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The effect of talc and chemical blowing agents on selected properties of polypropylene injection moulded parts

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ABSTRACT

The paper presents the results of selected properties, including weight, impact strength, and tensile strength, of moulded parts made of polypropylene (PP) composite containing talc and a chemical blowing agent. It was shown that adding 1% of chemical blowing agent to the processed plastic reduces part weight, whereas a higher content (2%) does not significantly affect the tested properties. The study also investigated the structure using a special mould insert with a variable cavity height, in which the flow conditions of the plastic cause different shear intensity. It was demonstrated that various zones of the moulded parts exhibit different number and size of pores, which results from different flow conditions and solidification of the plastic within the mould cavity.

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

INTRODUCTION

Thermoplastic polypropylene composites are widely used in household goods, as well as automotive, packaging, and electrical engineering industries. Their popularity stems from their low cost and the ease of processing by injection moulding, which is facilitated by their broad processing temperature range. The choice of a filler (e.g. talc, calcium carbonate, glass fibre) depends on whether the aim is to reduce production costs or to change the mechanical properties of the moulded part. The use of thermoplastic composites is determined by the intended application and operating temperature range. Similar to many other thermoplastics processed by injection moulding, most thermoplastic polymers can be foamed [1–5].

Pore injection moulding is one of the unconventional methods of injection moulding. This process results in moulded parts with a solid outer skin and a porous inner core [1–7]. The poring process can be carried out using conventional injection moulding machines and standard moulds, which is highly beneficial from a production cost perspective. Other advantages include a reduction in the weight of moulded parts, lower shrinkage and collapse, as well as shortening the injection cycle time (by reducing or eliminating pressure and compression time). There are two methods of moulded part foaming: injection moulding using chemical blowing agents (CBAs) and physical foaming agents (PFAs) (e.g. microcellular injection moulding using the MuCell technology [8]). Chemical blowing agents are substances (typically in the form of powders or granules) that are introduced into the polymer before processing. They are usually added in quantities ranging from 0.1% to 3% by weight. Porosity is formed as the blowing agent decomposes, releasing gases (such as nitrogen, hydrogen, or carbon dioxide) due to the pressure drop during mould cavity filling with the liquid material. Chemical blowing agents are further divided into endothermic (inorganic) and exothermic (organic) types. Nowadays, endothermic agents are more widely used due to their ability to produce a more favourable pore structure, characterised by fine and densely distributed pores. This simplifies the setting of injection moulding parameters. The properties and internal structure of porous moulded parts depend on numerous process parameters, such as mould temperature, melt temperature, injection pressure, clamping pressure, holding time, plasticising back pressure, etc. Additionally, the shape and dimensions of the mould cavity and the length of the feed channels have a significant effect on the final structure [1–16]

Polymer composites represent a rapidly growing class of materials with a wide range of industrial applications. The possibility of applying various types of modification (e.g., the addition of glass fibres, talc, or carbon fibres) makes it possible to enhance a wide range of properties, including structural, mechanical, and functional characteristics (e.g., weight, thickness, hardness, impact strength, tensile strength, elongation at maximum force, and surface quality of moulded parts, assessed by gloss and colour), as well as electrical and thermal properties (e.g., thermal conductivity) [15–26]. Modifications can be performed through chemical, physical, or physico-chemical methods. The primary objective of polymer modification is often to improve mechanical properties (e.g., stiffness), processability, or dimensional stability. However, it is not possible to achieve simultaneous improvements in all areas. In recent years, a significant emphasis has been placed on reducing the unit cost of finished products, which is strongly influenced by the cost of polymer granules. Mineral filler additives, in addition to improving processability and reducing shrinkage anisotropy (the difference between longitudinal and transverse shrinkage), also enable considerable cost savings on polymer material used to manufacture plastic products (e.g., due to the low cost of talc) [22]. Blowing agents are also widely used in the extrusion process and can be combined with various types of fillers [27, 28]. Certain powder fillers (e.g., talc) and blowing agents can act as nucleation sites for crystallisation during extrusion [29–31]. Furthermore, porous moulded parts can be utilised in recycling processes [32].

