Advances in Science and Technology Research Journal

*Advances in Science and Technology Research Journal*, 2026, 20(9), 437–448
https://doi.org/10.12913/22998624/224273
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Received: 2026.05.12
Accepted: 2026.07.10
Published: 2026.08.01

# Analysis of the properties of polypropylene injection moulded parts with talc and blowing agent in the areas of weld lines

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## ABSTRACT

This article presents results on selected properties, including weight, thickness, tensile strength, and structure, of moulded parts made from a polypropylene (PP) composite containing talc and a chemical blowing agent. It was shown that adding 3% by weight of the chemical blowing agent to the processed plastic reduced the moulded part weight, while a lower content (1.5%) did not significantly affect the properties studied. The structure was also analysed using a special mould insert with a variable cavity height, where the plastic flow conditions caused different shear intensities. It was shown that different zones of the moulded parts exhibited different pore counts and sizes, which resulted from different flow and solidification conditions of the plastic in the mould cavity.

**Keywords:** injection moulding, composites, blowing agent, polypropylene, talc.

## INTRODUCTION

One of the key issues in polypropylene injection moulding is the influence of filler shape on the formation and properties of weld lines, which may significantly reduce the mechanical strength of moulded parts [1]. A similar phenomenon is also observed in talc-filled composites, where the presence of weld lines leads to a reduction in mechanical properties despite an increase in material stiffness [2]. In polymer processing, the influence of foaming agents and injection moulding process parameters on the physical and surface properties of moulded parts is also of considerable importance. It has been demonstrated that the application of foaming agents and appropriate processing conditions affects the structure and surface quality of polypropylene components [3]. Studies concerning the influence of injection moulding parameters confirm their significant effect on weld line formation and the quality of moulded parts [4].

Microporous injection moulding technology enables the production of moulded parts with reduced weight and improved surface quality whilst maintaining control over the cellular structure of the material [5]. In the case of micro-injection moulding, weld lines were shown to have a particularly significant influence on mechanical properties due to the small flow scale and substantial structural changes occurring within the material [6].

Research conducted by the authors [7] indicates that the simultaneous use of mineral fillers, foaming agents, and appropriate injection moulding parameters enables controlled modification of the mechanical properties and structure of moulded parts. It was also demonstrated that, in polypropylene composites containing talc and foaming agents, maintaining a balance between weight reduction and preservation of mechanical properties is of major importance [8].

Similarly, in PP/TALC/EPDM composites, injection moulding process parameters were found to have a crucial effect on the structure of moulded parts and the mechanical properties of the material [9]. The significant influence of filler shape on weld lines in polypropylene was highlighted in study [1], which analysed the important role of particle orientation in the weld line region. Studies on talc-filled PP composites have shown that weld lines significantly reduce mechanical properties, particularly at higher filler contents [2]. A literature review concerning thermoplastics indicates that factors such as mould geometry, temperature, and material flow are critical for the formation and quality of weld lines [10].

Optimisation of injection moulding parameters, for example using the Taguchi method, enables improvement of the mechanical properties in weld line regions through appropriate selection of processing conditions [11]. Experimental studies confirm that parameters such as mould temperature and injection speed have a significant influence on weld line quality [4].

Analysis of polypropylene flow in regions containing geometric obstacles demonstrates the complex nature of weld line formation and their influence on the material structure [12]. In the case of talc-filled PP composites, the presence of weld lines was confirmed to deteriorate the mechanical properties of the material [2].

The influence of filler shape on weld line properties has been investigated using various composite formulations containing fillers in studies of polypropylene composites, highlighting the significant role of the material microstructure [1,8]. Characterisation of moulded parts containing weld lines revealed their structural heterogeneity and reduced mechanical properties [1,8,13].

For engineering polymer materials such as PA6, it was demonstrated that foaming agents, fillers, and mould temperature all affect the structure and properties of moulded parts [14]. Similarly, in HDPE, the influence of foaming additives and injection moulding parameters on material properties and structure has been confirmed [15].

Studies on filled polypropylene have shown that foaming agents affect both the mechanical and physical properties of the material, leading to a reduction in density [16]. The literature also emphasises that the structure of injection-moulded products enables weight reduction whilst maintaining adequate stiffness and material functionality [17–20].

## AIM AND SCOPE OF THE STUDY

The aim of the present study was to investigate selected properties of injection-moulded parts containing weld line regions formed by converging polymer melt fronts. An experimental two-cavity injection mould was used in the study (Figure 1). The mould enabled the production of plate-shaped mouldings (plaques) with dimensions of 60 × 90 × 3.1 mm. The mould cavities were designed in such a way that the polymer melt encountered obstacles along the flow path, resulting in the formation of weld lines. In one cavity, a circular obstacle with a diameter of 40 mm was applied, whereas in the second cavity, a square obstacle with a side length of 42 mm was used.

Additionally, the mould was designed to allow modification of the melt flow direction into the mould cavity by means of an interchangeable gate insert system, enabling injection from different sides of the moulded parts and in various configurations. In the present study, the mouldings were injected through the lower gates, whilst the upper gates were sealed. The dimensions of the cavity are presented in Figure 2 (the cavity depth was 3 mm), whereas Figure 3 shows an example of a finished moulded part together with the runner system used for polymer delivery.

