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ADDITION OF MODIFYING AGENTS VS BASIC FUNCTIONAL PROPERTIES OF MOLDINGS MADE OF ABS

Unconventional injection methods include i.e. blowing injection that allows for production of moldings with a lower weight while maintaining mechanical properties of detail. Due to the fact that most polymers are dyed at the processing stage, it is important to examine the simultaneous effect of blowing and colorbatch, as well as variable processing conditions, on the functional properties of moldings made of the most popular construction material, i.e. ABS.

Samples were made of ABS polymer without and with the addition of a colorbatch containing brown pigment on ABS matrix, and blowing agent. Variable processing conditions were: mold and injection temperature, holding pressure and time. Other parameters were constant. Samples were tested for basic functional properties such as color, gloss, mass, density and thickness. Moldings produced with a higher blowing agent content and a higher injection temperature were characterized by lower mass. No significant influence of processing parameters and content of colorbatch on mass of samples was found. Blowing agent has no significant impact on thickness of moldings, regardless of processing conditions. Addition of a colorbatch influenced samples' gloss. Increase in colorbatch and blowing agent content and mold temperature allow to obtain moldings with a higher surface gloss. Colorbatch also changed color of samples – a decrease in luminance L even by about 40% and great changes in parameters "*a*" and slight changes in parameter "*b*". It was found that blowing agent content had the greatest influence on density of moldings. Injection temperature and colorbatch, do not significantly affect density of moldings.

Keywords: Colorbatch; blowing agent; ABS; color; gloss

1. Introduction

Due to climate changes and legal regulations of the European Union, which put more and more emphasis on reducing the consumption of polymers and their recycling, it becomes necessary to look for solutions that, on the one hand, will be less burdensome to the environment, and on the other hand, will enable the use of polymeric products, whose properties will remain unchanged.

Acrylonitrile – butadiene – styrene (ABS) is one of the most popular engineering copolymer. Thanks to its easy processing, chemical resistance, good surface quality of moldings, good mechanical properties, as well as good quality-price correlation, ABS can be used in many branches [1-5]. Injection molding is the most popular method of processing polymers. It enables the production of simple elements and complex structures, most often during one technological process. Continuous development of unconventional injection methods makes it possible to make more complex details, that are used in practically every area of life (our activities). To reduce the consumption of polymers unconventional injection methods i.e. foaming, are used. This method makes it possible to produce elements with a good surface quality, and good mechanical and functional properties, but with a lower mass, with a porous core [6-9]. The formation of a porous structure in injection molded parts is a complex process depending on the type of polymer, blowing agent and the injection molding conditions and the construction of mold runners and shape of mold cavities. The size and distribution of the pores in the plastic affect the properties of the whole part. In the literature, it can be found a description and results of studies on the impact of basic injection conditions on the foaming process [9,10]. Blowing agents in small amounts can be used as modifiers to improve the quality of molded parts, mainly to reduce their shrinkage and collapse [6,7]. The distribution of pores and their sizes affect the properties of molded parts [6,7,9,11,12]. At the same time, coloring agents so-called color-

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batches (pigment on a polymer matrix), are used all the time. Pigments are used for dyeing inks, paints, varnishes, textiles, and polymers [13]. Chemical and physical properties of pigments along with processing parameters are modified to obtain desired properties, e.g. a specific shade of color, opacity, gloss, rheological properties, or aesthetics [14-18].

The aim of the study was to determine the effect of various processing parameters and the addition of a colorbatch on ABS matrix in the amount of 0%, 1 wt.%, and 2 wt.% and blowing agent in the amount of 0%, 1.5%, and 3% (by weight) on selected functional properties of moldings such as mass, thickness, density, color, and gloss. The research compared samples made of ABS with and without colorbatch. Test results were obtained for moldings made of ABS.

