Introduction

Previously we reported to Antec [1-2] our studies on the efficiency of various welding technologies (linear vibration, orbital vibration, hot plate, infrared/laser and ultrasonic) on the mechanical performance of welded thermoplastics. Mechanical performance of the welded joints depends from key welding processing parameters, such as weld-melt temperature, clamp and hold pressure, melt-down (melt collapse), hold/cooling time, and thickness of inter-phase. The mechanical properties of the injection-molded thermoplastic components depends on the part and the molding tool design, and utilized molding processing parameters such as melt and mold temperatures, molding pressure, injection rate, cooling time, etc. [3-4].

There are many design and technology cases for welded plastic components, which require multiple gated injection molding systems. Mechanical performance of these welded, injection molded multiple gated plastic parts such as chassis/bodies (Figure 1), air intake manifolds (Figure 2), etc., depends from uniform distribution and orientation of flows and welds, and the material property patterns. Both the design of these welded parts and the molding tool design is very important to get optimum flow patterns and to predict the locations of stress-bearing areas and knit (molding)^a and

weld (joining) lines (planes). Mechanical performance, of the injection molded and welded thermoplastic components, is very critical for the various industrial applications (automotive under-the-hood, bumpers, appliances, power-tools, etc.) [5-6]. High performance non-reinforced, fiber-glass reinforced and glass/mineral versions of nylon 6 based plastics were utilized in many applications [6-8].

The process of weld (weld inter-phase) formation during welding is similar to knit/meld line formation in injection molding. In [1-2], we tried to describe the vibration welding process as “micro re-molding”, when the weld (weld inter-phase) is created where two plastic flow’s front meet and formed a weld. The following welding processing parameters, such as a clamp pressure, melt-down (melt collapse), melt-weld temperature, thickness of the flows and inter-phase, hold (cooling) time, etc., may affect the mechanical performance of the weld (“weld line”).

Similarities and Differences in Formation of the Weld, Knit and Meld Lines

Key Parameters Affecting Mechanical Performance of the Weld and Knit Lines

The successful design and advanced manufacturing of injection molded and welded thermoplastics components require a correct combination of knowledge in material, design and processing technology. Both, the welding and injection molding processes offers a wide degree of freedom of design and optimized mechanical performance of the components, which may be obtained only if:

- The material developers, plastic part, mold and weld tools designers take the numerous specific processing factors related to the knit and weld lines formation into account.
- They will realize these combined effects in finalizing:
 - All welding and injection molding processing conditions and optimized gate(s) location.

^a Sometimes called the weld line or weld plane [1-2]. In this study, we will use the term “knit line” for injection

molding, and the term “weld line” for welding of thermoplastics.

- Welding and molding tools design.

In general, the following “key” material and parameters affect the weld (welding) and knit (molding) line integrity [3-4, 9-11]:

- The extent of physical and mechanical property change depends on the ability of the two melt flows to knit (joint) together homogeneously.
- Type and properties of base resin (matrix).
- Molded part thickness.
- Presents of fillers, reinforcements and impact modifiers
- Welding and injection molding process conditions such as:
 - Temperature and viscosity of the molten polymer/plastic when it meets.
 - Mold (or welded part) temperature.
 - Molding (or welding), clamp/hold/back pressure.
 - Molding (or welding) and cooling/hold time.
- Orientation and interaction of the melt flows and stress-strain patterns.

Formation of the Knit and Meld Lines

By geometry (shape and sizes), the knit and weld lines are very similar. These sizes depend upon the design of molded and welded parts, including the design of welded joints (Figures 1-3). By length, they are long and are equal to the length of the contour of the welded part(s) or to the width/length w of the molded wall. The thickness t of the knit (or weld) lines is equal to the thickness of a wall (or weld bead). Specific data on localized material properties in knit and weld areas are very important for the structural analysis and life assessment of various multiple gated and welded plastic parts such as chassis (Figure 1), air intake manifolds (Figure 2), resonators, fluid reservoirs, etc.

