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Kovács J. G., Sikló B.

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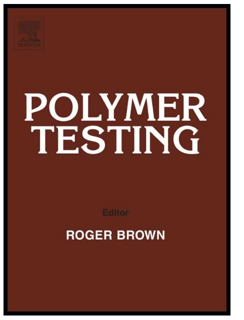

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Authors: J.G. Kovács, B. Sikló

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Property modelling

Experimental validation of simulated weld line formation in injection moulded parts

*J. G. Kovács[1], B. Sikló[1],

[1]Department of Polymer Engineering, Budapest University of Technology and Economics,
H-1111 Budapest, Műegyetem rkp. 3., Hungary
*Corresponding author J. G. Kovács, e-mail: kovacs@pt.bme.hu

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*J. G. Kovács[1], B. Sikló[1],

[1]Department of Polymer Engineering, Budapest University of Technology and Economics, H-1111 Budapest, Műegyetem rkp. 3., Hungary
*Corresponding author J. G. Kovács, e-mail: kovacs@pt.bme.hu

Abstract

The interest in weld line analysis of injection-moulded parts has increased in the past few years, mainly because of the ever-increasing requirements for the performance of injection-moulded items. Weld lines are formed when two melt fronts come in contact with each other. Whereas the total elimination of weld lines is not always possible without modifying the part geometry, their negative influence on part performance and appearance can be minimized. This can be done by trial and error experiments or by model prediction. The cost and time efficiency of the latter makes it a preferred route for weld lines analysis. Computer simulation packages of injection moulding are capable of accurately predicting the weld line location, but none of the current ones can predict the weld line contact angle or mechanical properties quantitatively. This paper focuses on the analysis of weld line formation and suggests ways to modify the finite element mesh to get better results.

Key-words: weld line, knit line, injection moulding, simulation, finite element mesh

Introduction

Injection moulding is one of the most productive processes used to form plastic parts [1-6]. The effectiveness of the method depends on the quality of the product, which can be hindered by inadequate process settings or mould construction causing various deficiencies. Many kind of defect such as weld lines, warpage, jetting or sink marks can reduce the quality of the injection moulded parts, worsening productivity. The occurrence of a weld line means a significant problem both aesthetically and mechanically in the design of injection moulded parts.

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 mould filling and the separated melt fronts create weld lines, causing numerous troubles in the part [7, 8]. 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. all [9].

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 [10,11]. Several researchers [12-15] 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 mould 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 [16].

The interest in weld line analysis of injection-moulded parts has increased greatly in the past few years, mainly because of the ever-increasing requirements for the performance of injection-moulded items. Whereas the total elimination of weld lines is not always possible without modifying the part geometry, their negative influence on part performance and appearance can be minimized. This can be done by trial and error experiment or by model prediction. The cost and time efficiency of the latter makes it a preferred route for weld line analysis. Computer simulation packages of injection moulding are capable of accurately predicting the weld line location, but none of the current ones can predict the weld line properties quantitatively. This is mainly because a mathematical model for weld line properties is, to date, unavailable [17]. In their article, Zhou and Li [17] presented an evaluation model for weld line strength based on the artificial neural network method (ANN). For the input of the network, the factors affecting weld line properties were chosen; those are the orientation coefficient of the material, the meeting angle and the melt mobility history coefficient. Comparison with experimental results shows that the presented model is capable of predicting weld line properties quantitatively for engineering design. Zhou et al. [18] examined the effects of melt temperature and hold pressure on the mechanical properties of specimens with weld lines and found that the yield and fatigue strengths of the specimens increased with increasing hold pressure as well as increasing melt temperature. They explained the observed differences in properties in terms of a skin-core morphology, which was influenced by both the melt temperature and the holding pressure.

Au [19] used a geometrical approach to generate the filling patterns of plastic parts and determine the approximate location of possible weld lines. Fathi and Behravesh [20] studied the kinematical behaviour of the flow during weld formation with a visualization technique, while Zhou and Li [17] developed an artificial network to predict weld line properties. The affecting factors were analyzed in detail in order to identify the input parameters for the network.