2. Research Material and Methods

Copolymer acrylonitrile – butadiene – styrene under the trade name ABS Terluran GP 35 Natur, intended for injection, was used. As part of the research, samples were made of ABS polymer without and with the addition of a coloring agent (colorbatch) containing 30% (by weight) brown pigment PBr 33 (trade name PE9780 [19]) on a 70% ABS matrix in the amount of 0%, 1% and 2% by weight, as well as a blowing agent (trade name Plastron NUC C20) in the amount of 0%, 1.5% and 3% by weight. Polymer, colorbatch and blowing agent were not dried as they were stored in original bags.

Test samples (shape A) in accordance with the PN-EN ISO 527 [20] standard ware obtained on injection molding machine Krauss – Maffei model KM65 – 160 C4. Moldings were produced in various processing parameters (recommended by the manufacturer and literature [21]), in accordance with the research plan (TABLE 1). Constant processing conditions were as follows:

- injection velocity $V_w = 50\ cm^3/s$,
- injection time $t_w = 0.7$ s,
- injection pressure $p_w = 80$ MPa.

Other processing conditions are shown in TABLE 1.

Obtained moldings were tested for research in which the following properties were determined: mass, thickness, density, gloss and color.

3. Results of experiments

3.1. Mass

A Sartorius CP225 laboratory scale with a closed measuring space was used for mass measurement. All test results are shown in Fig. 1.

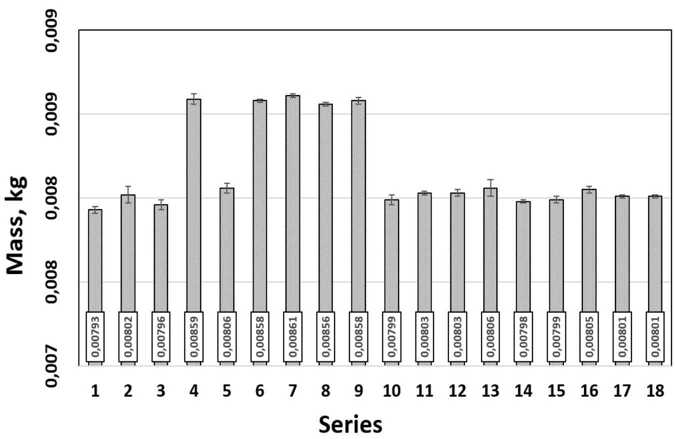

Fig. 1. Mass of samples

TABLE 1

Research plan

Series	Mold temperature T_f [°C]	Blowing agent [%]	Colorbatch [%]	Injection temperature T_w [°C]	Holding time t_d [s]	Holding pressure p_d [MPa]
1	70	3	0	250	1	5
2	70	3	0	220	1	5
3	30	3	2	250	1	5
4	70	0	2	220	20	60
5	30	3	2	220	1	5
6	30	0	0	250	20	60
7	70	0	2	250	20	60
8	30	0	0	220	20	60
9	50	0	1	235	20	60
10	50	3	1	235	1	5
11	30	1,5	1	235	1	5
12	70	1,5	1	235	1	5
13	50	1,5	1	220	1	5
14	50	1,5	1	250	1	5
15	50	1,5	0	235	1	5
16	50	1,5	2	235	1	5
17	50	1,5	1	235	1	5
18	50	1,5	1	235	1	5

On the basis of research, it was found that moldings from 7 series (0.00861 kg) have the highest mass, while from series 1 (0.00793 kg) the lowest one. It was noted that the blowing agent had the greatest influence on the mass of moldings, and more precisely change in the amount of blowing agent – samples with the highest content of blowing agent (3 wt.%) had the lowest mass (series 1, 3, 10, 13, 15). This is a logical consequence of the use of a blowing agent and a reduction of polymer participation in the moldings volume. It was also found that simultaneous use of a blowing agent and increasing injection temperature T_w to 250°C contributed to the reduction of the mass of molded parts (e.g. series 14). A slight increase in mass was also noted due to the use of a colorbatch (e.g. series 17 and 16). At the same time, an extension of holding time t_d to 20 s and holding pressure p_d to 60 MPa contributes to obtaining moldings of greater mass (e.g. series 4). At this stage, it is worth mentioning that changes in the mass of molded parts are 7.89 %.

