IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Investigation of segregation in the runner system during injection moulding

To cite this article: D. R. Fris and F. Szabó 2022 *IOP Conf. Ser.: Mater. Sci. Eng.* **1246** 012029

Investigation of segregation in the runner system during injection moulding

D. R. Fris, F. Szabó

Department of Polymer Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics, H-1111 Budapest, Műegyetem rkp. 3., Hungary

E-mail: szabof@pt.bme.hu

Abstract. The goal of this study is to investigate segregation in the runner system during injection moulding. Segregation is a phenomenon which occurs during the injection moulding of filled or reinforced polymer systems. The effects of segregation can be so severe that the process can lead to waste products. Even though segregation is an important problem, so far it has been little researched. However, it would be very beneficial if segregation during injection moulding could be predicted through simulation software. In order to achieve that, we must first understand what causes segregation. We injection moulded several specimens using polypropylene, a transparent polymer, and used 10.8 V% ceramic beads as filler with different injection moulding parameters. We investigated the effect of melt temperature and injection rate, which were set to 180, 220, 260 °C and 5, 20, 80 cm^3/s. We observed segregation with an optical microscope and used a furnace to burn the PP and measured the weight of the leftover beads in order to determine the bead content in various regions.

1. Introduction

Although plastic products have been manufactured only since the second half of the 20^{th}-century, nowadays there is virtually no industry that is not using polymers. Injection moulding is one of the most widely used and cost-effective polymer processing technologies, with which practically any kind of product can be manufactured. Injection moulding is fast and waste is minimal. It is essential, however, to optimise the parameters of the process.

One of the most sensitive aspects of the quality of injection moulded products is homogeneity. Proper mixing and setting the injection moulding parameters correctly are key to achieving good homogeneity [1, 2]. Inhomogeneity can take the form of colour streaks, which is a relatively common problem during injection moulding. It is caused by the irregular distribution of the colour pigments, the masterbatch.

In order to enhance or alter the properties of polymer products, engineers often use fibre reinforcement or filler materials. The proper distribution of these materials is more important than the distribution of the masterbatch; improper distribution of the reinforcement or filler materials can make the product defective. When reinforcements or fillers are used during injection moulding, segregation must be taken into account. A segregated system or mixture is different from an inhomogeneous system—the latter is a perfectly randomised distribution of two phases, while the former means that the probability of finding a particle in a certain region differs from the overall average of particle content [3, 4]. The purpose of reinforcement in polymers is to strengthen the structure, but due to segregation and the unfavourable orientation of the fibers, considerably weaker regions may form across the weld lines [5-7]. Although segregation is important in designing the product [8], only a few studies

IOP Conf. Series: Materials Science and Engineering 1246 (2022) 012029 doi:10.1088/1757-899X/1246/1/012029

investigate the reason why and how segregation occurs during injection moulding. Since the exact mechanism of segregation is unknown, industrial simulation software cannot calculate it properly.
Our long-term goal is to develop a method that would be capable of simulating segregation by either using a FEM-DEM coupled system or developing a new material model. But first, it is necessary to investigate segregation. In this study, we investigate how different injection moulding parameters affect segregation, and attempt to find what causes segregation. We injection moulded a product with a geometry that resembles the runner system. We suspect, that segregation somehow correlates with the thickness and formulation of the frozen layer during injection moulding. We intend to investigate segregation by comparing simulation results describing the frozen layer to the rate of segregation.

2. Materials, machinery and methods

In order to examine segregation, we injection moulded specimens using a mould with several branches to represent the runner system. The injection moulding machine was an Arburg Allrounder Advance 270S 400-170. The matrix was polypropylene (PP), MOL TIPPLEN H145 F and the filler (10,8 V%/32 m%) was ceramic beads, Saint-Gobain ZirPro Microblast® B120. We used PP because it is a polymer not prone to shear-induced fill imbalances, therefore the lengths of how the polymer melt fills each cavity is more uniform and the measurements can be done more easily. We used ceramic beads, since they are opaque, and can be seen more clearly under a microscope. We investigated the effect of two injection moulding parameters: melt temperature and injection rate. Melt temperature was 180, 220 and 260 °C and injection rates were 5, 20 and 80 cm^3/s. Mould temperature was set to a fixed 50 °C. We selected 5 regions from the eight-branched geometry and examined the surface of the cross-section with a Keyence VHX-5000 optical microscope. Then we burnt off the matrix near the relevant regions with a Denkal 6B furnace to determine filler content in m%. We injection moulded specimens and ran simulations in Autodesk Moldflow with the same injection moulding settings, to examine how the thickness of the frozen layer correlates with segregation.