This study investigated the effect of adding a blowing agent and fillers (glass and carbon fibres) on the properties of PA6 and PP injection moulded parts. PA6 is typically used for manufacturing components subjected to high mechanical loads, such as structural elements, whereas PP is used for products that are not usually exposed to high mechanical stresses (e.g., car bumpers, hubcaps, or interior trim components). Moreover, polypropylene is extensively employed in the packaging industry.

AIM AND SCOPE OF THE STUDY

The primary aim of this study was to evaluate the effect of mineral additives, in the form of talc, and a chemical blowing agent, on the properties of the resulting composite material. Both solid polypropylene specimens with talc and polypropylene specimens with blowing agent additives were tested. The analysis focused on changes in moulded part weight, impact strength, and tensile strength. In the experiments, polypropylene filled with 20% talc, marketed under the trade name Polypropylene RESLEN PPH 20T (Polimarky), was used. The basic parameters of the polymer were as follows:

- melt index (230 °C / 2.16 kg) ISO 1133: 3.0 g / 10 min,
- vicat softening temperature (A120) ISO 306: 150 °C.

The porous structure of the moulded parts was obtained by adding 1% and 2% (by weight) of Hydrocerol ITP 848, an endothermic blowing agent in granular form (Clariant), containing 70% of the active component. The polymer was blended with the blowing agent before the plasticisation process. The test specimens consisted of static tensile dumbbell specimens with a thickness of 4 mm, manufactured in accordance with EN ISO 527-1:2020-01. Additionally, special non-standard specimens were produced in the form of porous moulded parts with variable cavity heights to examine the effect of shear forces on the porous structure (Figure 1). All specimens underwent microscopic examination. The flow conditions for cavities with different heights resulted in varying shear intensities. Consequently, this specimen shape made it possible to evaluate the effect of moulded part wall thickness and shear intensity on the porosity of the filled material. All specimens were manufactured using a KM65-160 C4 injection moulding machine (Krauss-Maffei) with a clamping force of 650 kN and a screw diameter of 30 mm. For the specimens containing the blowing agent, the holding time and pressure were reduced, as the foaming pressure ensured obtaining good quality moulded parts while reducing the injection cycle time. The injection conditions were as follows:

- injection temperature: 230 °C,
- mould temperature: 20 °C,
- injection time: 0.8 s,
- injection rate 45 mm/s,
- injection pressure: 80 MPa,

- holding pressure: 60 MPa for specimens without blowing agent, 20 MPa for the specimens with blowing agent,
- holding time: 20 s for specimens without blowing agent, 5 s for the specimens with blowing agent,
- cooling time: 20 s for specimens without blowing agent, 25 s, for the specimens with blowing agent,

Due to the varying volumes of the mould cavities, different dosing values were used: 35.5 ccm for dumbbell-type tensile specimens, 25 ccm for four-stage specimens, and 41 ccm for three-stage specimens. Figure 1 illustrates the shape and dimensions of the moulded parts used in the tests.

RESULTS AND DISCUSSION

Weight of moulded parts

The mass of moulded parts (dumbbell specimens according to PN-EN ISO 527-1:2020-01) from a single mould cavity was measured to prevent measurement errors due to inaccuracies in mould manufacturing, and the results obtained