3.2. Thickness

Measurements were made with a caliper because no dips or unevenness were noted on the surface of the moldings, especially in the central part of the moldings. The measured thickness of samples ranges from 3.899 mm (series 14) to 4.246 mm (series 7). Results are presented in Fig. 2.

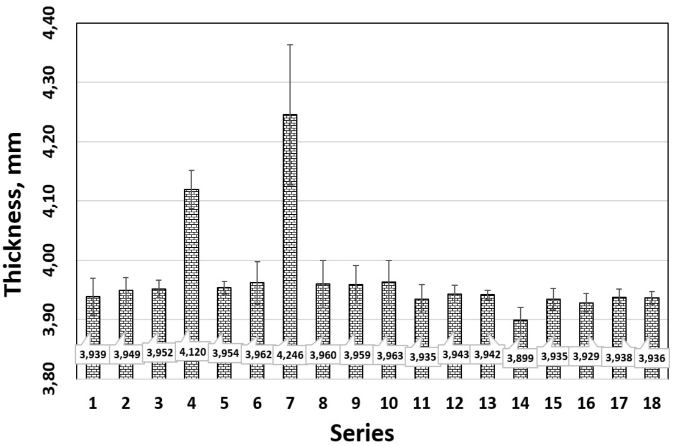

Fig. 2. Thickness of samples

It was noticed that the addition of a colorbatch, blowing agent and mold temperature had the greatest influence on the thickness. With their values increase – moldings thickness grows slightly (e.g. series 4 and 7). It was found that the use of the extreme values of mold temperature with the simultaneous use of the extreme values of injection temperature (e.g. high T_w = 250°C and low T_f = 30°C) and the addition of a blowing agent resulted in obtaining samples with a smaller thickness (e.g. series 3). A similar trend was observed for some moldings produced at the lowest injection temperature and the highest mold temperature. It was also noted that moldings made of ABS in the extreme processing conditions, without a blowing agent, with the addition of 2% colorbatch, are characterized by the greatest thickness. The thickness of moldings without the addition of a blowing agent increases with the growth of injection temperature (series 4 and 7). On the other hand, it was found that increasing the amount of blowing agent to 3% resulted in obtaining moldings with greater thickness. A high content of blowing agent (3%) and the highest injection temperature T_w = 250°C allow obtaining moldings with a slightly smaller thickness (series 1). It was noticed that the thickness of samples increases with the increase in the mold temperature, for moldings without the addition of a blowing agent. A similar trend was observed for moldings made of ABS with 3 wt.% addition of blowing agent, at 30°C mold temperature. Simultaneous increase of mold temperature and blowing agent content allows obtaining molded parts of similar thickness as moldings made without the addition of blowing agent at low mold temperature. It was found that for samples from ABS without the blowing agent, the thickness of moldings was grown with increasing content of colorbatch, while for ABS with 3 % blowing agent, molding thickness decreased with increasing colorbatch content.

3.3. Density

Density was measured in accordance with the standard [22]. Based on density measurements (Fig. 3), density of samples was found to be in the range of 0.000967 kg/m^3 to 0.001040 kg/m^3.

