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# Influence of processing conditions on strength of plastic parts produced with gas assisted injection moulding method

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## ABSTRACT

**Purpose:** An article is supposed to show an influence of processing industry and gas assisted injection moulding into plastic parts on its durability conditions. The main goal of the article is to calculate the characteristics of geometrical sections described as the durability of bending index.

**Design/methodology/approach:** in the article presents an influence of the most valuable parameters of the process like the temperature of injected material, an over time of injection material faze on gas injection and time of gas injection on plastic moulding durability on bending process. The research was made till the deflection was equal 5 mm. The results of the durability index of bending process were compared with the results of bending force measurement.

**Findings:** The result of all researches was comparison of an influence of material and gas injection conditions on plastic moulding durability in bending process and value of bending force used to gain the deflection equal 5 mm.

**Research limitations/implications:** All the researches were just limited to the one type of material - it was a copolymer polipropylene – ethylene. The plastic moulding in shape of proms equipment were made using technology of gas injection moulding. The researches were made according to the research plan, included extreme value of manufacturing parameters.

**Practical implications:** Conducted researches give an information about temperatures of injected material and an over times and gas injection on plastic moulding durability in bending process. An exact selection of those parameters allow to gain plastic mouldings with satisfied quality and durability properties.

**Originality/value:** The process of gas assisted injection moulding is a modern technology that gives possibility of getting an empty plastic mouldings. This process, as it is incredibly dynamic, has not been well known or written about yet.

**Keywords:** Mechanical properties; Gas assisted injection moulding

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## METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

## 1. Introduction

The article presents the results of geometrical characteristics calculations of plastic parts cross-section - pram holder and the results of measurement of the power equivalent to definite value of deflection this holder with triple-point bending. The plastic parts were made with gas assisted injection moulding technology while using different parameters of technological process. A careful analyze of one of those characteristics has been done, namely the durability for bending parameter, for chosen sections of plastic parts which were the result of using the eight parameters' constructions of technological process.

The plastic parts made whit gas assisted injection moulding method is rank to the unconventional group of technologies. In this process we received empty plastic parts which are characterized by huge precision of dimension and shape and very good quality of the surface. Another advantage is that injection plastic parts not necessarily must be treated with the processing operations. The process as itself is very economic and gives an opportunity of the automatization of production. It allows to make the time of manufacturing of plastic parts much shorter and to cut the costs of the production. The very important meaning in the plastic part manufactured by gas assisted injection moulding method is that they have technolgical parameters. The biggest meaning has the temperature of injection, gas delay time and time of gas injection [1-7,11-13]. Any changes of the parameters have an influence on gas channel in plastic part and quality and features of plastic parts including durability features [7,8]. Taking under consideration different possibilities of gas channel shapes very important durability meaning have parameters of plastic moulding section: field - $A$, the force of inertia - $I_{xc}$, and a durability bending index $W_x$ (its growth causes higher bending durability [9,14-24].

## 2. The researches, researches results and its consideration

In the process of gas assisted injection moulding we received plastic parts that were an element of prams' equipment - hand holder to push the pram. Tested plastic parts were made of copolymer polypropylene - ethylene, which is marked as Tipplen K597. This copolymer is characterized by features mentioned below: tension durability with the plasticity limits - 22 MPa, elongation with the plasticity limits 9%, an resilience module with elongation - 950 MPa, an elasticity module - 900 MPa, resilience according to Izod ( with notch) 48 kJ/m$^2$, the bending temperature (0.46 N/mm$^2$) 77°C. The whole injection process was based on the researches plan elaborated in Statistica program. For the first three entered parameters - basic technological parameters (injection temperature, over time and time of the gas injection) plan assumed 16 constructions. In the article presents only a small part of the researches plan that contains the edges values of the input parameters. The reason for that was to show better its influence on the durability characteristics of plastic parts (Table 1).

In the holder part of plastic parts there is a gas channel which shape in the cross-section is similar to ellipse shape. This channel makes the stiffness of the holder lower which in the end makes the possibility of deformation much higher. The lengthwise section of the plastic parts and the points of its cross-sections measurements were presented on the first picture (Fig. 1).