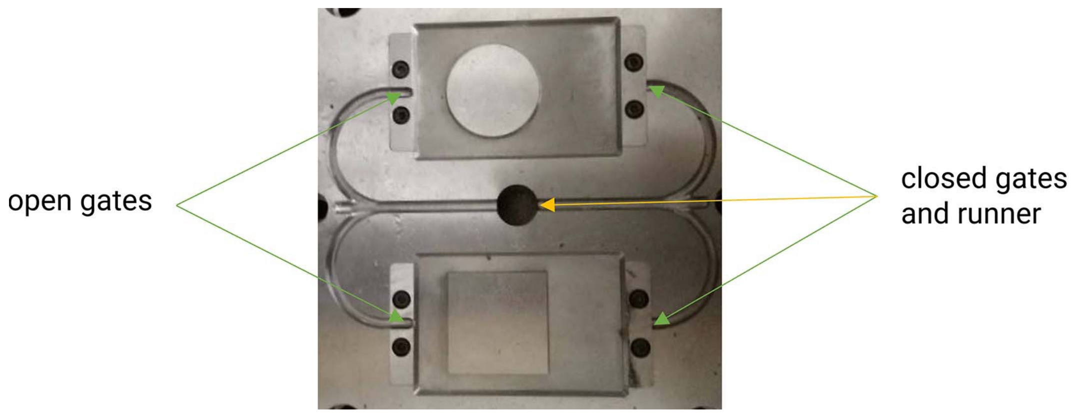


**Figure 1.** View of the moulding cavities of the experimental mould

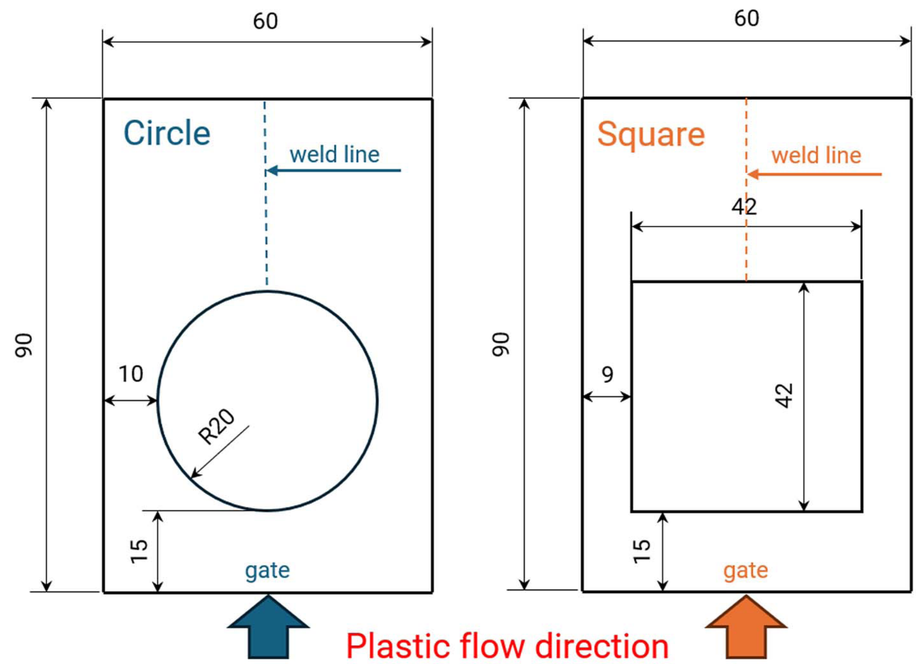


**Figure 2.** Dimensions of mould cavities, thickness of cavities is 3.1 mm

**Figure 3.** Examples of injection moulded parts with runners

Two types of polypropylene were used: neat PP Moplen HP548R with an MFR of 23 g/10 min (230 °C/1.16 kg) and Vicat softening temperatures of 154 °C (method A50: 50 °C/h, 10 N) and 94 °C (method B50: 50 °C/h, 50 N), and Moplen HP548R compounded with 20 wt.% talc by Granulat Bis. A chemical blowing agent, Plastron NUC C20, characterised by an endothermic decomposition mechanism, was added to the tested materials. The blowing agent was introduced at concentrations of 1.5 wt.% and 3 wt.%.

The injection-moulded parts were produced using an Engel Victory 50 injection moulding machine with a clamping force of 50 tonnes. The most important injection moulding parameters and sample designations are presented in Table 1. The addition of the chemical blowing agent contributed to a reduction in injection time due to faster filling of the mould cavity. Therefore, as the blowing agent content increased, both the injection time and holding pressure time were reduced accordingly.

As part of the study, measurements of the moulded part mass and thickness were carried out, both at the beginning and at the end of the melt flow path. Mechanical properties in the weld line regions were also investigated for moulded parts containing the square obstacle. In addition, structural analyses were performed, together with photographic documentation of selected short-shot mouldings illustrating the polymer melt flow behaviour within the cavities of the experimental injection mould.

## RESULTS AND DISCUSSION

### Weight of moulded parts

The weight of the moulded parts was determined with an accuracy of ±0.1 mg using a Sartorius CP225 laboratory balance equipped with a closed measuring chamber.

Due to differences in the volumes of the two mould cavities resulting from the shape and

**Table 1.** Sample designations and injection moulding process parameters

| Processed plastic | Moplen HP548R | Moplen HP548R + Plastron NUC C20 1.5% wt | Moplen HP548R + Plastron NUC C20 3% wt | Moplen HP548R + T20 | Moplen HP548R + T20 + Plastron NUC C20 1.5% wt | Moplen HP548R + T20 + Plastron NUC C20 3% wt |
|---|---|---|---|---|---|---|
| Abbreviation in this work | PP | PP + 1,5% ba | PP + 3% ba | PP T20 | PP T20 + 1,5% ba | PP T20 + 3% ba |
| Injection temperature, °C | 220 | 220 | 220 | 220 | 220 | 220 |
| Mould temperature, °C | 20 | 20 | 20 | 20 | 20 | 20 |
| Injection velocity, ccm/s | 71.8 | 71.8 | 71.8 | 71.8 | 71.8 | 71.8 |
| Injection time, s | 0.72 | 0.7 | 0.66 | 0.72 | 0.7 | 0.66 |
| Injection pressure, MPa | 80 | 80 | 80 | 80 | 80 | 80 |
| Holding time, s | 7 | 5 | 3 | 7 | 5 | 3 |
| Holding pressure, MPa | 60 | 60 | 60 | 60 | 60 | 60 |
| Cooling time, s | 15 | 15 | 15 | 15 | 15 | 15 |

dimensions of the circular and square obstacles, and consequently the different volumes and masses of the obtained moulded parts, the test results are presented in two separate graphs (Figures 4 and 5). The graphs present the average weight of the moulded parts obtained in each test cycle.