The formation and positioning in noncritical areas of unavoidable weld lines are also investigated with simulation analyses. The controlling of the flow for weld line positioning for multi-gated parts was carried out with a runner resizing method [21]. Mezghani [22] compared the simulated weld line location results with the real position on injection moulded parts. Zhou and Li [23] presented a weld detector algorithm, which is based on the characteristics of the initial meeting node. Chen [24] applied fuzzy theory for controlling the weld line position by varying the wall thickness and the gate location in part simulation models. Chun [25] showed by simulation the effect of wall thickness and gate location on the formation and position of weld lines.

Experimental

The experiments were performed on an Arburg Allrounder 320C 600-250 injection moulding machine using a two cavity-injection mould (Figure 1.). This special mould has changeable inserts to be able to inject with different gate types (standard, film, special-film, multi gates, etc.), with different mould surface finishes (polished, fine eroded, rough eroded) and to inject different thickness specimens (0.5-4 mm). The thickness of the samples is set by a moving part to position the depth of the cavities. The ejection system of the injection mould differs from the conventional one; it does not include ejector pins but operates on the whole part surface area, so eliminating deformation of the sample. The gate type can be varied with the change of an insert interposed between the cavities without dismounting the mould from the injection moulding machine. For the experiments, a fine eroded surface finish was used and an insert with double standard gates was set in the mould.

Each part, having nominal dimensions of 80 mm x 80 mm x 2 mm, was injection moulded from two points (Figure 2.). The two standard gates are located on one side of the cavity 10 mm from the part edge and 60 mm apart.

Polyamide 6 (Durethan B30S, Lanxess) was used for the investigations. Before injection moulding, the material was dried at 80°C for 4 hours. The injection processing conditions were kept constant; the mould temperature was 90°C, while the melt temperature was set on 280°C. The specimens were produced with short shot technology using different switch-over point settings (Figure 3.). The meeting angle of the melt front was measured on the samples as a function of the flow distance (Figure 4.).

The results of the measurement are plotted on Figure 5. It can be clearly seen that the meeting angle increased with the flow length. At a flow distance of 7 mm, it reached a measurable weld line angle of about 28°, while at a distance of 22 mm the angle achieved was 100°. At longer flows the measurement of the meeting angle was not possible because of the profile of the melt front.

The meeting angles were also constructed from the visualization of the melt fronts using concentric circles centred at the gate locations. The results showed that the increase of the drawn meeting angle was not as high as the measured values (Figure 5.). At a theoretical flow distance of 10 mm it represented the measured values well but at a longer distance it underestimated the experimental scale.

Analysis

Injection moulding simulation with the finite element method is the most advanced technique for designing injection moulds. There are different levels of program available on the market. The basic ones are helpful in product design, which can be used without having deep knowledge of plastic manufacturing. The more complex programs are able to simulate the whole injection moulding process so one can see whether the mould will be able to work perfectly or not. Such software cover enormous databases of materials and machines and the designers must have professional knowledge of plastic manufacturing.

For an injection moulding simulation, in most cases two-dimensional triangular elements or three-dimensional tetrahedron elements are used to describe the cavity, with two-node tube elements for the runners, connectors and channels. The melt front advancements are calculated by the control volume method. The pressure, temperature and velocity field can be obtained in each time step. These results constitute the basis of the stress and deformation analysis as well as results for weld lines.

Moldflow Plastics Insight 6.2 was used for the simulation analyses with a model of the part used in the experiments (Figure 6.). During the analyses, three different midplane mesh types were used and compared: original mesh, ideal mesh and smoothed mesh. Each mesh type was completed in 4 mesh edge lengths: 1, 2, 2.5 and 5 mm.

Original mesh means that the model consists of equilateral triangles and the nodes along the estimated weld line did not produce a straight line. The advantage of this mesh type is the good aspect ratio. The aspect ratio of the mesh elements is important because it affects the accuracy of the results. The ratio defines the correlation between the longest side of the triangle and the triangle area, and the recommended maximum aspect ratio for a midplane mesh is about 6. It can be seen that at every edge length this type of mesh triangle was greater than an average aspect ratio of 1.5.