3. Experiments

We examined the specimens in certain regions with an optical microscope and burnt off the matrix. We compared the results of segregation to the simulation results.

3.1. Simulation results

We ran simulations with the same injection moulding settings with which the specimens were manufactured. The temperature results of the simulations can help predict the thickness of the frozen layer. Table 1 shows the simulation results of the volume ratio of the frozen layer with different injection moulding settings. The left column shows the notation of the specimens. As the table suggests, the higher the melt temperature, the thinner the frozen layer on the surface of the 50 °C mold. The explanation is quite simple, the hotter melt cannot cool down so easily and freeze. The results indicate that with a lower injection speed, the frozen layer will be thicker. This is because the frozen layer has more time to form.

Table 1. The results of the volume ratio of the frozen layer with different injection moulding parameters.

Notation of the specimen	Melt temperature (°C)	Injection speed (cm^3/s)	Volume ratio of the frozen layer (%)
A	180	20	19,13
B*	220	5	37,54
C	220	20	13,57
D	220	80	5,28
E	260	20	10,47

3.2. Optical Microscope

Before the experiment, we decided where we would examine the cross-section in the specimens. We examined the runner in the first branch (figure 1, B), which carries the melt towards the junctions directly from the sprue and in the “1st” and ”3rd” junction at both the top (figure 1, F1 and F3) and the bottom (figure 1, A1 and A3), so overall there are 5 regions to check. We cut the specimens at these areas and produced images of the cross-sections using an optical microscope. Figure 1 shows the

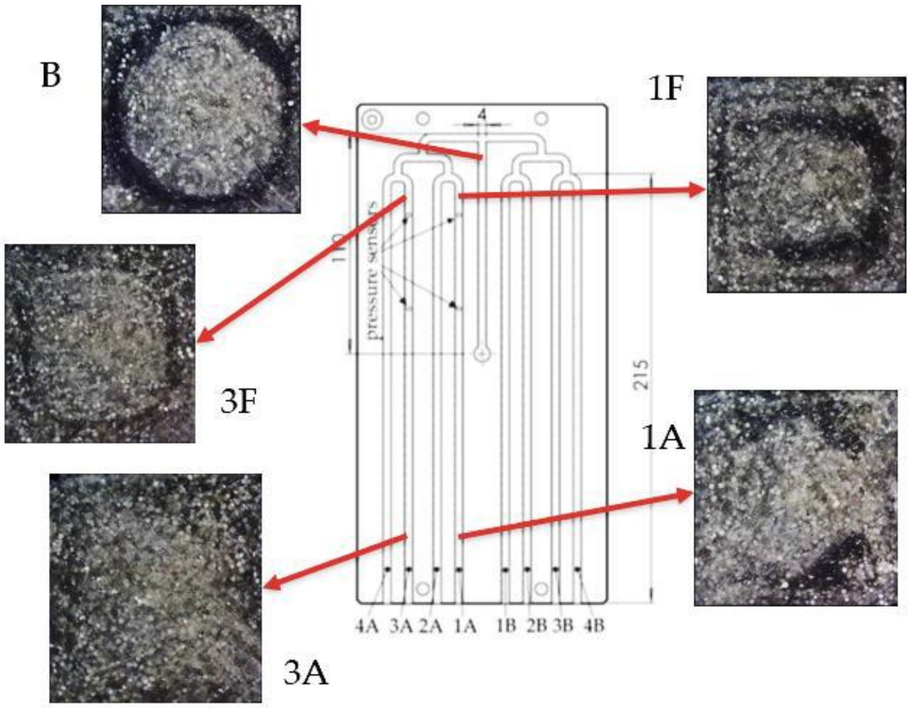

Figure 1. The characteristic microscope image of each cross-section and their notations.