Table 1.
Plan of an experimental researches

| Set of experimental researches | Injection temperature $T_w$, °C | Delay time $t_{pg}$, s | Gas injection time $t_d$, s |
|---|---|---|---|
| 1 | 200 | 0 | 41 |
| 2 | 200 | 4 | 41 |
| 3 | 175 | 2 | 41 |
| 4 | 225 | 2 | 41 |
| 5 | 200 | 2 | 31 |
| 6 | 200 | 2 | 52 |
| 7 | 200 | 2 | 41 |
| 8 | 200 | 2 | 41 |

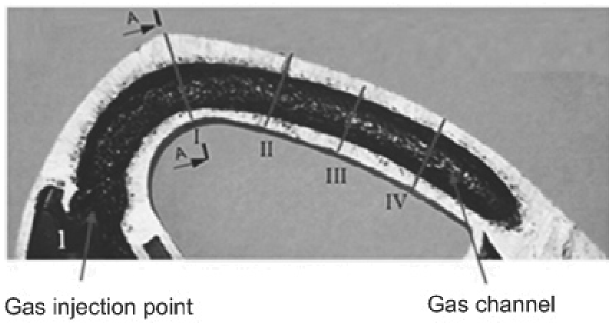


Fig. 1. The lengthwise section with demonstrated point of gas injection, the gas channel and particular measurement sections

The note of the durability holder part of the plastic parts was conducted on the base of the analyze of changing the durability index on bending parameter for the low edge surface tensioned during the pulling process of pram holder. This index was presented on the four sections(I, II, III and IV) of this part of plastic parts (Fig. 1). The get the index of bending force $\boldsymbol{F}$ needed to gain the bending arrow equal $f$ = 5 mm for probes taken from that part of plastic parts were made some measurements.

The scheme of the plastic part and its measurements are shown on the Figure 2a. The scheme of taking holder part contains the gas tunnel is shown on the Fig. 2b.

Each measurement section (cross-section - Fig. 3) was divided into simple integral figures (rectangles - A1, A2, squares - A3, circle's quarters - A4 and ellipse - A5). The fields of those figures were determinated and its centers of gravity as well. On this base the coordinate $y_o$ of plastic part cross-section gravity center was found:

$$y_0 = \frac{A_1 y_1 + A_2 y_2 - 2A_3 y_3 + 2A_4 y_4 - A_5 y_5}{A_1 + A_2 - 2A_3 + 2A_4 - A_5} \quad (1)$$

where: A1-A5 - fields of particular figures of plastic part integral section; $y_1$-$y_5$ - coordinates of gravity centres accordingly for fields A1-A5.