Ideal mesh is made up of isosceles triangles with collinear nodes. The advantage of the generation of this mesh type is that it can be well automated, however, because of the worse aspect ratio, namely 2, it was not as accurate as the original mesh (Figure 7). In the case of the smoothed mesh, the nodes of the original mesh are converged to form a line creating a more uniform path of the mesh triangle sides in the area of the predicted weld line.

It was generated from the original mesh type with modification at the weld line region. The nodes positioned on the weld line were made nearer to the ideal weld line position.

The process settings for the simulation analyses were identical to the experimental injection moulding, constant mould temperature and melt temperature namely 90°C and 280°C.

The weld line analysis results were compared to the experimental. In most cases, the ideal mesh type best fitted the results of the measurements. At an edge length of 1 mm, the analyses with ideal and smoothed mesh type came close to the measurement results between flow lengths of 7 and 10 mm (Figure 8.). The values calculated with original mesh type fluctuated around the measured results along the whole examined flow length and did not approach them, while the other mesh types differed from the measured at the beginning of the flow. It was also observed that after a distance of 10 mm a steep weld line angle increase was predicted by all of the meshes.

At a mesh length of 2 mm and a short flow distance an oscillation was again noticeable (Figure 9.). Original mesh gave the most inaccurate results compared to the measurements. There were big angle value changes: it calculated a weld line angle of 0° at a distance of 10.6 mm but 147°at 12 mm. Except for the original mesh, the difference from the measured results at longer flow paths was smaller than at an edge length of 2 mm.

Increasing the edge length to 2.5 mm, the similarity between measured and simulated results decreased (Figure 10.). Weld line angles calculated in the simulation with ideal mesh came nearer to the measured results in the flow distance region between 15 and 20 mm but other mesh variations did not follow the trend of measured values.

Using an edge length of 5 mm, there was weak agreement between the curves (Figure 11.). Although the analysis results showed some similarity, unexpectedly, results came near the measurement values at only a few flow lengths.

Comparing the different mesh types at each edge length, it can be noted that in every case ideal mesh possessed the best correlation with the measured data, varying between 0.95 and 0.98 (Figure 12.). It can also be seen that the best correlation of ideal mesh was at high edge length, namely at 5 mm, although the correlation decreased relatively little with reduction of edge length. With original mesh type the correlation was the lowest but improved considerably with edge length, however, this sort of mesh type did not reach as high correlation values as the ideal. Using smoothed mesh, the correlation improved with edge length but also did not reach the values of ideal mesh types.

Conclusions

The validation of weld line simulation results was attempted by comparing them with experimental values derived from the measurement of the meeting angle at different flow lengths. The results of analyses prepared with 3 different mesh types – ideal, original and smoothed – were compared. The results showed that ideal mesh type had the best correlation to the measured values and original the weakest concordance. The smoothing of the mesh in the region of the weld line improved the correlation of the results, however, it did not reach the ideal ones. It was also concluded that analyses using a higher edge length had, unexpectedly, better correlation than the smaller ones.