discussed regions and their notations, and a characteristic microscope image of the cross-sections. Figure 2 displays all the microscopic images with different injection moulding settings at the locations we selected. The white areas are the ceramic beads and the dark region is the PP matrix material with only a few beads. Sometimes a dark spot can be observed at the core region of the melt (e. g. 3F/E, figure 2); these are probably caused by air bubbles or vacuum during the injection moulding process. As figure 2 suggests, the 5 different cross-sectional regions each have their own characteristic segregation profile. The way the injection moulding settings affect these profiles can be observed for example in region B (figure 2, column B), where with setting B*, which is the slowest injection rate, the darker area near the surface of the mould is the largest Because of table 1, we know that with these parameters, the frozen layer is the thickest there.

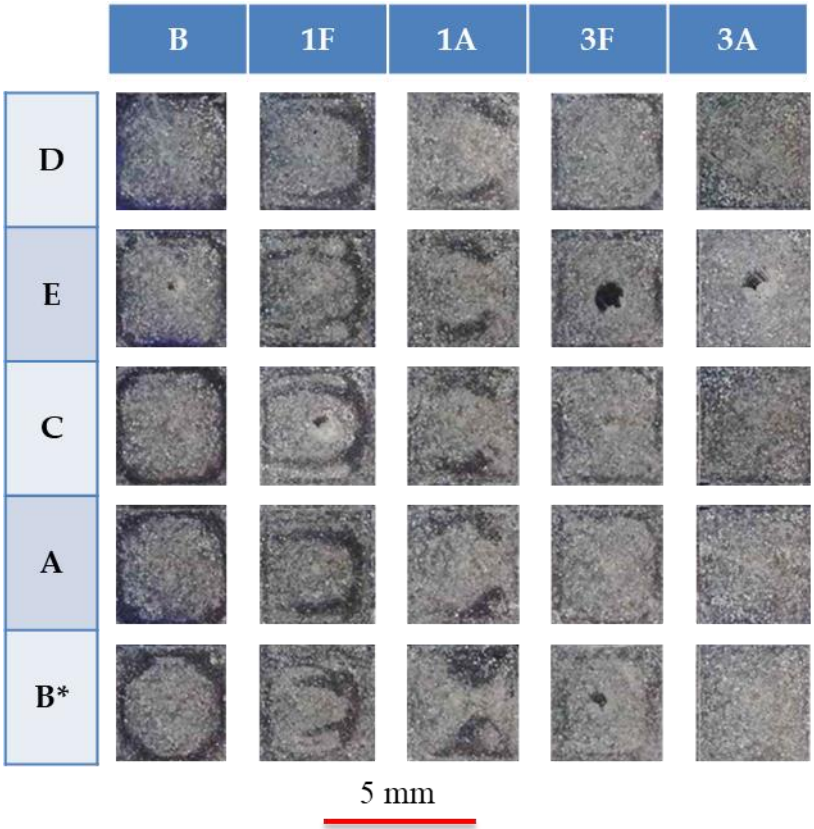

Figure 2. The microscopic images created from the cross-sections of different regions with different injection moulding settings.

3.3. Burnoff

To determine the filler content of the examined regions, we burnt off the matrix in 3 specimens with each set of settings. With the weight of the leftover ceramic beads the filler content can be easily calculated. The nominal bead content of specimens is 32 m%. We introduced a notation system in order to easily plot the results. The first part of the name of the specimen suggests the location of the cross-section (B, 1F, 1A, 3F and 3A, figure 1) and the second part is the injection moulding setting (A, B*, C, D, E, table 1). The burnoff results of cross-section B are shown in figure 3. The red line marks the nominal 32 m% value. Figure 4 shows all the microscopic images of cross-section "B" lined up according to the thickness of the frozen layer. A comparison of figure 3 and 4 indicates that the segregation of the system is only local, does not cause a quantitative change—figure 3 indicates that filler content is roughly the same. We compared the burnoff results (figure 5) in all the cross-sections of the specimens produced with injection moulding setting B*, which causes the thickest, and setting D, which causes the thinnest frozen layer. With both settings, cross-section B is low in ceramic beads, but while setting B* results in high filler content in cross-section 1F, 1FD stays below the nominal value.