The knit and meld lines (planes) are created wherever polymer flow's front meet from opposite or parallel directions correspondingly (Figure 4-6). These lines (planes)^b are significant for injection molded and subsequent welded thermoplastic part performance because the local mechanical properties in the knit, meld and weld lines areas differ significantly from those in the rest (bulk) areas of the molded parts. Knit lines are weaker than meld lines [3, 8-10]. The knit lines become likely areas of the crack initiation and propagation and possible injection molded part failure. These weaknesses can change the mechanical performance of thermoplastic components. A family of knit lines may be formed from

^b In the mechanical performance and morphology analysis, we will use the term “inter-phase” also as the three dimensional description of this very complicated by glass-fibers and polymer chains re-orientation areas.

one gate, and the divided plastic streams joins after flowing through ribs and a ring (Figures 6). Mechanical performance through cross-section of the knit line(s) will depend on melt flow temperature profile. The example of melt flow temperature distribution at the end of the fill cycle is presented in Figure 7 and Table 1. These results are showing the possibility for different cooling conditions or the skin and core layers. This will affect crystallinity distribution through cross-section of molded part/specimen also^c. Figure 7 (a, b, c) shows various plastic flow patterns, orientation patterns related to mechanical property performance. The melt in the center has a lower viscosity due to its higher melt temperature (see Table 1). As a result of this distribution, the maximum shear rate occurs not at the contact area with a mold surface but closer to center of the melt. Orientation of the knit lines in the round components is perpendicular to the tensile stresses, applied to the ring (Figure 6). The maximum of tensile strength of molded plastic is in the direction parallel to flow (Figure 8). In order to achieve controlled fill patterns, the mold designer should select the location and number of gates that will result in the desired areas.

Prediction of the Knit and Meld Lines Location

The methods of neural networks were successfully applied in prediction of the knit lines during injection molding process. Developed computational simulation packages have had success in predicting filling behavior in very complicated geometry of various hollow components. Molding parameters are influential on melt flow formation and finally on the performance of the knit line (inter-phase). A practical thermoplastic part design – melt flow consideration is to combine concepts of full optimization of *mechanical performance* of thermoplastic parts where multiple gating systems were used. The number of gates and internal shutoff cores should be considered as an important aspect of:

- Initial thermoplastic part design.
- Prediction of part performance with the influence of location of stress-bearing areas and weld planes/lines.

Standard mold filling and cooling analysis (MoldFlow® data, Figures 1, 5-6) provides the designer and technologist with a quantitative data on flow patterns and the knit lines (planes). Critical plastic flow distance and the number of gates and internal shutoff cores should be considered an important factor of thermoplastic part design for required uniform mechanical performance.

^c “Optimizing The Mechanical Performance In Semi-Crystalline Polymers: *Roles of Melt Temperature and Skin-Core Crystalline Morphology of Nylon*”, N. S. Murthy, V. A. Kagan, and R.G. Bray (report to Antec’2001)

Unfortunately, it was not possible to find in the published literature detailed recommendations on nylon based plastic selection and design for multiple gated injection molded and welded parts containing the knit lines. Published data on mechanical performance of fiber-glass reinforced nylon in knit line is limited also [3, 9-10]. Previously, it was assumed [10] to use for design of nylon made components the tensile strength of knit line in range from 46 to 93% of base material strength (for level of GF reinforcement from 10 to 30 wt.%^d GF). The above recommended [10] range of the ultimate strength of knit line is very wide for design purposes and needs to be defined more precisely for the critically loaded components, when a part weight saving is very important.