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Figure captions

Figure 1. The special injection mould

Figure 2. The parts with the runner system used for the experiments

Figure 3. Short shot technology based weld line angle measurements

Figure 4. Measurement points on the samples

Figure 5. Weld line angles, measured from the samples with short shot technique

Figure 6. Finite element model of the samples

Figure 7. Aspect ratio of the different mesh types

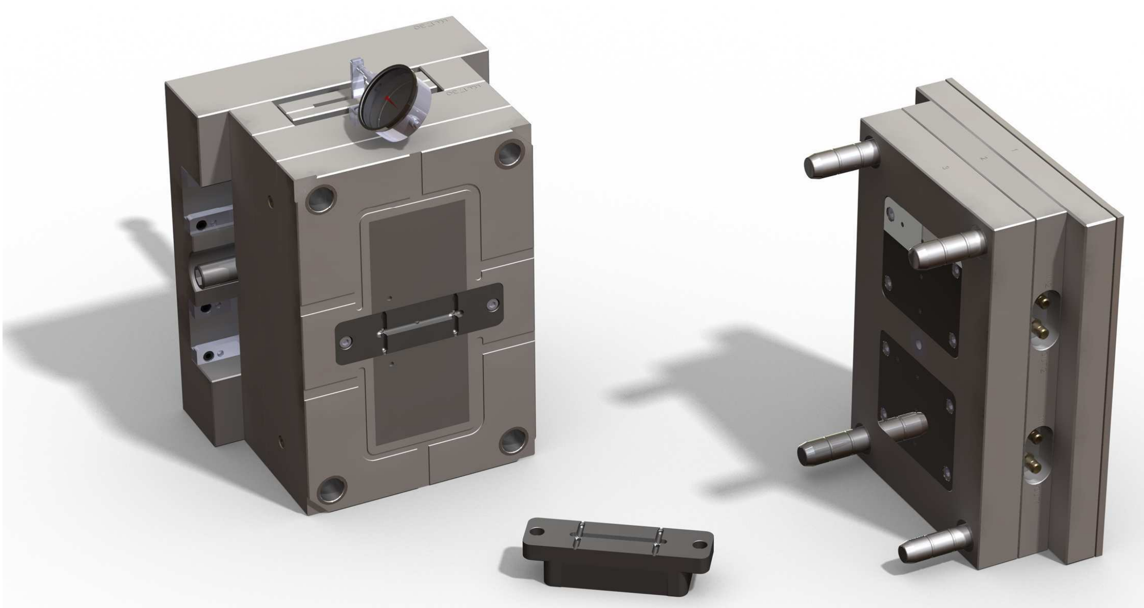
Figure 8. Weld line angles, measured and simulated values (with mesh length of 1 mm)

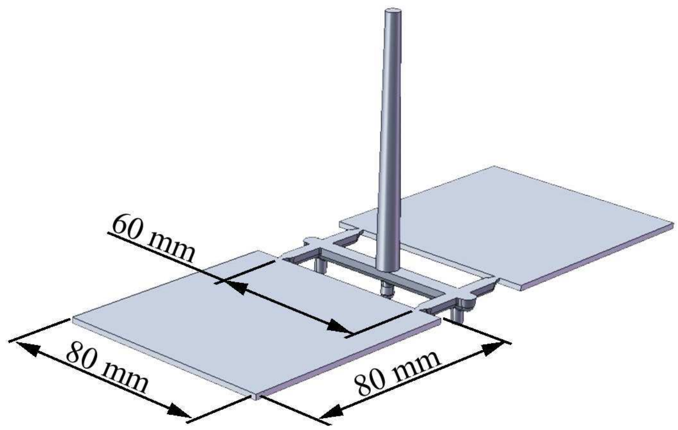
Figure 9. Weld line angles, measured and simulated values (with mesh length of 2 mm)

Figure 10. Weld line angles, measured and simulated values (with mesh length of 2.5 mm)

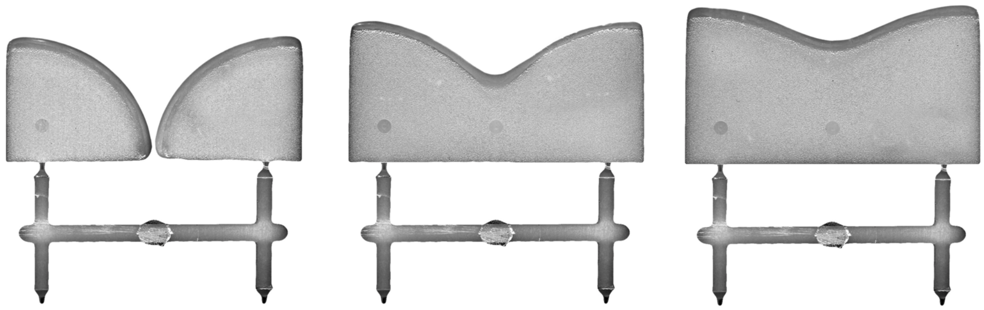
Figure 11. Weld line angles, measured and simulated values (with mesh length of 5 mm)

