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# BEHAVIOUR OF X5 CrNiMo 17-12-2 MATERIAL DURING DEEP DRAWING PROCESS

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The subject of this paper is investigation of steel X5CrNiMo 17-12-2 in a deep drawing process. Material and mechanical properties are investigated in order to obtain a number of parameters that are needed for the deep drawing process. Tolerances for final product dimensions were taken and a procedure for deep drawing process was calculated. Tooling was modelled with *Solidworks* software. Experiments were performed in order to determine functionality of tooling, feasibility and influential factors on process uncertainties.

*Key words*: deep drawing, sheet metal, modeling, tooling

**Ponašanje materijala X5CrNiMo 17-12-2 tijekom procesa dubokog vučenja.** Istraživana su materijalna i mehanička svojstva kako bi se saznalo niz parametara potrebnih u procesu dubokog vučenja. Uzete su tolerancije konačnih dimenzija proizvoda te je prema njima izračunat proces duboko vučenje. Modelirani su alati u računalnom programu *Solidworks.* Provedeni su eksperimenti kako bi se odredila funkcionalnost alata, sposobnost izrade gotovog proizvoda, te odredilo faktore koji utječu na nesigurnost postupka.

*Ključne riječi:* duboko vučenje, čelični lim, modeliranje, alati

## INTRODUCTION

During a production process there is a need to use the same parameters for every production cycle, in order to obtain stability of mechanical and material properties that can guarantee a stable technological window of production. Supply of needed material for specific production processes is often guaranteed by specific norms that determine compositions and usage procedures. The core objective of stamping die-makers is to design and manufacture a set of forming tools that can be used reliably for a defect-free sheet metal product within the desired dimensional tolerances and the required surface quality. Design models for the punch, the die and the binder tools are generated using the specifications of the manufacturing tools and presses. In this paper design of tooling and material used in the process are discussed. Design of the final product was done with *Solidworks* software (Figure 1).

This study aims to determinate the optimum shape of a cup, where the behavior of material thickness, earing etc. of deformed cup is predicted by taking in consideration the influence of anisotropic properties of sheet metal. With a random structure, before any deformation, properties will be equal in all directions and the material is said to be isotropic. Straining the material rotates slip planes and produces noticeable alignment (preferred orientation) of texture. As the sheet metal has been subjected to a rolling process, the material will have some directionality or anisotropy. The degree of initial anisotropy depends on the rolling and annealing program of the sheet. The normal anisotropy values are not constant over the whole range of orientation, mostly due to different microstructure properties in rolling and transverse directions [1, 2]. Anisotropy of material X5CrNiMo 17-12-2 will be determined by monitoring behavior of investigated physical properties. Mechanical anisotropy can be used to determine optimal blank shapes usually by focusing on earing [2]. The limiting drawing ratio (LDR) is commonly used to provide a measure of the drawability of sheet metal [3 - 6]. $D_0$ is drawn to final shape by the use of selected punch with a constant diameter $d_p$, until a limiting value is reached. The maximum blank diameter, $D_{0max}$ just before the first crack occurs determines the deep drawability of the material in the given sheet thickness and lubrication. Focusing on the GSE (geometrical shape error) [7, 8] possibility of beforehand process simulation of strain and wear effect is facilitated. GSE represents the root square of the difference between the target shape and the deformed shape.

## MATERIAL PROPERTIES

Nomenclature of used material was EN/W. Nr. (1.4401), DIN (X5 CrNiMo 17-12-2), AISI (316). Material composition comparison shows that the specimen chemical composition is corresponding with the standard (Table 1). However some elements such as C, Si, Mn are on the lower allowed tolerance.

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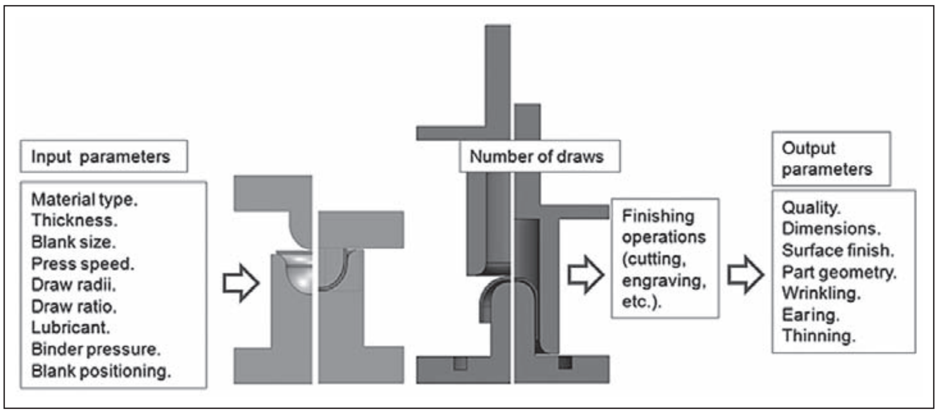