Formation of the Weld Lines

In general, process of development of the weld lines is very similar to knit lines formation when melt flows are coming from two opposite located gates (Figures 9-10). During the welding of thermoplastics, two uniform (by geometry) melt flows will develop and meet at weld plane area and will create the weld inter-phase. As an example for weld line formation, we will use the frictional method of welding. Frictional methods (linear vibration, orbital, spin and ultrasonic) of welding technologies all share the following phases, very important for weld line formation:

- Thermoplastic heated in areas where the joints are to be formed.
- Local melting in joined surfaces areas.
- Heated surfaces contacting/pressing together for joining.
- Cooling in the joint interface and other areas.

By geometry (shape and sizes), the weld lines are very similar to knit lines. These sizes of the weld lines depend upon the design of the welded beads (Figure 3). By the length, weld lines are very long (up to 2 m and more) and are equal to the length of contour l of the welded part(s). The thickness t of the weld line(s) is equal to the thickness of the narrow part of weld bead.

Morphology of the Knit and Weld Lines

Fiber-glass reinforcements display flow orientation during vibration welding and injection molding. For injection molding, the degree of orientation (fiber-glass and molecular) depends on aspect ratio, plastic part dimensions, injection rate, and gating. Plastic flow orientation leads to the clearly defined anisotropy of mechanical properties in fiber-glass reinforced nylon. Similar fiber-glass re-orientation effects were

found for multiple gated injection molded and welded part (Figure 10) and knit line (inter-phase) also (Figure 9). The tensile strength and modulus reaches a maximum value in the flow (longitudinal) directions and up to 50% less in the transverse (perpendicular to flow) direction. For 33 wt.% GF nylon 6, this decrease might reach up to 50–60% of the similar value due to micro-cracks orientation.

Developing of the knit-lines (inter-phase) are critical for the maximum stress area that results in the mechanical performance at knit line. As melt flow fronts meet, the fibers are turned 90° from the direction of flow. This is 90° from the direction of expected applied tensile stresses, so fibers are aligned perpendicular to the applied tensile stress and offer little reinforcing effects at knit line/plane (Figure 9). Molded part (or specimen) thickness does not play a major role in the knit line strength retention. The details on mechanical performance of the weld and knit lines will be discussed in Part II of this paper.

Concluding Remarks

Knit and weld lines become likely areas of a crack initiation and propagation, and possible molded and welded part(s) failure (or damage). For the multiple gating system, the melt-flow is largely governed by dimension and shape of the injection molded components, processing parameters and the location, number and sizes of the gates. Prediction of location and orientation the knit and weld lines are very important in the design of multiple gated injection molded and welded thermoplastic parts.

Prediction of the knit and weld lines should take into account orientation of *maximum* stress-stresses. It is recommended that the surface that is containing the subject to high load^e - bearing should not contain the knit and weld lines. Orientation of the knit and weld lines should be considered with loading and end-use conditions.

Acknowledgements

The author wish to thank Pransanna Godbole, Lynn Griffin, Jeff Kipnis, and Christopher Roth for help in preparing this study for publishing. Their contributions are greatly appreciated.

References

1. Kagan, V., A., Proceedings of the 57th Annual Conference and Exhibits, pp. 1349-1356, 1999.

^d Level of reinforcement of filler by weight (wt.%).

^e Stresses /strains - bearing

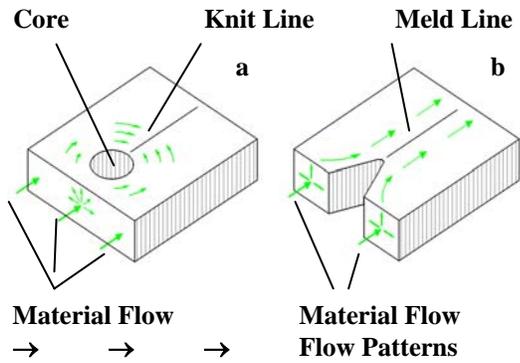


Figure 4. Knit (weld) and meld lines formation principles. Legend: a – formation of the knit (weld) line; b – formation of the meld line.