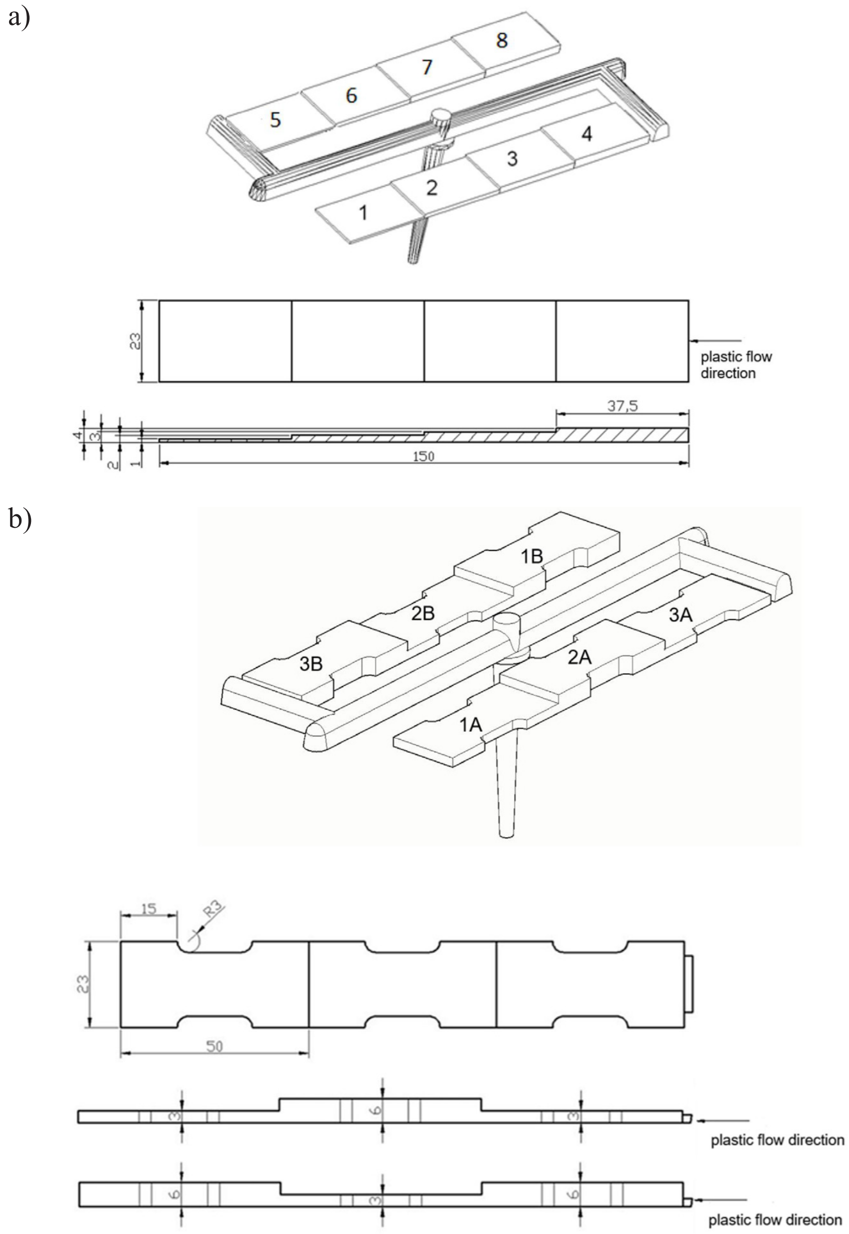

Figure 1. Shape and dimensions of the moulded parts used in the tests: (a) four-stage moulded part, (b) three-stage moulded part

were averaged using the arithmetic mean. The weight of the moulded parts was determined with an accuracy of ±0.1 mg using a Sartorius CP225 laboratory balance with a closed measuring chamber. Figure 2 presents the average weight of the moulded parts from each test cycle.

Analysis of the weight measurement results indicates that the addition of 1% chemical blowing agent to the polymer resulted in a 10% weight reduction, while the addition of 2% blowing agent led to a reduction of approximately 14% compared to solid polypropylene. This demonstrates the significant porosity effect, even with small amounts of blowing agent. However, the addition of blowing agent also caused an increase in the statistical scatter of the moulded part weights.

Impact strength of moulded parts

Impact strength (a_{cU}) was tested for unnotched specimens using the Charpy method. The tests were performed with a Charpy-Izod 25 J IT 503 impact tester (Toropol), equipped with Impact software. The measurements followed the PN-EN ISO 179-1:2023-11 standard. Impact test specimens with dimensions 80 × 10 × 4 mm were cut from the tensile test specimens. The results of the impact strength measurements are presented in Figure 3. Analysis of the impact strength results indicates that the addition of the blowing agent leads to a significant reduction in impact strength (approximately 48%). The presence of pores (voids) in the polymer contributes to the so-called notch effect.