IOP Conf. Series: Materials Science and Engineering 1246 (2022) 012029 doi:10.1088/1757-899X/1246/1/012029

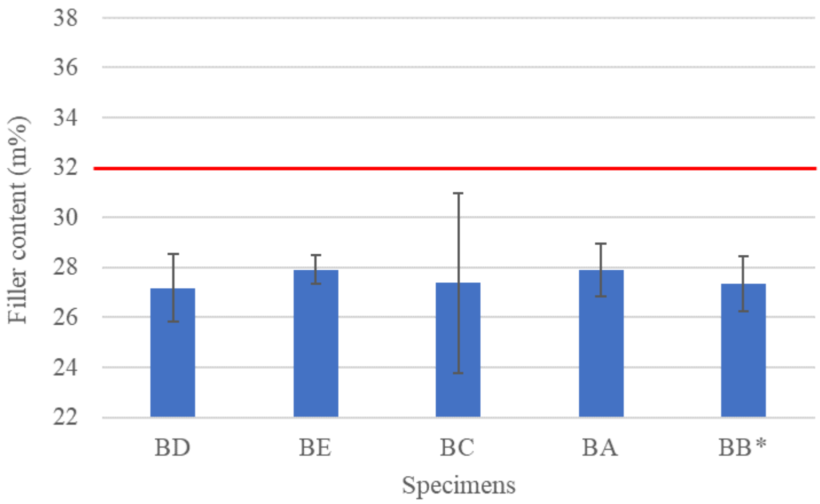

Figure 3. The burnoff results of cross-section B.

Figure 4. Microscopic images of cross-section B.

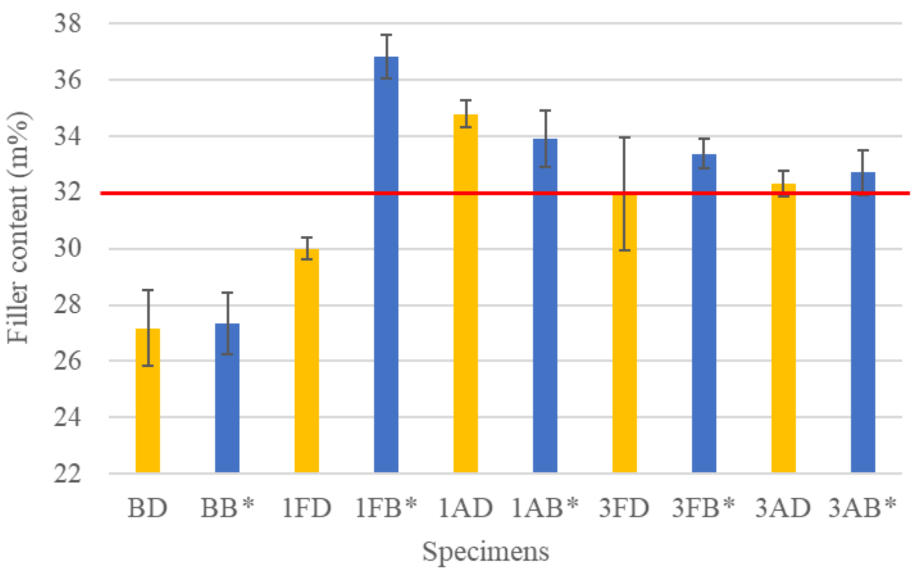

Figure 5. The burnoff results of setting B* and D.

4. Results and discussion

According to the literature, segregation during injection moulding causes an increase in filler content at the end of the flow path and a decrease at the beginning, near the sprue. We assume that this is because the flow is able to tear out beads or fibre, which are not fully embedded in the frozen layer. Hence, a correlation between the frozen layer and the rate of segregation can be assumed as well.