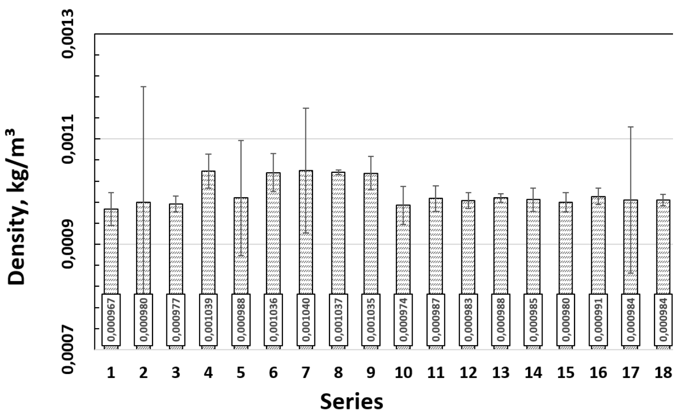

Fig. 3. Density of samples

It was found that the addition and content of the blowing agent and colorbatch had the greatest influence on density of moldings. It can be seen that molded parts made of ABS without the addition of blowing agent and with 2 wt.% addition of colorbatch (series 7) are characterized by highest density, which also had the highest mass (Fig. 2). Lowest density has moldings form ABS with 3% of blowing agent, without the addition of colorbatch, produced at high mold temperature T_f = 70°C and injection temperature T_w = 250°C (series 1). It was noticed that moldings made of ABS without the addition of a blowing agent are characterized by the highest density. The addition (dosage) of a colorbatch has insignificant impact on the density of samples. With the increase in the content of colorbatch, the density of samples increased slightly. Also, increasing blowing agent content while reducing injection temperature to 220°C and colorbatch content allows to obtain moldings characterized by higher density.

3.4. Gloss

Gloss measurements were taken with glossmeter Elcometer 406, according to standard [23]. Tests were carried out at an angle of incidence of light on the moldings surface (geometry) of 60°. It was measured in the same and in the opposite direction to material flow in mould cavity. Samples in the form of cuboids (dimensions of 150 × 23 × 4 mm) were made in accordance with the research plan (TABLE 1). Gloss was measured in three points on the surface of each molding, numbered in the direction of material flow at a distance of 37.5, 75, 112.5 mm from the gate (Fig. 4). Obtained values are shown in TABLE 2.

It can be seen that the greatest impact on gloss, tested at the angle of incidence of light on the surface of 60° in the direction of material flow in mould cavity, has the injection temperature and content of colorbatch. Other parameters, e.g. the mould temperature and blowing agent addition, have a slight effect on changes in the values of gloss. The highest gloss, amounting to 69.99 GU, is characterized by moldings from 4 series, made of ABS with the 2 wt.% addition of colorbatch. In turn, the smallest gloss is characterized by moldings from 3 series – 45.92 GU.

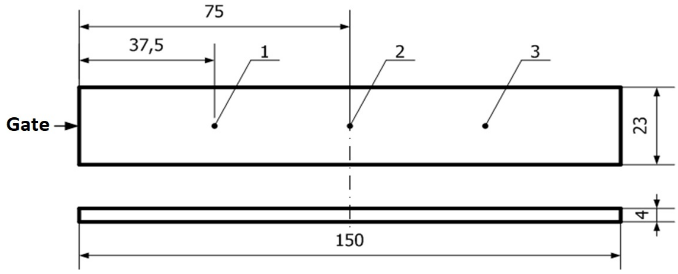

Fig. 4. Molding with marked measuring points

Based on obtained results, it can be seen that reducing injection temperature T_w to 220°C and mold temperature T_f to 30°C allows obtaining moldings with a lower gloss (e.g. series 5 and 8). Also, the reduction of colorbatch content contributes to the production of moldings with a lower gloss (e.g. series 6 and 15). For samples made of ABS with the addition of 1.5% and 3% blowing agent and molded at the highest injection temperature, the lowest gloss values were obtained (series 1 and 3). Gloss of these moldings ranges from 45.92 GU to 48.72 GU. On this basis, it can be assumed that the addition of a blowing agent reduces the gloss of the surface of molded parts.