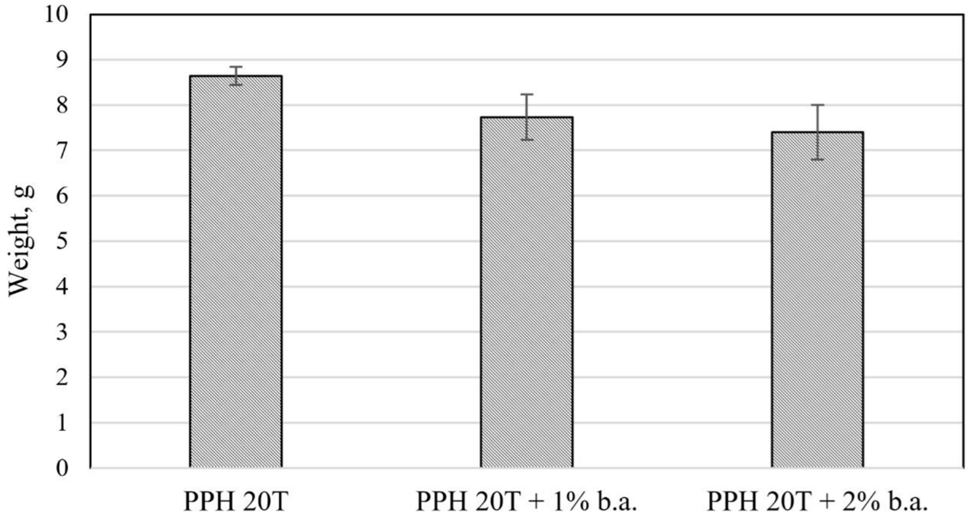

Figure 2. Weight measurement results for polypropylene with talc and for polypropylene with talc and blowing agent

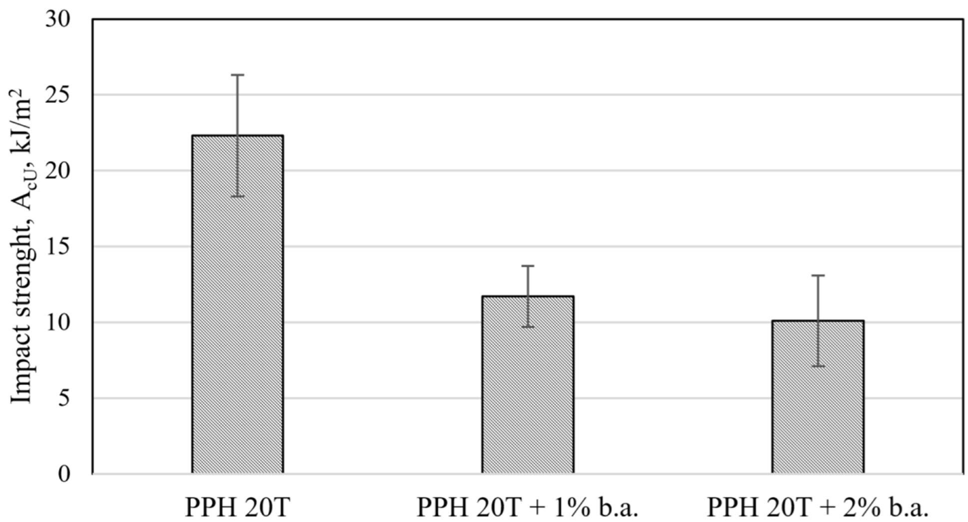

Figure 3. Impact strength results for polypropylene with talc and polypropylene with talc and blowing agent

A higher blowing agent content slightly reduces processing efficiency. Consequently, the use of a blowing agent can significantly decrease the suitability of the plastic for structural components subjected to dynamic loads.