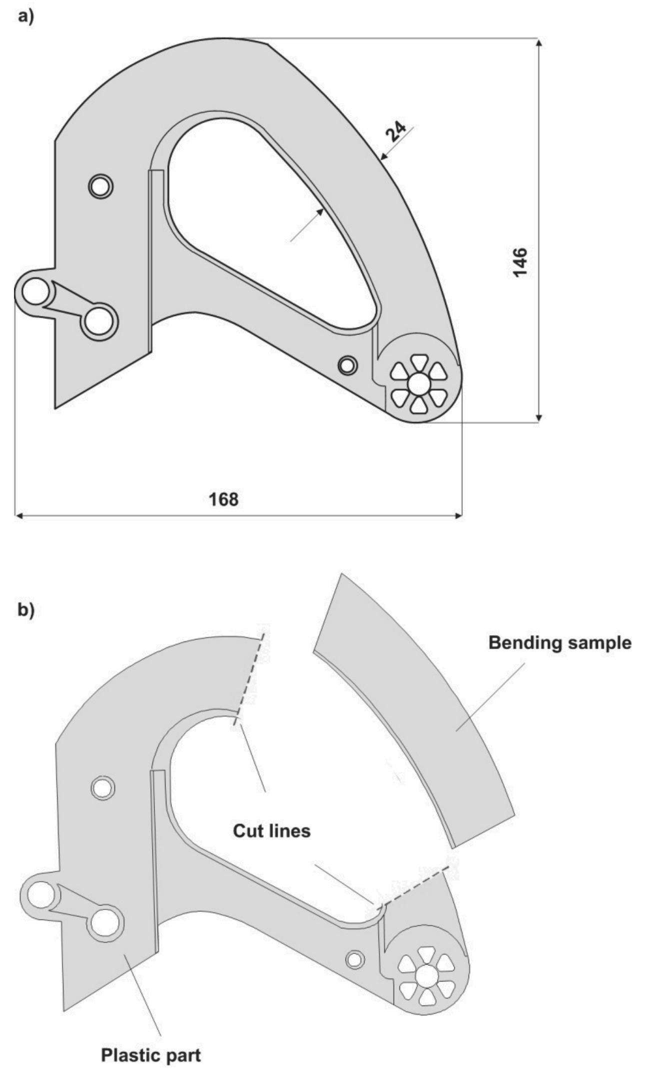


Fig. 2. The scheme of the plastic part (a) and taking a probe to test durability bending features (b)

On the base of Steiner theory calculated for individual integral figures the inertia's moments according to central section line $x_c$ [8,9]. The main central inertia moment of plastic part section is a sum of all inertia moments its individual figures:

$$I_{x_c} = I^1_{x_c} + I^2_{x_c} - 2I^3_{x_c} + 2I^4_{x_c} - I^5_{x_c} \quad (2)$$

The bending durability index of the lower holding plastic part surface determinate for every section (I-IV) and measurement construction (1-8) from formula:

$$W_x = \frac{I_x}{y_0} \quad (3)$$

The value decides about the tension bending's level ***σ*** assume the state value of flexible moment ***M*** and durability values of the material (the plasticity limit and tension durability). The maximum value of the flexible bending in the radical tensioned layer of plastic parts holding part should be lower than acceptable tension ***kr*** calculated on the base values presented below:

$$\sigma = \frac{M}{W_z} \le k_r \quad (4)$$

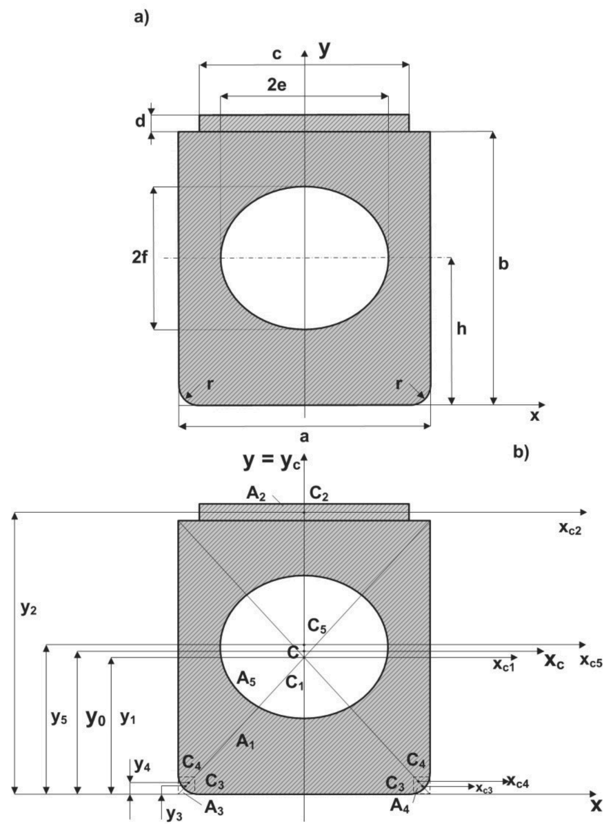


Fig. 3. The scheme of plastic part cross-section (the part of plastic part that range the gas channel) its measurement (a) and fields of individual integral figures, centers of gravity and its coordinates (b)