Tests were also carried out in the direction opposite to the flow of material in the mold cavity, and obtained results are summarized in TABLE 2. Differences in obtained results may be caused by the arrangement of copolymer macromolecules and the irregular shape of colorbatch particles [24,25]. This contributes to differences in scattering and absorption of light

TABLE 2

Results of gloss and color measurement in the same and opposite direction of polymer flow in the mold cavity

Series	Gloss, GU		Color – the same direction			Color – opposite direction		
	the same direction	opposite direction	L, cd/m^2	a	b	L, cd/m^2	a	b
1	45.92	43.30	88.19	–2.50	7.02	87.77	–2.46	6.99
2	55.12	52.32	88.50	–2.44	6.09	88.07	–2.41	6.08
3	48.72	41.46	44.58	12.06	7.97	44.66	11.90	7.88
4	69.99	65.54	41.54	11.68	7.64	41.86	11.56	7.49
5	61.42	54.48	44.55	11.57	7.21	44.96	11.25	7.04
6	54.36	49.98	84.33	–3.51	6.07	83.92	–3.49	6.09
7	69.95	65.34	41.72	11.24	7.38	42.23	10.93	7.04
8	54.64	50.46	83.88	–3.42	4.91	83.35	–3.39	4.87
9	61.34	58.20	51.49	10.26	6.28	51.31	10.23	6.13
10	67.94	61.50	51.31	11.75	7.46	50.91	11.35	7.13
11	63.72	55.28	49.20	11.66	7.35	49.17	11.49	7.21
12	59.44	54.40	46.02	12.23	7.81	46.14	12.03	7.90
13	64.24	59.24	48.42	11.78	6.98	48.57	11.56	6.73
14	60.86	54.62	51.42	11.29	7.27	51.42	11.04	7.04
15	50.44	46.84	86.83	–2.66	6.40	86.26	–2.63	6.39
16	63.86	57.46	44.79	11.95	7.76	44.85	11.76	7.60
17	64.88	59.98	49.91	11.81	7.53	49.54	11.69	7.29
18	64.86	59.96	50.61	11.98	7.60	49.44	11.73	7.37

falling on the surface of tested samples. Hence the differences in results obtained. Additional tests were performed to show how important it is to properly construct details so that they can be assembled in a specific, correct way.

3.5. Color

Color tests were carried out using an SP 60 spherical spectrophotometer by X-rite. Measurements were made at 3 measuring points in the direction of material flow in the mold cavity and in the opposite direction of copolymer flow (Fig. 4). Obtained test results are summarized in TABLE 2.

Color was determined using an independent CIE *Lab* model where "*L*" describes luminance (brightness, black to white), "*a*" represents color green (–*a*) to magenta (+*a*), and "*b*" represents color from blue (–*b*) to yellow (+*b*).

Based on obtained results, it was found that regardless of processing conditions, color of samples changed as a result of colorbatch content. The lowest luminance is found for moldings form ABS with 2 wt.% addition of colorbatch and manufactured at a high mold temperature – series 4 (41.54 cd/m^2) and series 7 (41.72 cd/m^2). In turn, the highest luminance value was recorded for moldings produced at high mold temperature (250°C) with the addition of 3% blowing agent, without colorbatch (series 1 and 2). Reducing mold temperature to 50°C and decreasing blowing agent content to 1.5 wt.% also allows for obtaining moldings with high luminance (series 15, 86.83 cd/m^2). Simultaneous use of medium injection and mold temperature, as well as 1.5% blowing agent and 1% colorbatch, allows for the manufacturing of moldings characterized by lower luminance, e.g. series 11, 49.20 cd/m^2.

When analysing the results of tests for "*a*" parameter, it was found that for ABS moldings without the content of colorbatch, "*a*" coordinate takes negative (minus) values, i.e. it is in the "green" part of the coordinate system (e.g. series 8, –3.42). The addition of a blowing agent, regardless of processing conditions, slightly shifts parameter "*a*" towards the origin (beginning) of the coordinate system (e.g. series 2, –2.44). On the other hand, a small addition of colorbatch shifts parameter "*a*" towards positive (plus) values and the "purple" part of a coordinate system (series 12, 12.23). Changing processing conditions has no significant effect on the value of parameter "*a*".