Analysis of the weight of the moulded parts containing the circular obstacle located in the centre of the mould cavity (Figure 4) indicates that the talc-filled mouldings exhibited higher weight than the unfilled solid mouldings, which was expected due to the presence of the mineral filler. The addition of 1.5% chemical blowing agent to the processed material did not result in any noticeable reduction in the weight of the moulded parts.

The incorporation of 3% blowing agent into the unfilled polypropylene resulted in a slight weight reduction of approximately 0.2%. In contrast, for talc-filled polypropylene, the reduction in weight reached approximately 2% in comparison with the corresponding solid mouldings.

For the samples containing the square obstacle positioned in the centre of the mould cavity (Figure 5), a trend analogous to that observed for the moulded parts with the circular obstacle can be identified. In the case of the unfilled material, the differences in weight were insignificant. However, for the talc-filled polypropylene, the addition of 3% blowing agent resulted in a weight reduction of approximately 1.7% compared with the corresponding solid mouldings.

## Thickness of moulded parts

The thickness measurements were performed using a Vis Sylvac System digital micrometer with an accuracy of ±0.01 mm, 24 hours after completion of the injection moulding cycle. The thickness was measured at the centre of the

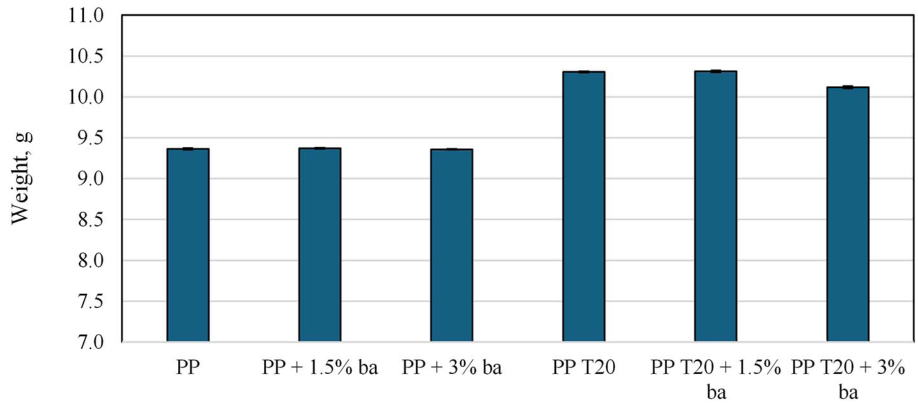


**Figure 4.** Weight measurement results of obtained samples (circle)

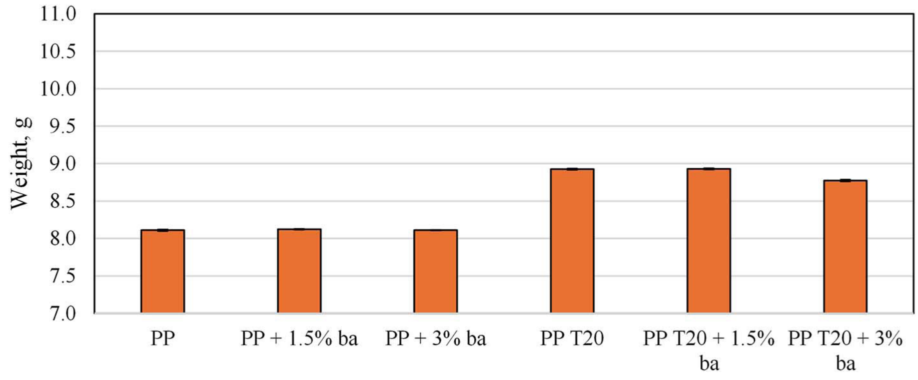


**Figure 5.** Weight measurement results of obtained samples (square)

moulded parts, as well as at the beginning and the end of the melt flow path, at the points indicated in Figure 6. The measurement results are presented in Figures 7 and 8. Analysis of Figure 7 for the moulded parts containing the circular opening indicates that, in the case of unfilled PP, a significant increase in sample thickness at the beginning of the melt flow path was observed only when 3% blowing agent was applied, reaching approximately 7% in comparison with the solid mouldings. For the talc-filled moulded parts, the blowing agent contributed only to a very slight increase in thickness.

The greatest differences were observed at the end of the melt flow path. For unfilled PP, the addition of 1.5% and 3% blowing agent resulted in thickness increases of 8.1% and 12.8%, respectively. A similar trend was observed for the talc-filled mouldings, where the thickness increased by 5.9% and 6.9%, respectively, relative to the PP T20 samples. In general, for moulded parts without the blowing agent, both unfilled and talc-filled, the wall thickness was greater at the beginning of the flow path than at its end. The application of the chemical blowing agent contributed to reducing these differences and, consequently, to achieving improved dimensional stability throughout the