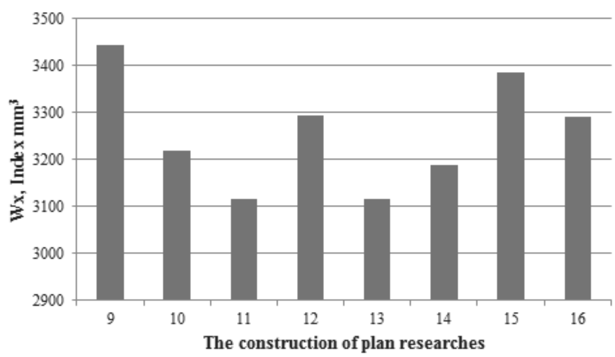


Fig. 4. The value of durability on bending index for I section of plastic parts

Table 2.
Bending durability index calculated for I section of plastic parts

| The construction of plan researches | The cross-section field A, mm$^2$ | The coordination of the gravity center$y_o$, mm | The central main moment of inertia$I_{xc}$, mm$^4$ | The index of bending durability $W_x$, mm$^3$ |
|---|---|---|---|---|
| 1 | 753.901 | 15.815 | 5.445x10$^4$ | 3.443x10$^3$ |
| 2 | 549.154 | 14.026 | 4.516x10$^4$ | 3.22x10$^3$ |
| 3 | 544.252 | 15.802 | 4.924x10$^4$ | 3.116x10$^3$ |
| 4 | 550.756 | 14.161 | 4.663x10$^4$ | 3.293x10$^3$ |
| 5 | 527.977 | 14.164 | 4.414x10$^4$ | 3.116x10$^3$ |
| 6 | 549.352 | 14.133 | 4.505x10$^4$ | 3.187x10$^3$ |
| 7 | 546.395 | 14.058 | 4.759x10$^4$ | 3.386x10$^3$ |
| 8 | 574.929 | 15.086 | 4.967x10$^4$ | 3.292x10$^3$ |

Table 3.
The bending durability index calculated for II plastic parts section

| The construction of plan researches | The cross-section field A, mm$^2$ | The coordination of the gravity center$y_o$, mm | The central main moment of inertia $I_{xc}$, mm$^4$ | The index of bending durability $W_x$, mm$^3$ |
|---|---|---|---|---|
| 1 | 575.913 | 13.133 | 3.052x10$^4$ | 2.324x10$^3$ |
| 2 | 448.912 | 11.951 | 2.502 x10$^4$ | 2.094x10$^3$ |
| 3 | 356.608 | 12.594 | 2.295x10$^4$ | 1.822x10$^3$ |
| 4 | 475.036 | 12.223 | 2.798x10$^4$ | 2.289x10$^3$ |
| 5 | 439.657 | 12.041 | 2.639x10$^4$ | 2.192x10$^3$ |
| 6 | 460.432 | 11.84 | 2.719x10$^4$ | 2.296x10$^3$ |
| 7 | 443.611 | 12.101 | 2.714x10$^4$ | 2.243x10$^3$ |
| 8 | 470.48 | 12.058 | 2.744x10$^4$ | 2.276x10$^3$ |

Table 4.
The value of durability on bending index calculated for III section of plastic parts

| The construction of plan researches | The cross-section field A, mm$^2$ | The coordination of the gravity center $y_o$, mm | The central main moment of inertia $I_{xc}$, mm$^4$ | The index of bending durability $W_x$, mm$^3$ |
|---|---|---|---|---|
| 1 | 588.887 | 12.911 | 3.202x10$^4$ | 2.48x10$^3$ |
| 2 | 468.94 | 12.377 | 2.843 x10$^4$ | 2.297x10$^3$ |
| 3 | 363.119 | 12.672 | 2.55x10$^4$ | 2.012x10$^3$ |
| 4 | 480.477 | 12.519 | 2.947x10$^4$ | 2.354x10$^3$ |
| 5 | 428.175 | 11.639 | 2.345x10$^4$ | 2.015x10$^3$ |
| 6 | 444.097 | 12.543 | 2.799x10$^4$ | 2.232x10$^3$ |
| 7 | 445.708 | 12.615 | 2.717x10$^4$ | 2.154x10$^3$ |
| 8 | 492.159 | 12.198 | 2.92x10$^4$ | 2.394x10$^3$ |

