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INVESTIGATION OF CROWN CORK DRAWING FORCE

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Abstract

In the paper an analysis and investigation of round metal sheet sharing force and crown cork drawing force are presented. Experimental test stand was created in order to perform analysis on sharing and drawing forces for several metal sheet thicknesses. Obtained results are sufficient for comparison of acting forces for different metal sheet thicknesses and hardness during cutting process.

Keywords: sharing force, drawing force, experimental system, crown cork

Streszczenie

W artykule przeprowadzono analizę oraz badania sił potrzebnych do wycinania krążka z blachy jako półproduktu do tłoczenia zakrywki koronowej oraz właściwej siły potrzebnej do wytłoczenia zakrywki. Zbudowano stanowisko badawcze oraz przeprowadzono badania przebiegu sił dla procesu cięcia i tłoczenia dla różnych grubości blach. Uzyskane wyniki pozwalają na ocenę sił w procesie cięcia dla blach o różnej grubości i wytrzymałości.

Słowa kluczowe: siły wycinania, siły tłoczenia, stanowisko badawcze, zakrywka koronowa

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Designations

g	– thickness of the cutting material
z	– number of notches
P_{\max}	– maximum shearing force
S	– shearing surface
l	– length of the cutting edge
k	– coefficient depending on the clearance
R_t	– shear strength
a	– pushing length
P_d	– holding pressures
P_p	– force necessary to pushing through the cutting die
k_p	– equivalent of pushing direction
P_w	– punch force
P_{id}	– ideal force of deformation
P^{gn}	– bending force on radius r_m
P_{tk}	– friction force between punch and die
P_{tr}	– friction force die radius
R_m	– maximum tensile stress
β	– distortion factor
D	– diameter of blank
d_1	– diameter of shell
d_s	– diameter of punch
μ_1	– friction coefficient between metal sheet, holder and forming die
μ_2	– friction coefficient on the forming die radius
β_0	– distortion factor

1. Introduction

One of the most common bottle metal closures in the World is crown cork. It is the simplest and the most inexpensive closure which was patented in 1890 in USA by William Painter [3]. Metal crown cork is defined precisely by standard [7] as a product in the shape of bowl with serrate side, commonly known as crown. Standard metal sheet thickness range from $g = 0.20$ to 0.26 mm, regular number of notches is $z = 21$. The seemingly simple system for bottle closure has not been significantly changed since its invention. Despite the fact, that crown cork itself is simple, large-scale production is very complex [2]. Because of that, globally not many companies produce machines for crown corks production. Starting material is metal sheet, provided in coils, the production is fully automated and consist of cutting the metal into smaller sheets, shearing blank and drawing process [1, 3]. The problem addressed in the paper was raised by Can-Pack S.A. company, which engineers took the task to improve crown cork by application of computational capabilities and new materials. In the paper the results on the acting forces determination during crown cork drawing process are presented. For the investigation, modern metal sheets with improved harness and 30% reduced thickness were applied.

2. Sharing blank and drawing process analysis

For the drawing process analysis, a model based on two drawing elements was applied [5, 6]. Such technological process has few phases: elastic-plastic, plastic flow and material crack (Fig. 1).

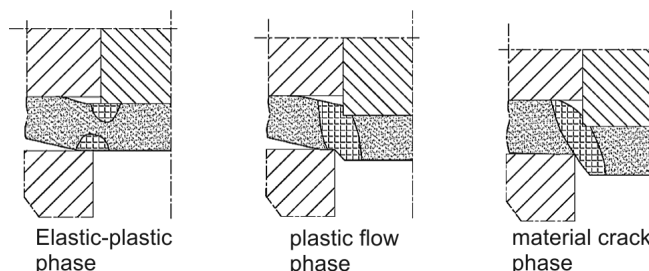


Fig. 1. Phases of drawing process

Rys. 1. Fazy procesu cieżcia

During the first phase, forces acting on metal sheet are generated by approaching cutting edges and are displaced in relation to each other which causes metal sheet bulge.

Further movement of cutting edges causes decreasing of the attachment area and increasing concentration of strains and plastic deformation. As a consequence, the whole cut material is covered with the defects. It results in material flow along the braking surface and movement towards the rest of material. This leads to second phase called the flowing plastic deformation. The force in both of the mentioned phases increases progressively. The thickness of the material decreases, but the hardness rises causing the growth of sharing force to the level P_{\max} . The sharing stress on the material increases to the moment of achieving the critical level of particular material and losing the cohesion. The third phase of breakage is started. The material begins to part not at the leading edge, but at the appearance of the first crack or breakage in the material.

The equation for the maximum sharing force is:

$$P_{\max} = k \cdot R_t \cdot S = k \cdot R_t \cdot \sum l \quad (1)$$

where:

- $S = g \sum l$ – sharing surface,
- R_t – shear strenght,
- $\sum l$ – length of the cutting edge,
- k – coefficient depending on the clearance ($k = 1$).