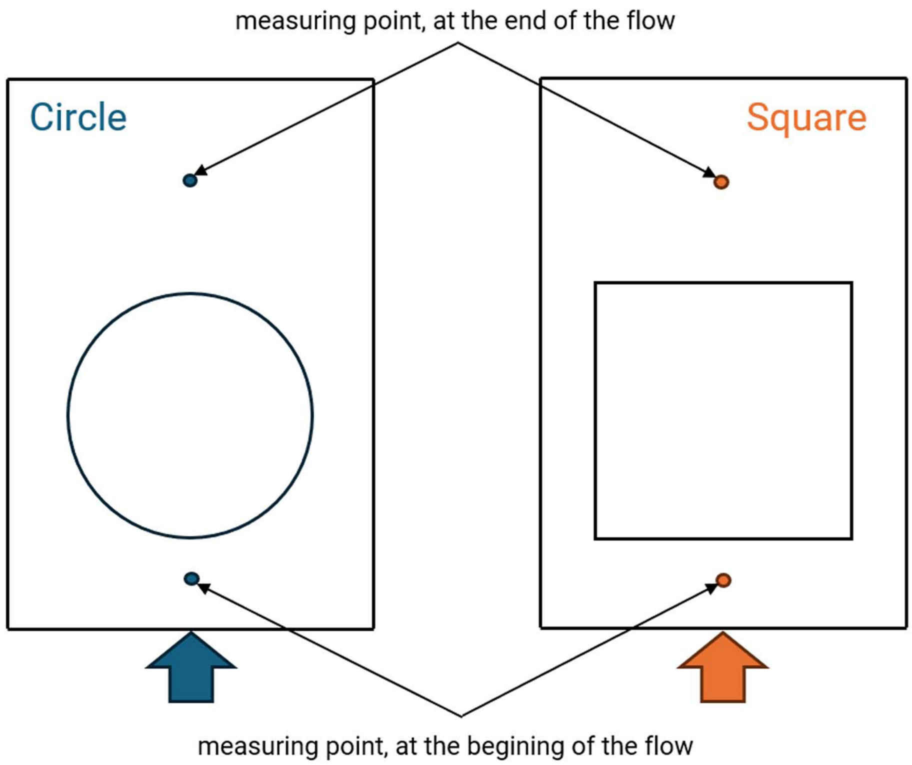


**Figure 6.** Points on injection moulded parts, where thickness was measured

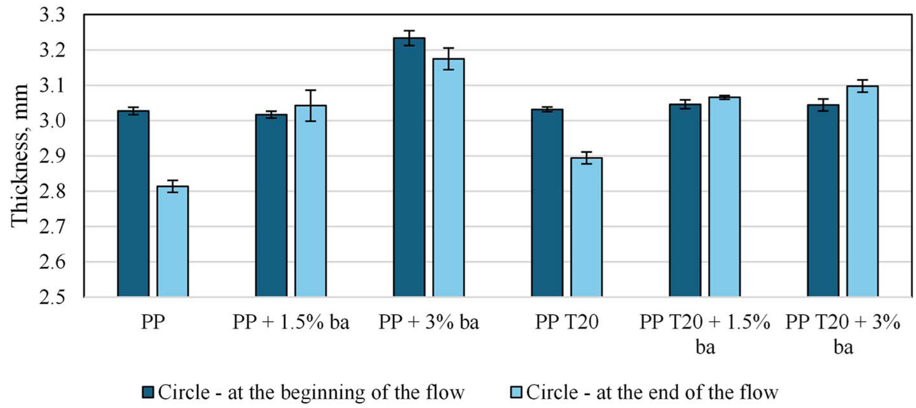


**Figure 7.** Thickness measurement results of obtained samples (circle, at the beginning and end of the flow)

entire moulded part, including the weld line region. An analogous trend was observed for the moulded parts containing the square obstacle (Figure 8).

From Figure 8, for the moulded parts containing the square opening, it can be observed that in the case of unfilled PP, the addition of 3% blowing agent leads to an increase in thickness at the beginning of the flow path by approximately 4% compared with the solid mouldings. For the talc-filled moulded parts, the addition of the blowing agent does not contribute to an increase in wall thickness at the beginning of the flow path.

At the end of the melt flow path, the thickness of the moulded parts increases with increasing blowing agent content, by approximately 6.3% and up to 12%, respectively. For the talc-filled mouldings, the corresponding increase in thickness at the end of the flow path is approximately 5.5% and 5.9%, respectively.

## Strength properties

Tensile strength ($\sigma_m$), elongation at maximum force ($\varepsilon_m$) and elongation at brake ($\varepsilon_B$) were determined using a static uniaxial tensile test. The tests were performed with an Inspekt Desk 20 testing machine (Hegewald and Peschke). Extension rate was 50 mm/min. The results of the measurements are presented in Figures 8, 9 and 10. The specimens for mechanical testing were cut from moulded parts containing the square opening, in the region of polymer melt flow convergence (Figure 9). The samples had a rectangular prism shape with dimensions of 60 × 33 × 3.1 mm.

Analysis of Figure 10, presenting the tensile strength results, indicates that the addition of a chemical blowing agent to the processed material leads to a slight reduction in tensile strength, which is a normal phenomenon widely reported in the literature. Furthermore, the talc-filled moulded parts exhibit approximately 50% lower tensile strength compared with the solid moulded parts.

In the case of elongation at maximum force (Figure 11), no significant differences can be observed between solid moulded parts and those containing the blowing agent. The addition of the blowing agent contributes to a greater scatter of results, particularly at a content level of 3%.