Table 5.
The values of bending durability index calculated for IV section of plastic parts

| The construction of plan researches | The cross-section field A, mm$^2$ | The coordination of the gravity center $y_o$, mm | The central main moment of inertia $I_{xc}$, mm$^4$ | The index of bending durability $W_x$, mm$^3$ |
|---|---|---|---|---|
| 1 | 608.837 | 12.312 | 3.055x10$^4$ | 2.481x10$^3$ |
| 2 | 442.398 | 12.3 | 2.606x10$^4$ | 2.119x10$^3$ |
| 3 | 360.459 | 12.212 | 2.365x10$^4$ | 1.936x10$^3$ |
| 4 | 422.203 | 11.228 | 2.462x10$^4$ | 2.193x10$^3$ |
| 5 | 439.474 | 11.802 | 2.669x10$^4$ | 2.262x10$^3$ |
| 6 | 423.404 | 12.115 | 2.624x10$^4$ | 2.166x10$^3$ |
| 7 | 431.786 | 12.04 | 2.616x10$^4$ | 2.173x10$^3$ |
| 8 | 440.28 | 11.755 | 2.511x10$^4$ | 2.136x10$^3$ |

In the considered constructions of the researches plan the technological parameters (temperature of injection, over time and gas injection time) had radical values. This allowed to analyze bending durability index of the plastic parts with wide range of changeability those parameters.

The results of calculated geometrical characteristics of plastic parts cross-section (***A, $I_{xc}$ i $W_x$***) for the accepted constructions of research plan are presented in schemes. The change of bending durability index presented on Figures 4-7.

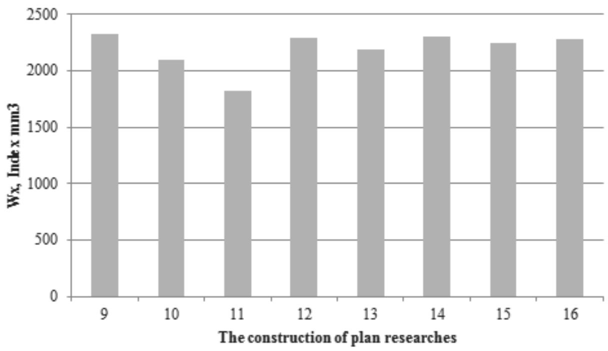


Fig. 5. The value of bending durability index for II plastic parts section

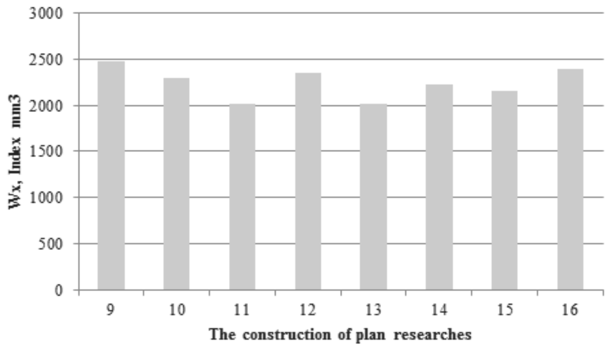


Fig. 6. The value of durability on bending index for III section of plastic parts

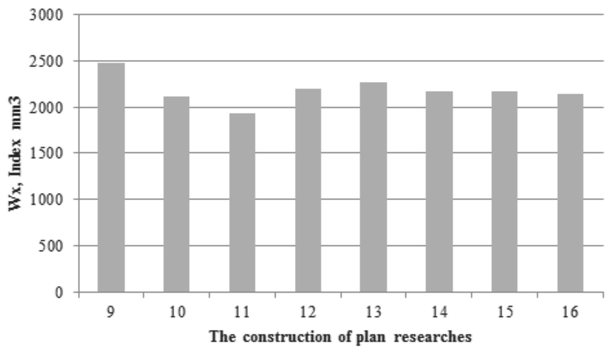


Fig. 7. The value of durability on bending index for IV section of plastic parts

For the next analyzed sections (II-IV) the values of durability on bending index are less differentia (Figs. 5-7). In those plastic parts the measurements of a gas channel are bigger. The differences in thickness of walls in particular sections of plastic parts are smaller, and a gas channel is situated more symmetrical. The plastic parts for constructions 4-6 are characterized by the high value of $\boldsymbol{W_x}$ index in those cross-sections. The value of $\boldsymbol{W_x}$ index for those constructions is common and contains itself in range from 2192 mm$^3$ to 2296 mm$^3$ for sections II, from 2015 mm$^3$ to 2394 mm$^3$ for section III and from 2136 mm$^3$ to 2262 mm$^3$ for section IV.