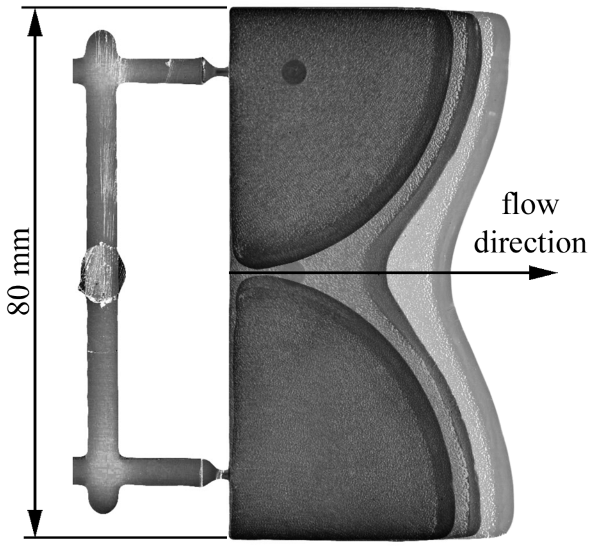
Figure 12. Correlation between the measured and simulated data

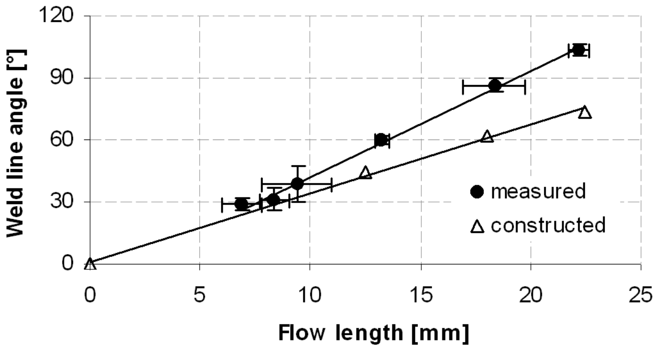




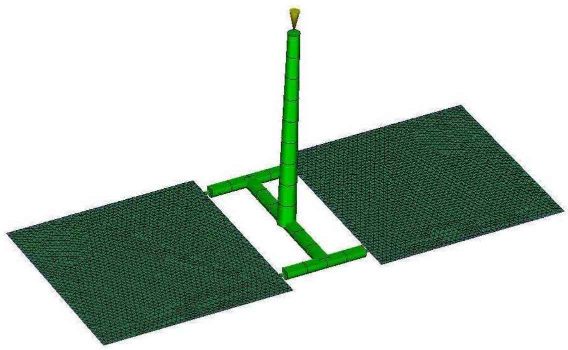
60 mm
80 mm
80 mm

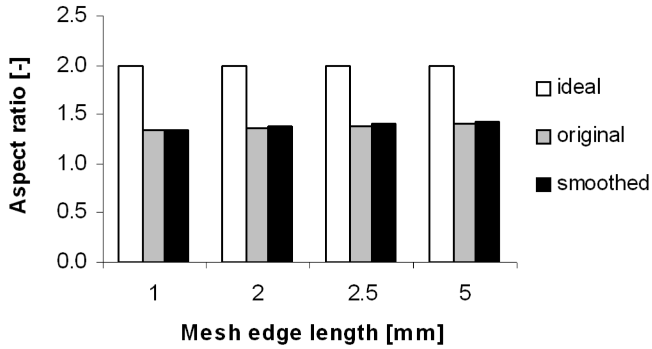


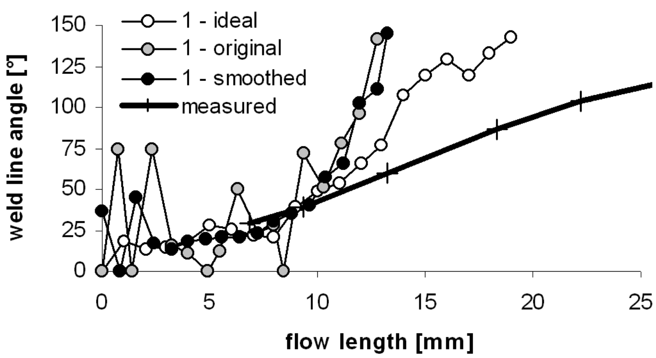

80 mm
flow
direction

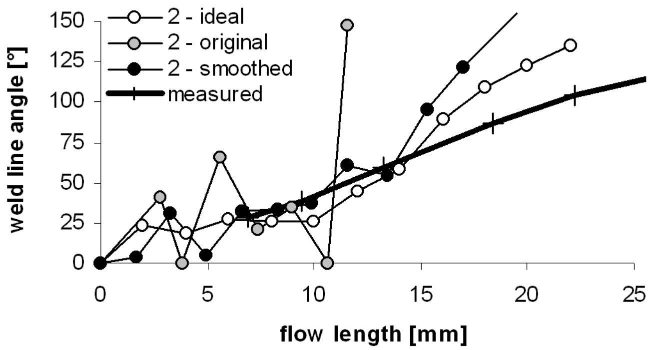


Weld line angle [°]
120
90
60
30
0
0
5
10
15
20
25
Flow length [mm]
measured
constructed

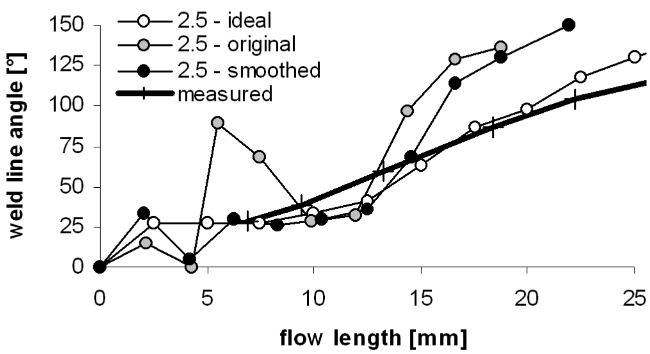



2.5
2.0
1.5
1.0
0.5
0.0
Aspect ratio [-]
1
2
2.5
5
Mesh edge length [mm]
ideal
original
smoothed

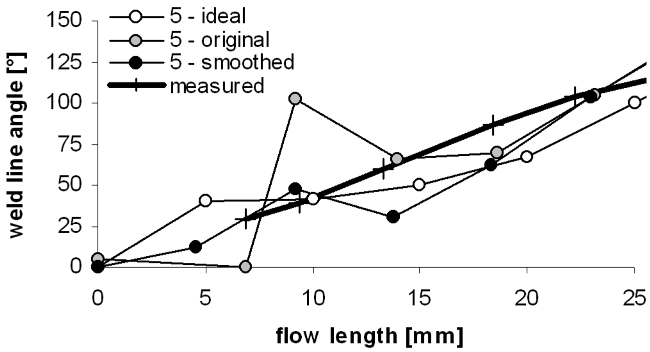

1 - ideal
1 - original