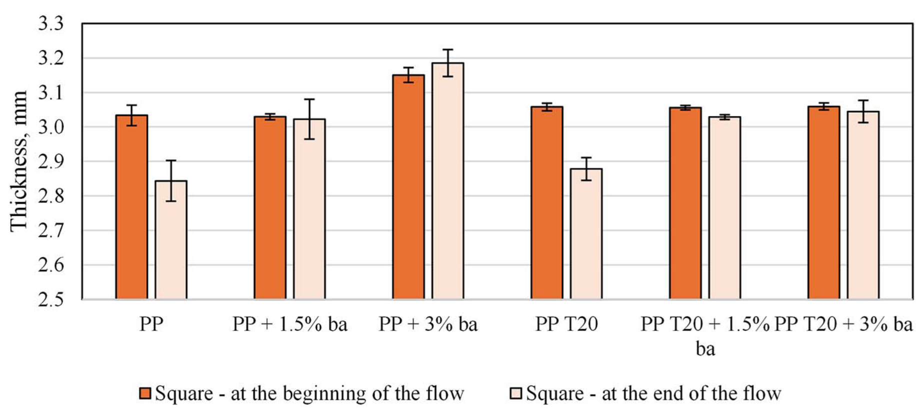


**Figure 8.** Thickness measurement results of obtained samples (square, at the beginning and end of the flow)

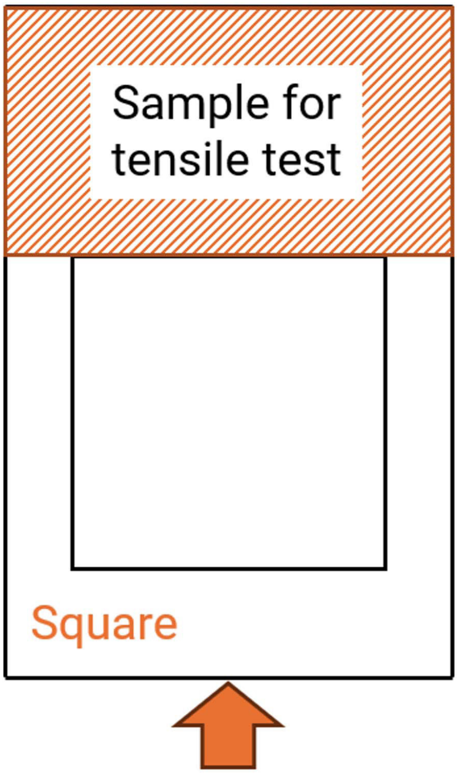


**Figure 9.** A place on the moulded part with a square in the centre from which samples for tensile strength tests were cut

Similarly to the tensile strength results, the talc-filled moulded parts exhibit approximately 50% lower elongation at maximum force compared with the unfilled moulded parts.

Figure 12 presents the results of elongation at break. The highest elongation at break is exhibited by solid, unfilled polypropylene moulded parts. The addition of the blowing agent leads to a significant reduction in elongation. The most pronounced decrease in elongation at break was observed for talc-filled moulded parts, as well as for those containing both talc and blowing agents.

### Structure of moulded parts

Structural analysis was performed using a Nikon SMZ80 stereoscopic inspection microscope equipped with a Nikon Digital Sight DS-5M camera, enabling observation of the structure under reflected light. Fracture surfaces were examined in cross-sections perpendicular to the polymer flow direction. Microscopic specimens were prepared using a Thermo Scientific Shandon Finesse ME+ rotary microtome. The location of the samples for microscopic examination is shown in Figure 11. The results of microscopic observations are shown in Figures 12 ÷ 17.

Figure 14 shows that in polypropylene samples, a dense distribution of pores with small diameters can be observed, whereas in polypropylene samples filled with talc, only a limited number of pores with larger diameters are present. No significant structural differences were observed between the orientations of the sample cross-sections. Figure 15 (circular-opening sample) indicates that in the case of 3% blowing agent, larger pores were obtained compared with the 1.5% blowing agent content. It can also be observed that the addition of talc reduces the foaming process in the material. When analysing differences between cross-sections taken along and across the melt flow direction, no significant variations in the porous structure were found, except for the PP T20 sample containing 3% blowing agent. Furthermore, no significant differences were observed between the structures