Strength properties

Tensile strength (σ_m) and elongation at maximum force (ε_m) 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 4 and 5. The addition of a blowing agent to the polymer matrix also reduces tensile strength by approximately 13% for a 1% blowing agent content. A further increase in the blowing agent content results in an additional reduction of tensile strength.

A similar trend is observed for elongation at maximum force. The addition of a blowing agent increases the brittleness of the moulded parts, which in turn leads to a reduction in elongation at maximum force.

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

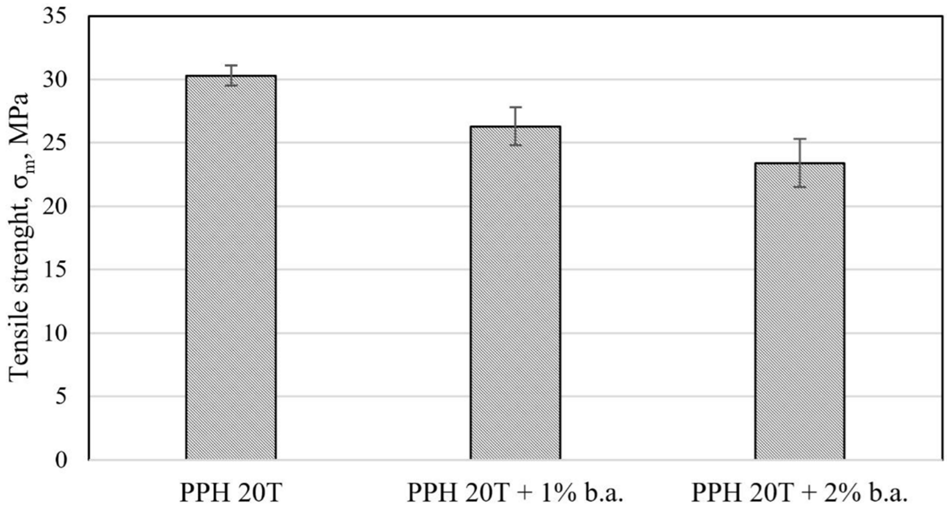

Figure 4. Tensile strength results for the moulded parts made of polypropylene with talc as well as polypropylene with talc and blowing agent

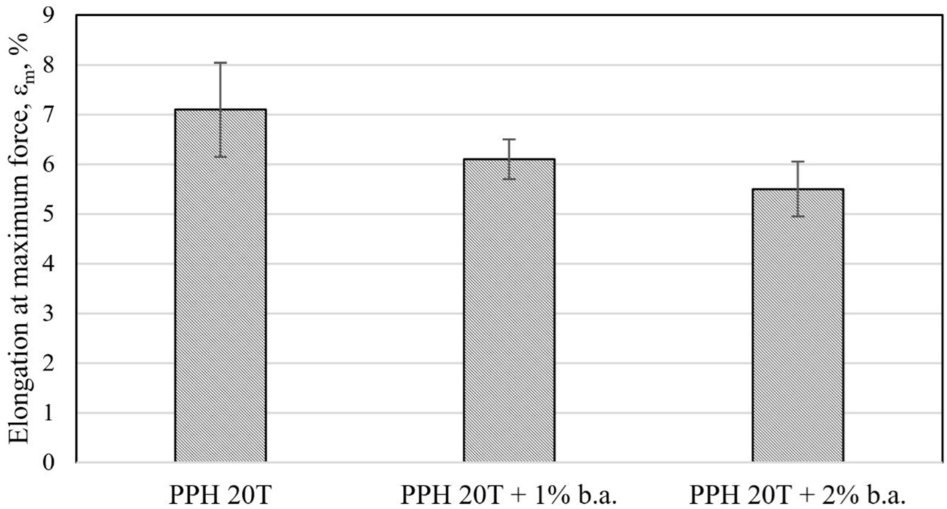

Figure 5. Results of elongation at maximum force for polypropylene with talc as well as polypropylene with talc and blowing agent

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 results are shown in Figure 9. Analysis of the microstructure images of the four-stage moulded part, filled from the section with the largest volume (4 mm) to the smallest (1 mm) (Figure 6), shows that in all areas of the cavity, the pore diameter remains relatively uniform, but the number of pores varies. In the sections with greater cavity thickness, the pores are more numerous and densely packed. A distinct division between the solid skin and the porous core can also be observed. Increasing the blowing agent content not only raises the number of pores, but also leads to the formation of a finer pore structure when 2% blowing agent is used, compared to 1%.