Microscopic images in different cross-sections show different bead distributions. We assume that these segregation profiles are related to the viscosity profile during injection moulding. If we compare the temperature profiles of the simulation results (figure 6) with the microscopic images, a similar distribution can be observed. The temperature profiles are asymmetric due to shear induction. Figure 2 shows that segregation, the distribution of the beads, is also asymmetric. The profile of the simulation results and segregation are similar in the case of 1F. This suggests a similar phenomenon to the one discussed with cross-section B (figure 4), where the frozen layer might be the reason behind the segregation profile. However, based on shear induced fill imbalances, the right side of cross-section 1F is filled with a hotter melt, therefore the frozen layer is theoretically considerably thinner there. The reason why this hot melt region is absent in the simulation results (figure 6) is that even industrial simulation software is not able to correctly calculate the effects of shear induction. The segregation

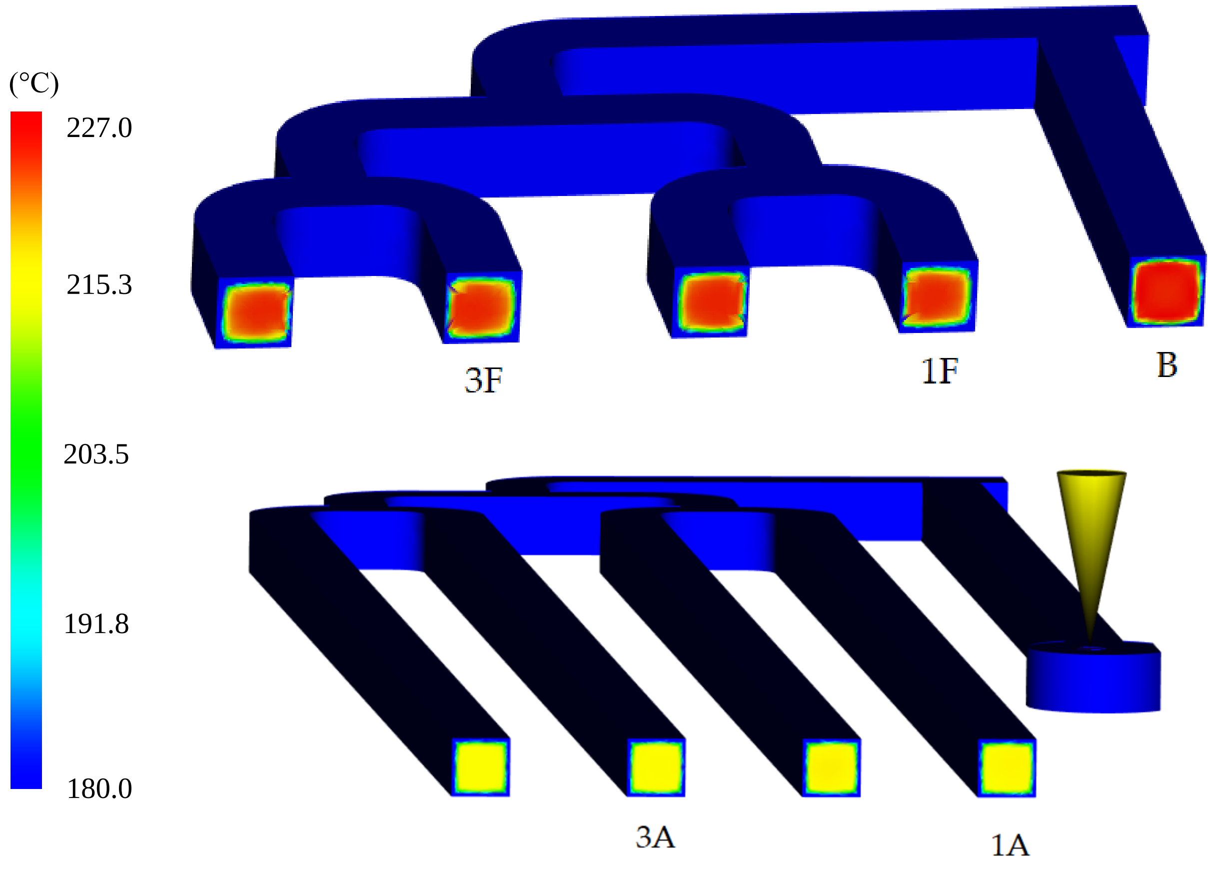

Figure 6. The temperature profiles of the simulation results.