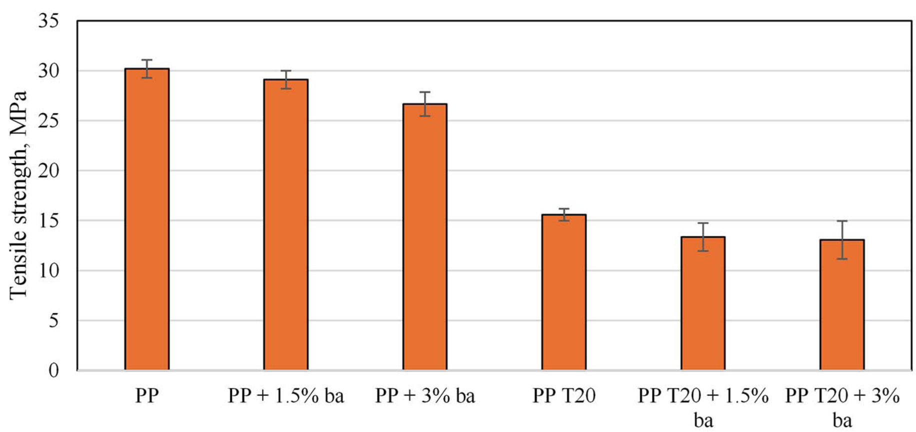


**Figure 10.** Tensile strength ($\sigma_m$) results of obtained samples (square)

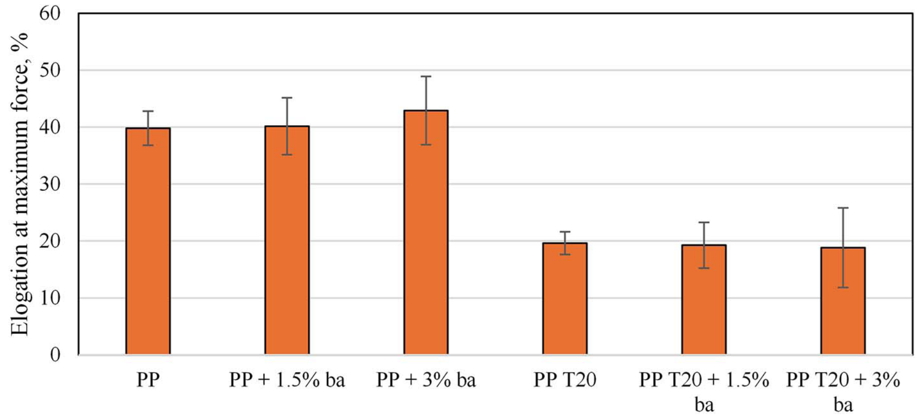


**Figure 11.** Elongation at maximum force ($\varepsilon_m$) results of obtained samples (square)

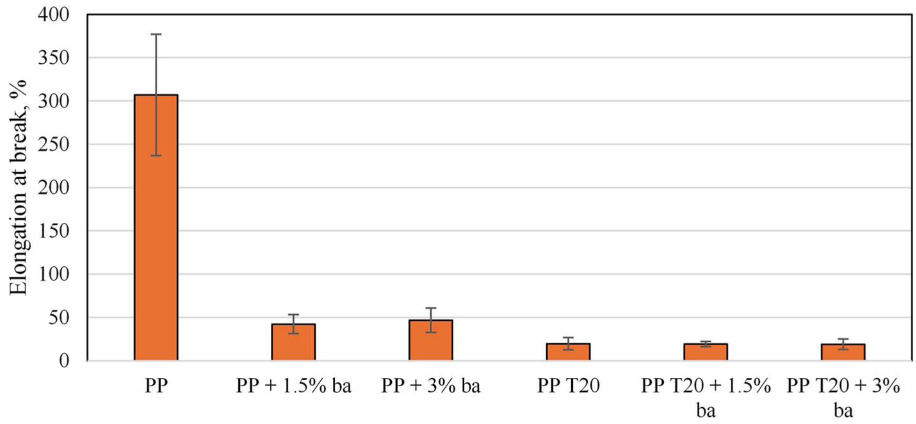


**Figure 12.** Elongation at break ($\varepsilon_B$) results of obtained samples (square)

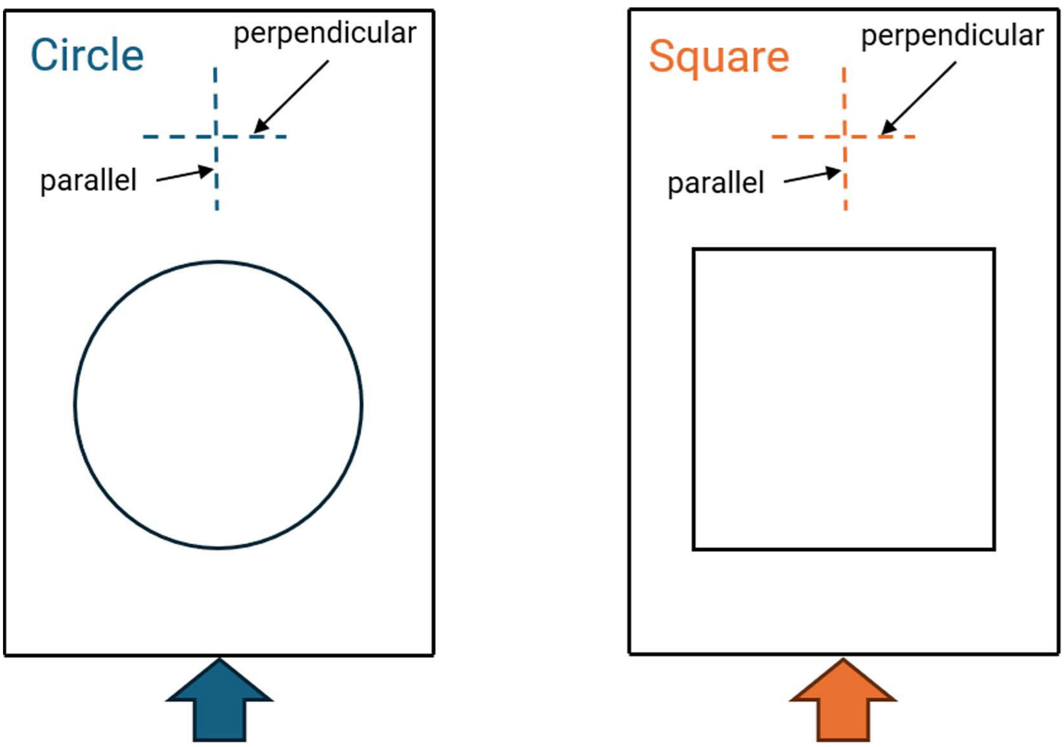


**Figure 13.** The location of the samples for microscopic examination

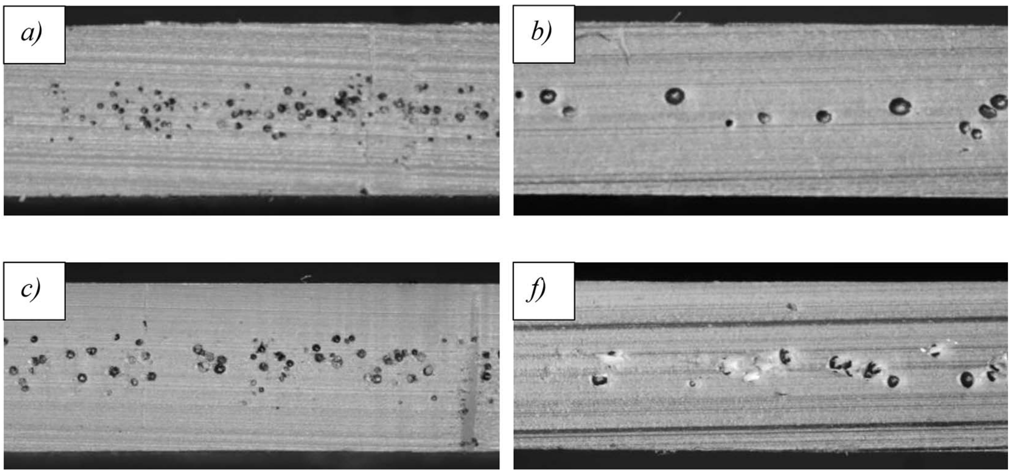


**Figure 14.** Structure of the moulded part cross-section (circle): a) parallel to flow direction for PP + 1.5% ba, b) parallel to flow direction for PP T20 + 1.5% ba, c) perpendicular to flow direction for PP + 1.5% ba, d) perpendicular to flow direction for PP T20 + 1.5% ba