The highest value of durability on bending index gained for technological parameters from first construction of the plan researches. But those plastic parts were found as not proper ones because of the subsidence that can be seen on its external surface. The lowest value of $\boldsymbol{W_x}$, which is equal to the lowest bending durability have got plastic parts for technological parameters from constructions 3 and 5 in sections I and III and from 3 construction in sections II i IV.

We have to remember that about durability of the particular bend element with moment ***M*** decides not only the value of durability on bending index but the value of acceptable tension $\boldsymbol{k_r}$ (Formula 4) of the plastic part material. The one mentioned as the last one is being calculated on the base of material attributes (the plasticity limits or tension durability) and assumed safety factor.

The material attributes of plastic parts according to a different technological parameters might have a huge differences between them which could be caused by gain different state of crystallization. That's why when we are making the conclusion of plastic parts durability researches gained with a technological parameters must be taken under consideration material's attributes corresponded with particular technological parameter construction.

There was conducted researches about triple bend point of probes taken from holding plastic part which consist gas channel. The scheme of ballast of the probe is presented in Fig. 8 [10,14-24]. The line of acting force was lying in the common ground of section III. The researches were being led till the probe deflection *f* was equal 5 mm. There was different values of ballast force for the constructions researches plan which changed from F = 3000 N to 3600 N.

An example of graph with changes of bending force in function of bending arrow of plastic part from 7$^{th}$ construction researches plan is shown on the Fig. 9.

The value of bending force and the tension during the bending process of the extended layers for probes from constructions 1 to 8 are presented in the Table 6.

The highest value of bending force (3600 N), the same it means the highest resistance on bending have got plastic parts produced with injection parameters described in 4 and 5 of the construction of plan researches. For those constructions for the process of injection the high was used (200-225ºC), switch-over time 1-2 s and the time of the gas injection from 31 to 41 s. With high temperature of injection the cooling time is a bit longer what allows to possess higher degree of crystallization. The effect is an improvement of the basic mechanical values including Young module. Those plastic parts characterized the very similar mass and equal distribution of walls thickness. It means that the gas tunnel is symmetrical situated. This type of plastic parts construction is very good according to its mechanical values. In this case the plastic parts were manufactured under conditions of injection described in constructions 4 and 5 were possessed good quality of surface.

The lowest values of bending force were gain for plastic parts from constructions 1 and 3. Those parts were produced with radical parameters: switch-over time ($t_{pg}$= 0 for construction 1) and temperature ($T_w$=175ºC for construction 3). Those parameters made the durability attributes of plastic parts worse. This caused the reduction of the force needed to gain the estimated value of bending arrow even though the highest value of inertia moment $I_{xc}$ of the probe section from first construction was reached (Table 4). Calculated tension should be treated as a contractual because after the cross of plastic limit in radical layers of plastic parts there is going to start the redistribution of tensions. The direction of this redistribution would come across to fully flexibility in part of the section.