The force P_p necessary for pushing the round element through the cutting die is calculated by the equation:

$$P_p = \frac{a}{g} \cdot k_p \cdot P_{\max} \quad (2)$$

where:

- g – thickness of the cutting material,
- a – pushing length,
- k_p – equivalent of pushing direction.

The value of this equivalent is around 0.05–0.1 by pushing the element in the working direction.

Drawing causes creation of three dimension seamless shells [4]. Schematic drawing process is shown in Figure 2. Cutting punch 2 is moving down forming g – thickness of the metal sheet on forming die 3. During drawing process the collar is hold by holder 4.

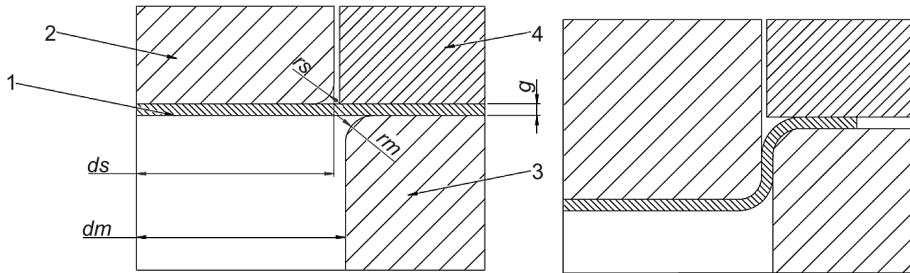


Fig. 2. Phases of drawing: a) initial and b) final

Rys. 2. Fazy wytłaczania: a) początkowa, b) końcowa

For analysis of drawing process, the punch force and blank holder pressure is necessary. The punch force needs supply the various types of work required in drawing:

$$P_w = P_{id} + P_{gn} + P_{tk} + P_{tr} \quad (3)$$

where:

- P_{id} – ideal force of deformation,
- P_{gn} – bending force on radius r_m ,
- P_{tk} – friction force between punch and die,
- P_{tr} – friction force die radius.

Crown cork forming process characterizes the lack of direct holding pressure. Between metal sheet and holder some clearance occurs and it allows controlled forming process of serrate. That kind of process causes two local maximum of drawing forces. In the analysis, maximum forming force from complete process is presented. Ideal force of deformation may be calculated by the following formula:

$$P_{id} = \pi \cdot d_s \cdot g \cdot R_m \cdot \ln(\beta) \quad (4)$$

where:

$$\beta - \text{distortion factor, } \beta = \frac{D}{d_1} \left[\frac{\text{diameter of blank}}{\text{diameter of shell}} \right]$$

$$P_{gn} = \pi \cdot d_s \cdot g \cdot R_m \cdot \frac{g}{4r_m} \quad (5)$$

$$P_{id} = \frac{\pi}{2} \cdot \mu_1 \cdot d_s^2 \cdot \frac{\beta_0^2 - 1}{\beta} \cdot q \quad (6)$$

where:

μ_1 – friction coefficient between metal sheet, holder and forming die,

β_0 – distortion factor, $\beta_0 = \frac{D}{d_s + 2r_m}$

$$P_{tr} = \left(e^{\mu_2 \frac{\pi}{2}} - 1 \right) \cdot (P_{id} + P_{tk}) \quad (7)$$

where:

μ_2 – friction coefficient on the forming die radius.

3. Experimental system

Sharing force and drawing force on standard production machine measurement is difficult because lack of space for installation of measuring transducers. For measurements of the forces, an experimental bench was built based on inertial mechanical press (Fig. 3).



Fig. 3. View of the experimental system for measuring pressing forces

Rys. 3. Widok stanowiska badawczego do pomiaru sił tłoczenia

Sharing blank and drawing processes by building in the punch and the forming die were executed. Between the forming die and the punch force measuring transducer was installed. Construction of the punch is prepared to work as a holder with appropriate clearance. Sharing force with holding force and drawing force were independently measured. Sampling frequency was 1000 Hz. Diagram of the measuring equipment is shown in Fig. 4. The study consisted of measuring of drawing force value during the forming process.

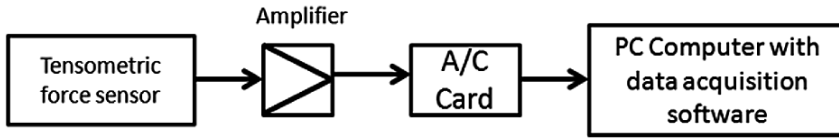


Fig. 4. Schematic diagram of the measuring equipment

Rys. 4. Schemat układu pomiarowego siły

4. Results

For drawing process, two kinds of materials were used: metal sheet with a thickness 0.21 mm and maximum tensile stress 380 MPa as well as 0.15 mm with maximum tensile stress 410 MPa. Sharing clearance was set as 0.02 mm. The measurement was performed under controlled temperature and metal closure parameters. The results obtained for sharing force of metal sheet 0.21 mm are shown in Fig. 5. Maximum value of the sharing force was 5193 N. Calculated sharing force for this kind of metal sheet was 5618 N. During the sharing force run, the plastic deformation flow can be observed. The material hardness is improved due to deformation which causes further increase of sharing force till the material breakage. As a result, the material hardness is improved significantly. Run of cutting and holding forces