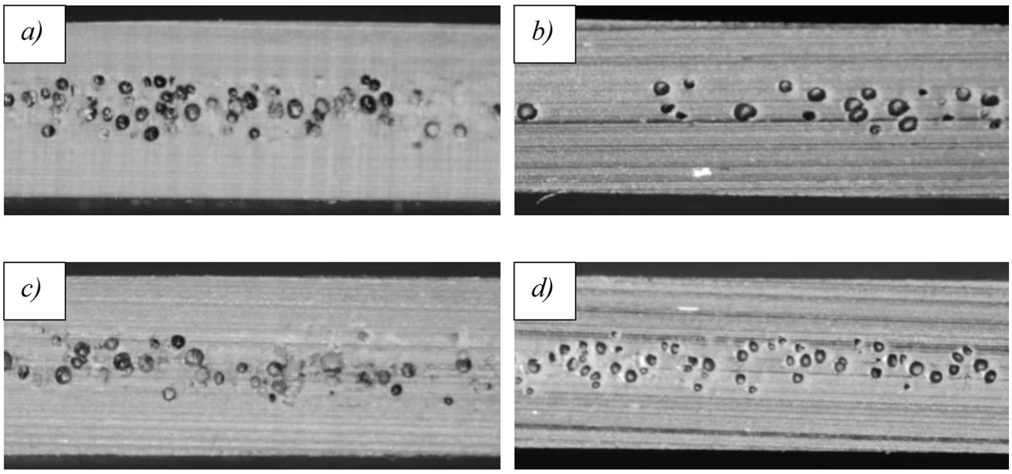


**Figure 15.** Structure of the moulded part cross-section (circle): a) parallel to flow direction for PP + 3% ba, b) parallel to flow direction for PP T20 + 3% ba, c) perpendicular to flow direction for PP + 3% ba, d) perpendicular to flow direction for PP T20 + 3% ba

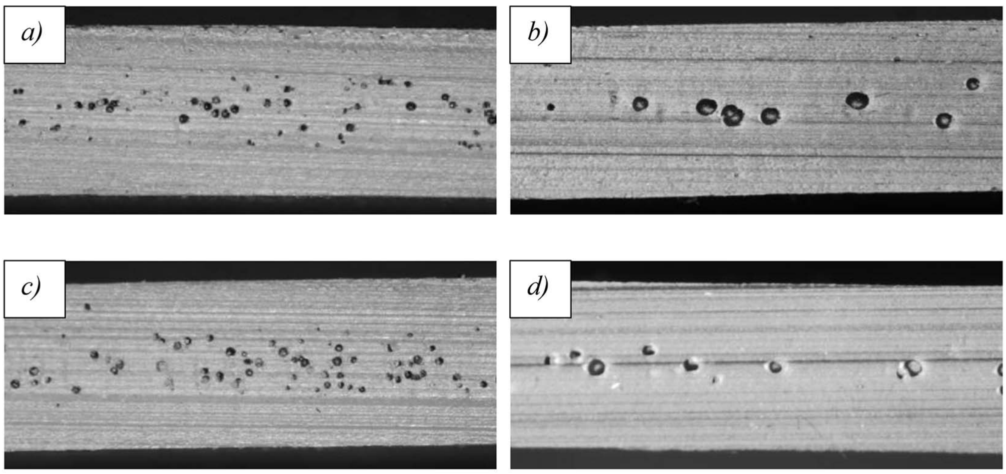


**Figure 16.** Structure of the moulded part cross-section (square): a) parallel to flow direction for PP + 1.5% ba, b) parallel to flow direction for PP T20 + 1.5% ba, c) perpendicular to flow direction for PP + 1.5% ba, d) perpendicular to flow direction for PP T20 + 1.5% ba

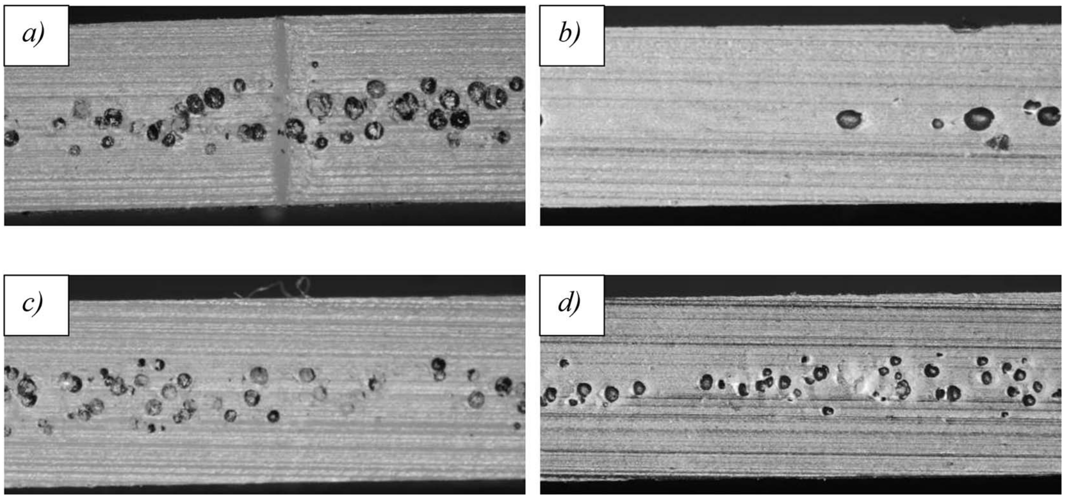


**Figure 17.** Structure of the moulded part cross-section (square): a) parallel to flow direction for PP + 3% ba, b) parallel to flow direction for PP T20 + 3% ba, c) perpendicular to flow direction for PP + 3 % ba, d) perpendicular to flow direction for PP T20 + 3% ba

of moulded parts with a circular opening and those with a square opening.