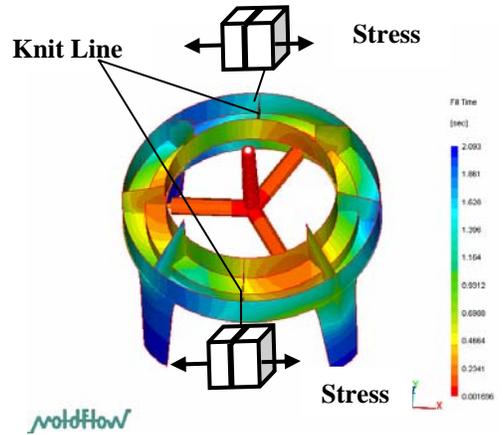


Figure 6. An example of the flow patterns and knit lines formation (MoldFlow® data) in the injection molded housing (nylon 6, 33 wt.% GF).

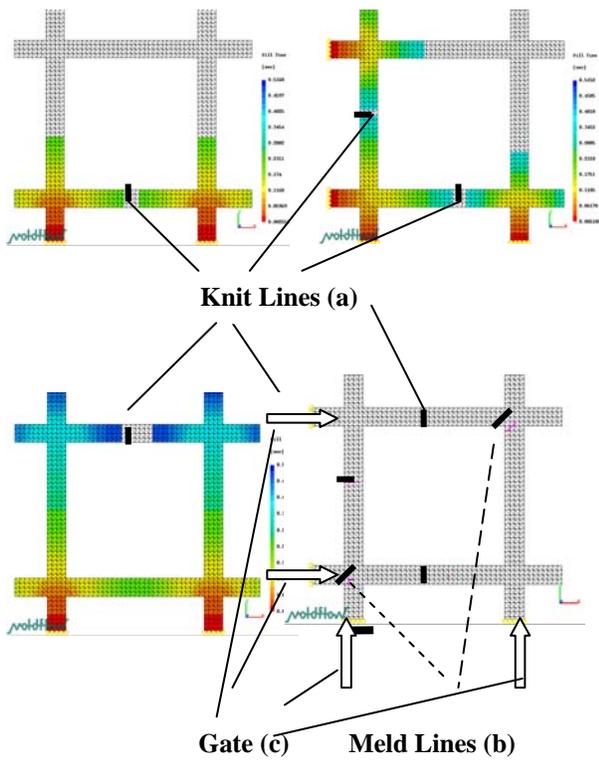


Figure 5. Different plastic flow patterns create knit and meld lines (MoldFlow® data). Legend: a – knit line; b – meld line; (c) – molding gate.

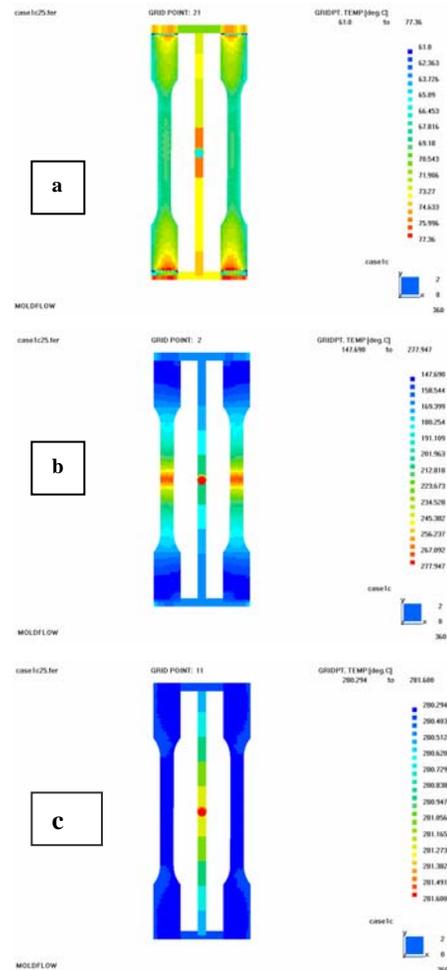


Figure 7. An example of the melt flow temperature distribution through thickness of gated from both sides injection molded ISO tensile specimen (MoldFlow® data, nylon 6, 33 wt.% GF). Legend: a – skin layer/area; b – inter-layer (between the skin and a melt core); c – flow/melt core central layer.