1 - smoothed
measured
weld line angle [°]
flow length [mm]
150
125
100
75
50
25
0
0
5
10
15
20
25



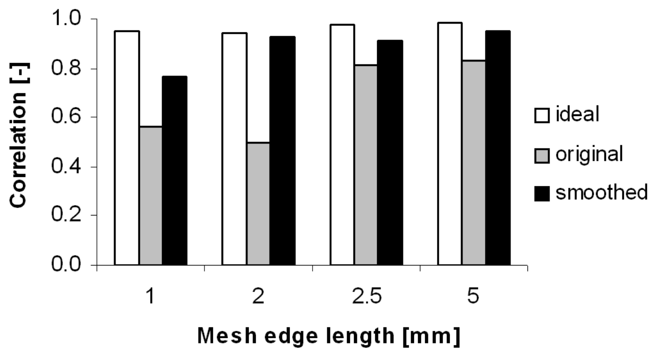
2 - ideal
2 - original
2 - smoothed
measured
weld line angle [°]
flow length [mm]
0
25
50
75
100
125
150
0
5
10
15
20
25



weld line angle [°]
flow length [mm]
2.5 - ideal
2.5 - original
2.5 - smoothed
measured
0
25
50
75
100
125
150
0
5
10
15
20
25



5 - ideal
5 - original
5 - smoothed
measured
weld line angle [°]
150
125
100
75
50
25
0
0
5
10
15
20
25
flow length [mm]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0.8
0.6
0.4
0.2
0.0
Correlation [-]
1
2
2.5
5
Mesh edge length [mm]
ideal
original
smoothed