In turn, analysing results obtained for parameter "*b*", it can be concluded that changes are not as significant, as in the case of previously discussed parameter "*a*". Moldings made of ABS at low injection and mold temperature, without the addition of colorbatch and blowing agent, have the lowest value of "*b*" parameter and it is 4.91 for series 8. The highest value of "*b*" parameter and its further shift towards yellow color was recorded for series 3, for moldings made at high injection temperature and low mold temperature, made of ABS with 3 wt.% blowing agent and 2 wt.% colorbatch addition. It was found that reducing colorbatch content, regardless of processing conditions, shifts parameter "*b*" towards the origin (beginning) of the coordinate system. In the case of the remaining variables, it is difficult to determine dependencies and their impact on "*b*" parameter.

4. Conclusions

The tests were carried out on samples of ABS Terluran GP 35 Natur, without and with the addition of 1% and 2 wt.% of a colorbatch, containing 30% of brown pigment PE9780 on ABS matrix, and without and with the addition of 1.5% and 3 wt.% of blowing agent Plastron NUC C20. The mass, thickness, density, gloss, and color of molded parts were tested.

It was noted, that blowing agent content has the greatest impact on mass changes. The mass of samples significantly decreases with the increase of blowing agent content. The mass decrease of molded parts was caused too by the increase in injection temperature. The addition of colorbatch insignificant impacts the mass changes of ABS molded parts. Similar conclusions were made in the work [11].

Based on results obtained during thickness measurements of moldings, it was found that increasing the content of blowing agents, colorbatch, and mold temperature contribute to the increasing thickness of moldings. Molded parts made of ABS without the addition of a blowing agent at a low mold temperature have the same thickness as those produced at a higher mold temperature and increased blowing agent content. It was found that for ABS samples without a blowing agent, the thickness of moldings increased with the growth of colorbatch addition, while for samples with 3 wt.% blowing agent content, the thickness of moldings decreased with increasing colorbatch content.

The blowing agent content has the greatest influence on the density of samples. Moldings made of ABS without the addition of a blowing agent and with 2 wt.% colorbatch content (series 7) are characterized by the highest density, which were also characterized by the highest mass. It was found that molded parts from ABS without a blowing agent have the highest density. In turn, the addition of colorbatch has a slight effect on the density of samples.

The use of high mold temperature T_f = 70°C, holding time 20 s and holding pressure 60 s without the addition of a blowing agent allows obtaining samples with the highest mass, thickness and density. In order to obtain lighter samples with a porous core, which slightly affects their density and thickness, it is worth using a 2% of a blowing agent and high T_f and low T_w or low T_f and high T_w.

It was noticed that mold and injection temperature and content of colorbatch have the greatest influence on the gloss of ABS samples. Other parameters, e.g. blowing agent addition, have a slight effect on changes in gloss value. Gloss tests were also carried out with light incidence on the surface of the sample in the opposite to the flow direction of polymer alloy in the mold cavity. At the same time, it is worth paying attention to the way the research is carried out. Samples whose surface was tested with the geometry 60° in the flow direction were usually characterized by higher gloss. Values obtained when measured in the opposite direction to material flow were lower, which indicates a lower gloss. These studies were aimed at showing the differences in moldings gloss depending on the direction of measurements.

Conducted color research shows that the content of colorbatch has the greatest impact on all three parameters of the CIE *Lab* color space model. Regardless of whether tests were carried out in the direction of and in the opposite direction to the material flow in the mold cavity, for moldings from ABS without addition of colorbatch, brightness "*L*" is the highest. This conclusion is logical because material used is milky white and the used colorbatch is brown. The use of the blowing agent and changes in processing conditions have little effect on moldings luminance. In the case of "*a*" parameter, it was found that for molded parts made of ABS without the addition of colorbatch, "*a*" coordinate is in "a green" part of the coordinate system. A small addition of colorbatch shifts "*a*" parameter towards "a purple" part of the coordinate system. Parameter "*b*", regardless of processing conditions and additives used, is in "an yellow" part of the coordinate system. Its changes are minor.

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