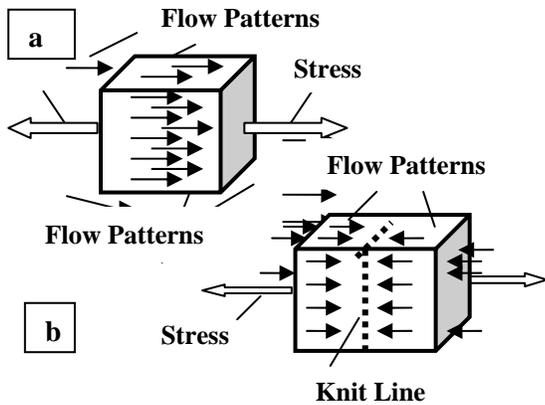


Figure 8. The effect of melt flow orientation on mechanical performance of injection molded parts/specimens. Legend: a – applied stress is parallel to flow direction (unidirectional fiber-glass orientation); b – applied stress is perpendicular to the knit (weld) line.

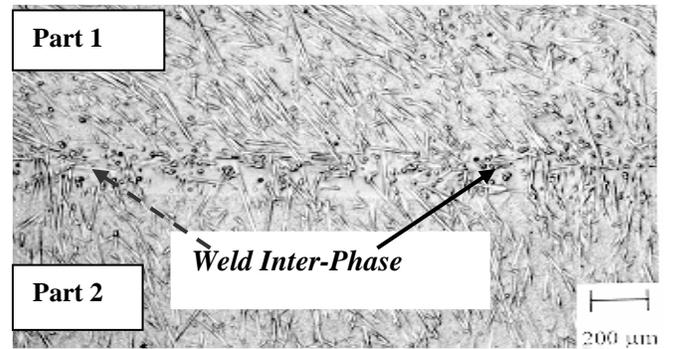


Figure 10. Local reinforcement effects at the weld inter-phase (a part of fibers are crossing the weld inter-phase). Data obtained for linear vibration welded nylon 6, 33 wt.% GF.

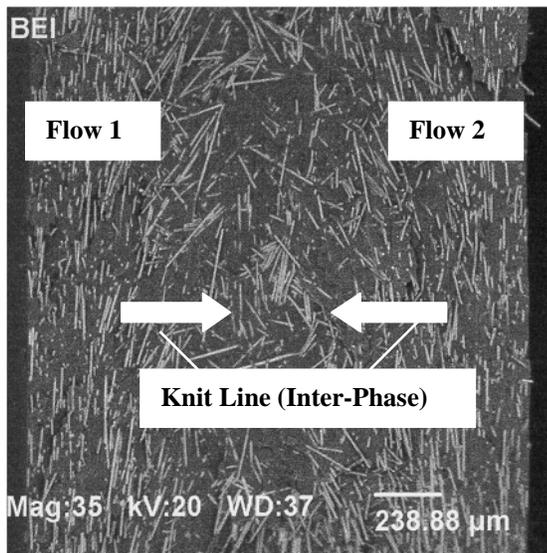


Figure 9. Example of fiber-glass orientation at knit-line (inter-phase area) in injection molded multi-gated part. Data obtained using nylon 6, 33 wt.% GF.

This information is provided for your guidance only. We urge you to make all tests you deem appropriate prior to use. No warranties, either expressed or implied, including warranties of merchantability or fitness for a particular purpose, are made regarding products described or information set forth, or that such products or information may be used without infringing patents of others.

BASF Corporation
3000 Continental Drive - North
Mount Olive, New Jersey 07828-1234

www.basf.com/usa
www.plasticsportal.com

©Copyright BASF Corporation 2003

HELPING MAKE PRODUCTS BETTER™

BASF