When injecting liquid polymer with a blowing agent, starting from the smallest cavity thickness to the largest (Figure 7) (the design that is not always recommended, but sometimes unavoidable in certain mould configurations), it can be observed that, as in the previous case, the pore distribution and average pore size remain similar across all four cavity thicknesses. Similarly, an increase in the blowing agent content leads to a higher number of pores in the polymer matrix.

For the moulded parts produced using a three-stage mould, with the polymer injected from the smallest cavity thickness (3 mm) to the larger section (6 mm) and then again to the smaller one (3 mm), it can be observed that a relatively thick solid skin is present in all cavity sections. With 1% blowing agent, the largest pores are located near the end of the moulded part, while with 2% blowing agent, pores with larger diameters are found at the beginning of the flow path. Additionally, the pore diameter increases with higher blowing agent content. It can therefore be hypothesised that with higher blowing agent content, pores tend to merge, and the resulting endothermic characteristics of the blowing agent's decomposition hinder pore formation further downstream (Figure 9).

By examining the structure of the moulded parts injected into a cavity sequence of 6 mm, 3 mm, and 6 mm, it can be observed that pores are primarily concentrated in the thicker sections of the cavity. Furthermore, pores with a larger diameter are observed at the beginning of the flow path

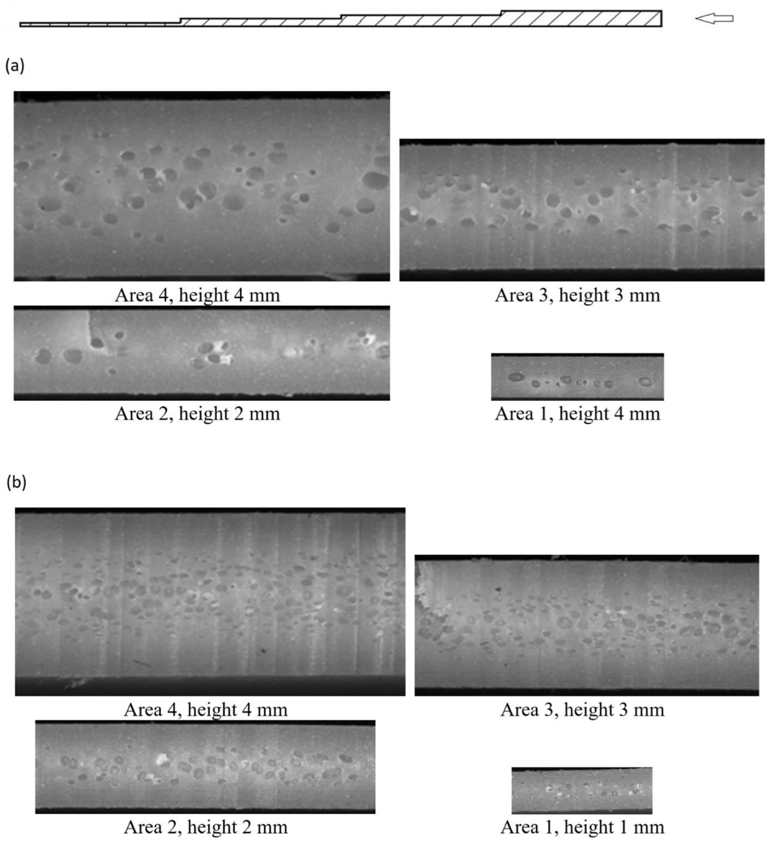

Figure 6. Structure of the PP T20 moulded parts with a 4 - 3 - 2 - 1 mm arrangement: (a) 1% blowing agent, (b) 2% blowing agent