### Short shots study

The short shots analysis was performed by injecting melted polymer at 0.025 second intervals. After each shot, the obtained filling was photographed. Photos of individual cycles in each series are presented in the Figures 18 ÷ 20. Analysis of the short-shot mouldings indicates that the addition of a blowing agent to the processed material contributes to an increase in the cavity filling rate. In the case of solid unfilled polypropylene (Figure 18), 28 injections were required to achieve 100% cavity filling. For polypropylene containing 1.5% blowing agent, this number decreased to 27 injections, whereas for material with 3% blowing agent it further decreased to 25 injections. For this reason, different injection times were applied, as presented in Table 1. When analysing cavity filling behaviour, it can be observed that the moulded part with the circular obstacle is filled more rapidly, despite the larger cavity volume compared with the part containing the square obstacle. This may indicate higher flow resistance associated with the square-shaped obstacle.

## CONCLUSIONS

The conducted research indicates that the addition of 1.5% of the Plastron NUC C20 had

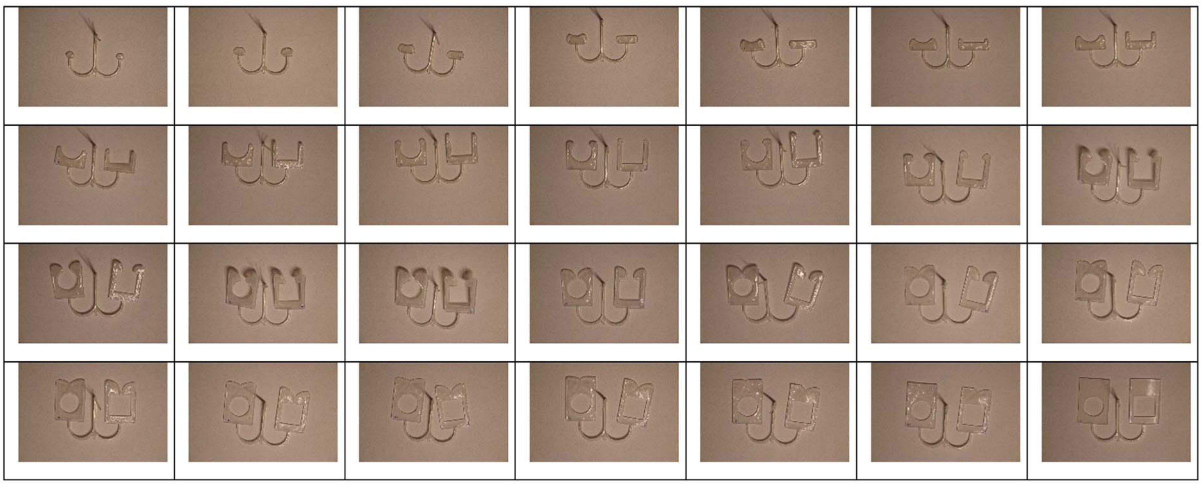

**Figure 18.** Short injections at 0.025 second intervals for PP, (28 short shots total)

**Figure 19.** Short injections at 0.025 second intervals for PP + 1.5% ba, (27 short shots total)

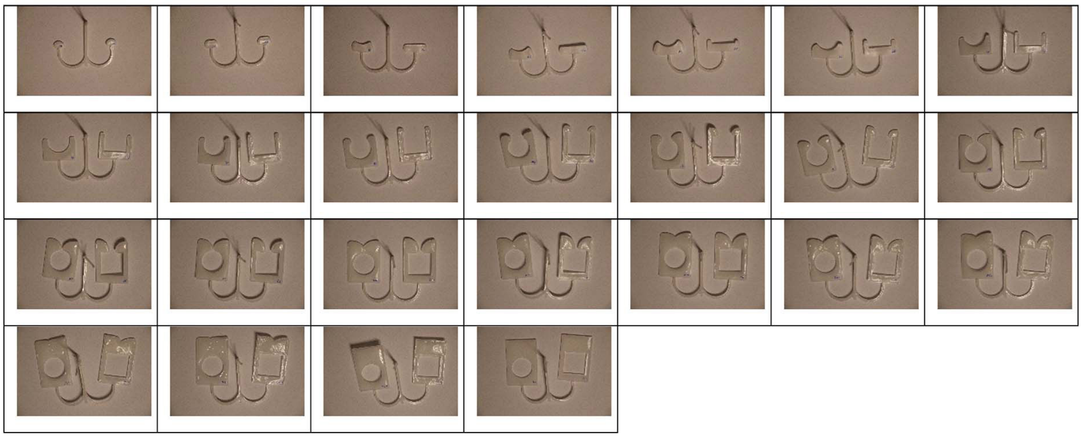

**Figure 20.** Short injections at 0.025 second intervals for PP + 3% ba, (25 short shots total)

no influence on the mass of the moulded parts. In contrast, the incorporation of 3% of the same blowing agent resulted in a slight reduction in sample mass.

Analysis of the moulded part thickness shows that the most pronounced differences occur between measurement points located at the beginning and at the end of the melt flow path. At the end of the flow path, the moulded parts exhibit greater thickness. Moreover, an increase in the blowing agent content leads to an increase in the thickness of the moulded parts.

The addition of Plastron NUC C20 at levels of 1.5% and 3% deteriorated the mechanical properties of both unfilled polypropylene moulded parts and talc-filled polypropylene moulded parts. In general, the presence of talc leads to a reduction in tensile strength, elongation at maximum force, and elongation at break. Microscopic analysis shows that in polypropylene moulded parts, pores are typically small and densely distributed, whereas in talc-filled polypropylene moulded parts, the pores are larger but occur less frequently.

Analysis of short-shot mouldings indicates that the addition of a blowing agent to the processed material increases the cavity filling rate.

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