profile of 1F (figure 2) cannot be explained by the frozen layer—further studies are necessary.What we expected from the burnoff results was a tendency in segregation: increased filler content at the end of the flow path (cross-section 1A and 3A, figure 7) and lower filler content at the beginning of the flow path (cross-section B, figure 3). Cross-section 1A behaves according to this theory (figure 7) with every injection moulding setting. Segregation is shown by the amount of beads in a given location. The microscopic results indicate that the distribution of the ceramic beads is more even than in cross-section 1F (figure 2). In the case of cross-section 3A, the increase is less significant or non-existent (figure 7, 3AE). We also examined the filler content in cross-section 1F and 3F (figure 8). 1F has high filler content, except with setting D, which produces the thinnest frozen layer, while with setting B*, the

IOP Conf. Series: Materials Science and Engineering 1246 (2022) 012029 doi:10.1088/1757-899X/1246/1/012029

thickest frozen layer shows the greatest increase. This pattern cannot be observed in cross-section 3F. It would seem that Junction 3 is more uniform in bead content than Junction 1. Both the burnoff results (figure 7 and 8) and the microscopic images (figure 2) show more even distribution of the beads. This might also be connected to shear induction, but further studies are necessary for a definitive explanation.

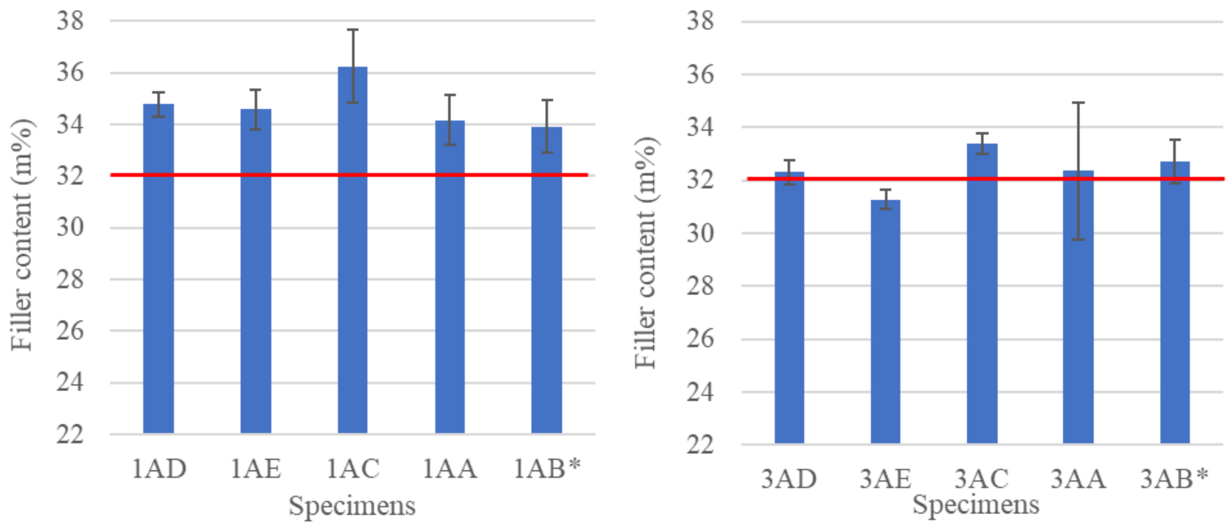

Figure 7. Burnoff results of cross-sections 1A and 3A.