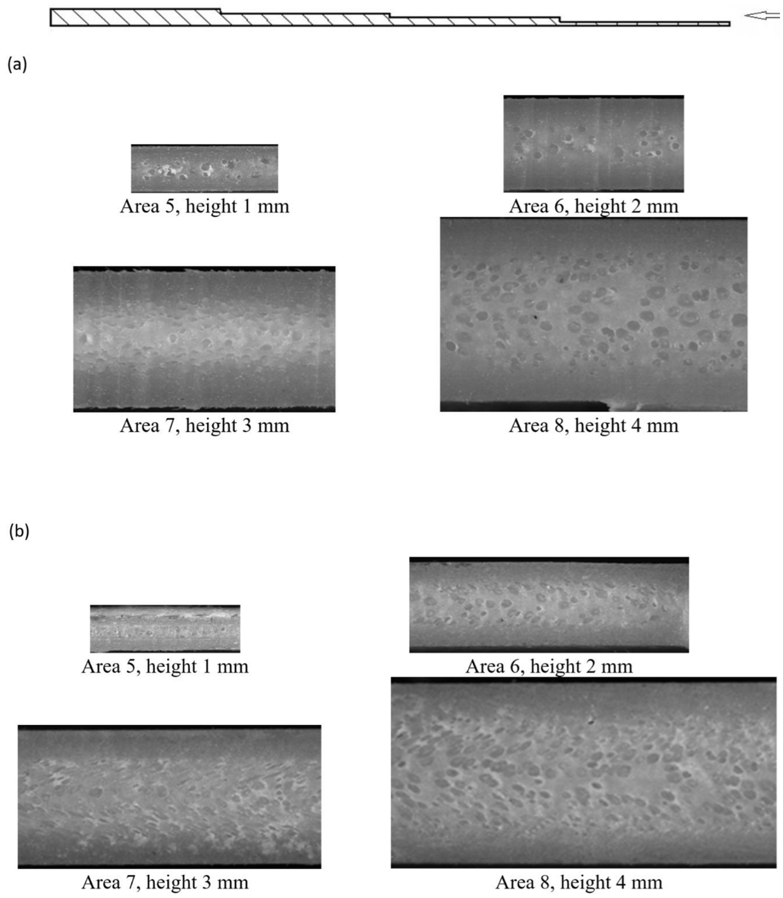

Figure 7. Structure of the PP T20 moulded parts with a 1 - 2 - 3 - 4 mm arrangement: (a) 1% blowing agent, (b) 2% blowing agent