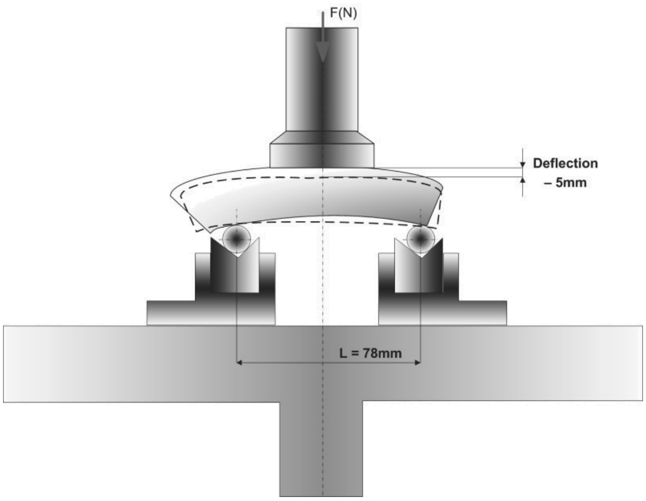


Fig. 8. The scheme of plastic parts durability bending researches

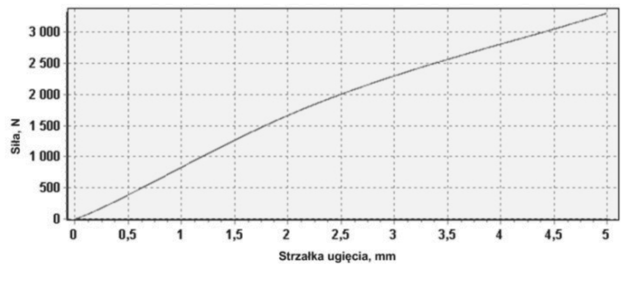


Fig. 9. The change of bending force in function of bending arrow of plastic parts for 7 constructions of researches plan

A bit smaller value of bending force gained in some others examples of plastic parts which were described as correct (from constructions 6, 7, 8). During the manufacturing process of those plastic parts the injection's temperature changes from 200 to 215ºC, switch-over time from 2 to 3 s and the time of gas injection from 41 to 52 s. Usage of the high injection temperature, relatively long switching time and long gas injection time allows to gain the plastic parts with comparatively thick set layer of material to which was no gas diffuse. It characterized quiet big durability on bending process.

## 3. Summary

Application of gas assisted injection moulding technology allow to reduce plastic parts weight, time of production and decrease cost of fabrication. Changes of technological parameters influence to geometrical characteristic and cross section of plastic parts with gas channel also on quality and properties of plastic parts.

The result of research cart handles made with copolymer Tipplen K597 demonstrate, that processing conditions influence on properties and different shape and location of gas channel inside molding. The different shapes of gas channel gives diversification of cross sections of molding: moment of inertia $\boldsymbol{I_{xc}}$, so determineted its stiffness and index of bending strength $\boldsymbol{W_x}$, defined level of bending stress for particular load of plastic part.

The worst strength properties of value moment of inertia Ixc and $\boldsymbol{W_x}$ index (the lowest stiffness and the greatest level of bending stress ) achieve for 3rd set of parameters in whole analysed cross section of handle. The best value of this quantities reveal for 1 set of plan researches first of all in I cross section, for other sets there are diversification of results. However plastic parts received with parameters specified in this set are incorrect for the sake of sink marks in the outer layer of mouldings.

The resistance of plastic parts bending with moment M is dependent not only on strength index but also allowable stress $\boldsymbol{k_r}$, determine on the basis of plastic part material (yield stress, tensile strength) and selected safety factor. This properties have different value for the sake of degree of crystallinity examine material achieve for different technological parameters. The bending force obtain with position parameters in 1,3 set plan of researches made with extreme delay time ($t_{pg}$ = 0 for 1 set) and temperature ($T_w$ = 175°C for 3 set) were the lowest. This parameters lead to worse strength properties of mouldings. It allowes also to reduce force taken advantage of assume of deflection, despite the maximum value moment of inertia cross section $\boldsymbol{I_{xc}}$ for 1 set of plan of research. For correct estimation of resistance except of geometrical characteristic plastic parts of mechanical properties connected with technological parameters are taken into consideration.

Table 6.
The values of bending force *F* and stress *σ* for probes from constructions 1-8

| | The construction of plan researches | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Force N | 3000 | 3300 | 3100 | 3600 | 3600 | 3500 | 3400 | 3200 |
| σ MPa | 23.58 | 28.01 | 30.04 | 29.82 | 34.83 | 30.57 | 30.77 | 26.06 |

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