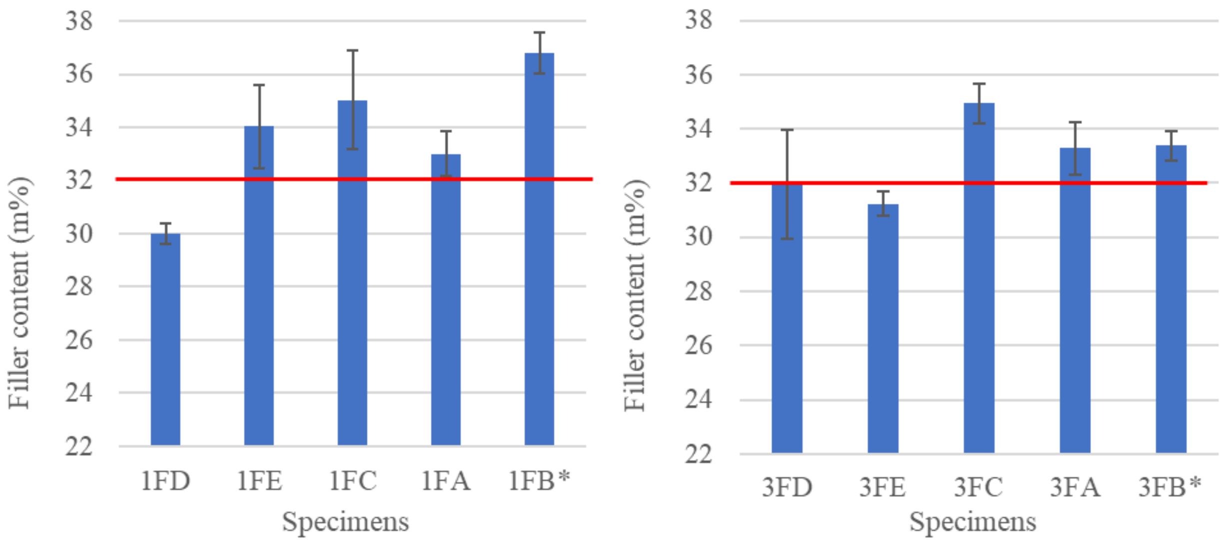

Figure 8. Burnoff results of cross-sections 1F and 3F.

5. Conclusion

Although the segregation of the filler or reinforcement during injection moulding is a considerable problem, it is little researched. Our long-term goal is to develop software that can simulate segregation during injection moulding. To do that, first we have to understand the phenomenon better.

We injection moulded specimens with different injection moulding settings using PP as matrix material and ceramic beads as filler. We chose 5 regions where we cut the specimens and observed the cross-sections with an optical microscope to observe the distribution of the beads. We also burnt off the matrix around the 5 examined cross-sections to determine filler content. We searched for a correlation between the thickness of the frozen layer and segregation. In the case of cross-section B, it seems that the frozen layer does have an effect on segregation, but only the distribution of the beads changed, their quantity did not. Junction 1 shows more segregation than Junction 3; we assume that the reason might be shear induction. For this, further experiments are needed and in the future, it might be expedient to use a polymer as matrix which is prone to extreme shear-induced fill imbalances.

6. References

[1] Zsíros L and Kovács J G 2018 Surface homogeneity of injection molded parts *Periodica Polytechnica Mechanical Engineering* **62** 284-291

[2] Wang M-V, Fatahul A and Vu V-H 2019 The Study of Optimal Molding of a LED Lens with Grey Relational Analysis and Molding Simulation *Periodica Polytechnica Mechanical Engineering* **63** 278-294

[3] Rhodes M 2008 Introduction to Particle Technology New Jersey (John Wiley & Sons, Ltd)

[4] Kovács J G 2011 Shrinkage alteration induced by segregation of glass beads in injection molded PA6 Experimental analysis and modeling *Polymer Engineering & Science* **51** 2517–25

[5] Albrecht K, Baur E, Endres H-J, Gente R, Graupner N, Koch M and Müssig J 2016 Measuring fibre orientation in sisal fibre-reinforced, injection moulded polypropylene – Pros and cons of the experimental methods to validate injection moulding simulation *Composites Part A: Applied Science and Manufacturing* **95** 54–64

[6] Hegler R P and Mennig G 1985 Phase separation effects in processing of glass-bead- and glass-fiber-filled thermoplastics by injection molding *Polymer Engineering and* Science **25** 395–405

[7] Wu H, Zhao G, Wang J, Wang G and Zhang M 2019 A kind of special weld lines with high specific strength and elongation obtained by core-back chemical foam injection molding *Express Polymer Letters* **13** 1041-1056

[8] Jozo M, Cui L and Pukanszky B 2020 Processing induced segregation in PLA/TPS blends: Factors and consequences *Express Polymer Letters* **14** 768-779

Acknowledgments

This research is funded by the (NKFIH) National Research, Development and Innovation Office (FK138501 - The utilization of the rheological and structural characteristics of polymer solutions and melts for their efficient processing).