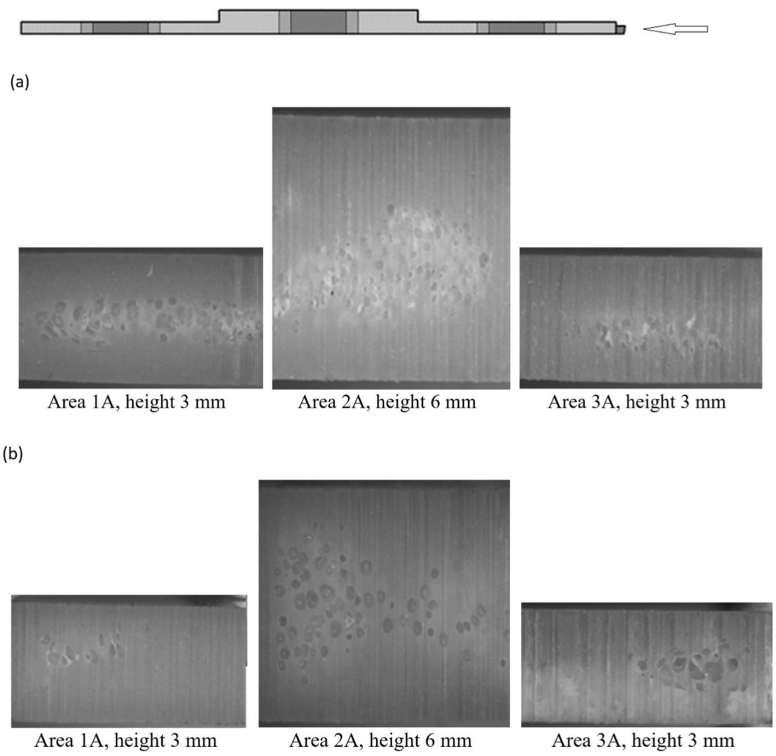

Figure 8. Structure of the PP T20 moulded parts with a 3 - 6 - 3 mm arrangement: (a) 1% blowing agent, (b) 2% blowing agent

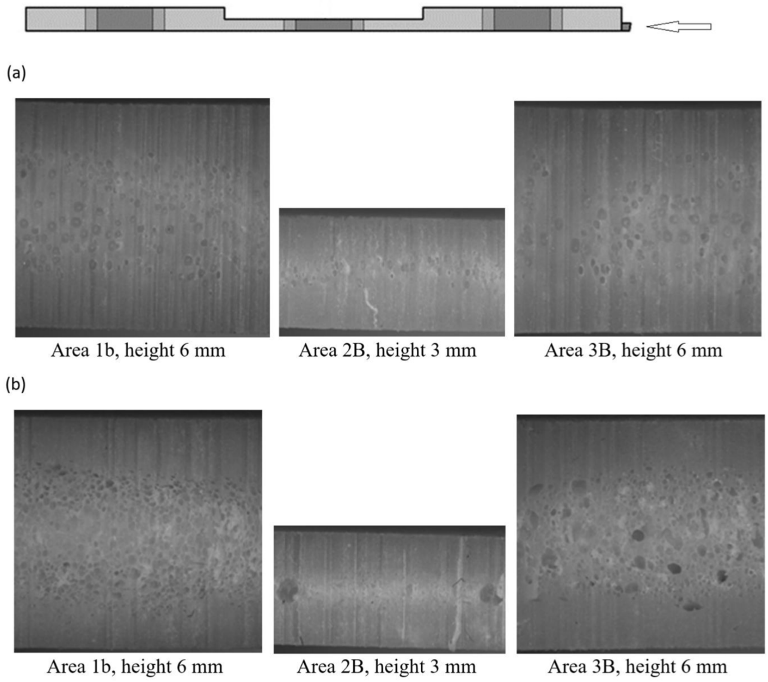

Figure 9. Structure of the PP T20 moulded parts with a 6 - 3 - 6 mm arrangement: (a) 1% blowing agent, (b) 2% blowing agent

compared to the end. However, the pores in the final part of the nest are more numerous. This may result from the slower cooling of the larger-volume areas, which promotes more intensive pore formation. Additionally, the moulded parts with 2% blowing agent exhibit a higher pore density than those containing 1%.

The flow behaviour of blowing agent-filled polymer inside the mould cavity is therefore influenced by various factors, including shear conditions. In the case of a four-stage mould, the shear effect can be more pronounced. Thus, as a result of the longer exposure to favourable temperatures for pore growth, the pores may be more numerous.

CONCLUSIONS

This study demonstrated that the addition of a blowing agent leads to both a reduction in the weight of the moulded parts and a shorter injection cycle time, as porous moulded parts were produced with reduced holding time and holding pressure. The use of a blowing agent also induces slight changes in the mechanical properties of the talc-filled polypropylene composite. The most significant effect was observed in impact strength tests, where the addition of a blowing agent resulted in nearly a 50% decrease in impact strength. This limits the potential applications of PP with talc and blowing agent to the products that are not exposed to significant impact loads. Analysis of the structure of moulded parts in cavities with varying thicknesses indicates that thicker sections, which remain molten for longer due to slower heat dissipation, favour an increase in material porosity.

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