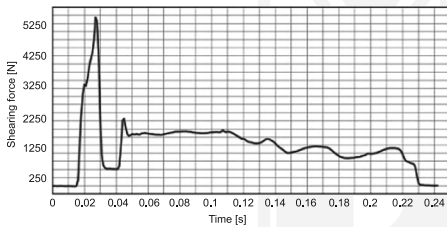


Fig. 5. Sharing and holding forces for the metal sheet 0.21 mm

Rys. 5. Przebieg siły cięcia i docisku dla blachy o grubości 0,21 mm

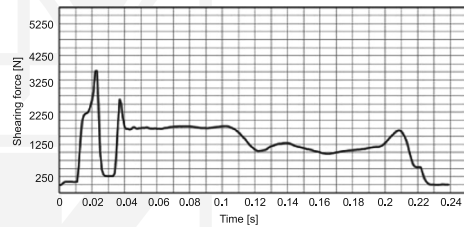


Fig. 6. Sharing and holding forces for the metal sheet 0.15mm

Rys. 6. Przebieg siły cięcia i docisku dla blachy o grubości 0,15 mm

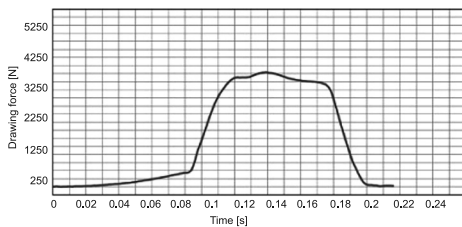


Fig. 7. Drawing force for the metal sheet 0.21 mm

Rys. 7. Przebieg siły wytłaczania dla blachy 0,21 mm

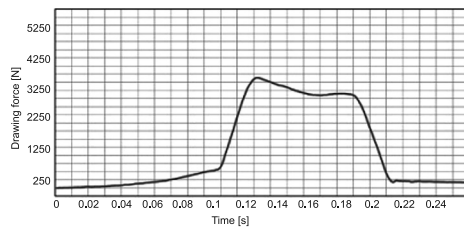


Fig. 8. Drawing force for the metal sheet 0.15 mm

Rys. 8. Przebieg siły tłoczenia dla blachy 0,15 mm

for metal sheet 0.15 mm thickness is shown in Fig. 6. Maximum value of sharing force was 3529 N, while the calculated was 4330 N. Plastic deformation flow is more pronounce for the metal sheet 0.15 mm, in addition the material hardness raised due to deformation presence. Material hardness is lower than for the metal sheet 0.21 mm.

Result of the run of drawing force for the metal sheet 0.21 mm is shown in Fig. 7. Maximum value of the forming force was 3545 N. Calculated drawing force was 3181 N. Run of forming force for metal sheet 0.15 mm is shown in Fig. 8. Maximum value of the drawing force was 3390 N, while the calculated force was 2348 N. Due to the clearance between the forming die and pressure pad, the drawing process takes place without the pre-hold. During the first phase of forming, there is no holding pressure, afterwards controlled pressing of the crown on the holder occurs. It is related to two local maximums of the drawing force. The first of them can be associated with the plastic deformation forces of forming the closures overcome. The second can be linked to pressing of the serrate and contact with the holder. Run of sharing and holding forces shows an impact of serrate on the holder (Fig. 5 and Fig. 6).

In the Table 1 calculated and measured values of forces for different material thickness are compared. Sufficient correspondence for maximum values was obtained. Obtained results provide significant knowledge on whole technological process.

Table 1

Calculated and measured values of forces for different material thickness

	Metal sheet 0,21		Metal sheet 0,15	
	Calculated value [N]	Measured value [N]	Calculated value [N]	Measured value [N]
P_{\max}	5618	5193	4330	3529
P_d	50	520	71	262
P_p	1605	1600	1732	1770
P_{id}	2176		1677	
P_{gn}	469		258	
P_{tk}	0.026		0.015	
P_{tr}	535		413	
P	3181	3546	2348	3390

5. Conclusions

In the paper the analysis of sharing blank forces from the metal sheet as a material for stamping crown corks and run of the pressing forces was performed. For measurements of the forces, an experimental system was built based on inertial mechanical press and measuring transducer. The system was used for the determination of forces runs during the crown corks production process and adjustment of parameters i.e. clearance height, metal sheet holding

pressure in order to obtain proper parameters of the metal closure. The original achievement of the authors is test stand, which allows to carry out dynamic tests during the forming process of crown closures. Results can be applied for testing new materials and reducing thickness of the closures.

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