**Figure 1** Product uncertainties in sheet drawing depend on input and the process set up

Table 1. **Comparison of material properties with standard / weight % [9]**

| Composition | C | Si | Mn | P |
|---|---|---|---|---|
| X5 CrNiMo 17-12-2 | ≤ 0,07 | ≤ 1,00 | ≤ 2,0 | 0,045 |
| Specimen | 0,0321 | 0,507 | 0,902 | 0,0357 |
| Composition | S | Cr | Mo | Ni |
| X5 CrNiMo 17-12-2 | ≤ 0,030 | 16,50 -18,50 | 2,0 -2,50 | 10 - 13 |
| Specimen | 0,0049 | 16,6 | 2,05 | 9,80 |

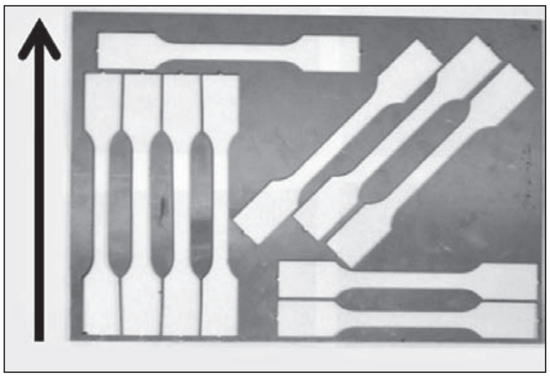

**Figure 2** Specimens were cut from a single plate in 0°, 45° and 90° from the rolling direction that is shown by the arrow

Tensile test were preformed in order to calculate and establish the needed forces for forming operations. Comparison with standard [9] mechanical properties at room temperature in the cold rolled, solution annealed condition is shown (Table 2). Values of coefficients for normal plastic anisotropy are dependent on direction of specimen cuts from the sheet metal. Figure 2 shows the sheet metal plate used for experiment and specimens were cut with water cutting technology at specified angles.

Flow curve approximation (1) is calculated by (2) for C and n.

$$k_f = C \cdot \varphi^n = 1111{,}65 \cdot \varphi^{0{,}3015} \text{ MPa.} \tag{1}$$

$$(\text{C, n}) = \frac{(x_0 + 2 \cdot x_{45} + x_{90})}{4} \tag{2}$$

Planar anisotropy - the r values vary at different directions to the rolling direction: $r_0$ not equal to $r_{45,}$ $r_{45}$ not equal to $r_{90}$, this can lead to 'earing' in deep drawing. The mean plastic anisotropy ($r_m$) (3) resulted as 0,864 and according to plastic anisotropy factor r for selected alloys [8] tolerance for sheet draw quality 0,7 - 2,8 is within tolerances for deep drawing. The coefficient of planar anisotropy (4) resulted as Δr = - 0,198 therefore an uneven edge is expected. Further experiment of the cup should demonstrate at what conditions the cup will be produced.

$$r_m = \frac{(x_0 + 2 \cdot x_{45} + x_{90})}{4} \tag{3}$$

$$\Delta r = \frac{(x_0 - 2 \cdot x_{45} + x_{90})}{2} \tag{4}$$

Table 2 **Mechanical properties - Tensile test**

| Rolling direction | Standard [9] | 0° | 45° | 90° |
|---|---|---|---|---|
| $R_{p0,2}$ / MPa | 240 | 297 | 300,93 | 322,73 |
| $R_{p0,5}$ / MPa | | 316,63 | 319,46 | 339,76 |
| A / % | 40 | 42,2 | 44,33 | 45 |
| $A_{80}$ | | 49,4 | 54,7 | 53,06 |
| $R_m$ / Mpa | 530 - 680 | 520,7 | 508,2 | 528,6 |
| n | | 0,307 | 0,301 | 0,297 |
| C / MPa | | 1125,6 | 1092,6 | 1135,8 |
| $r_{10}$ | | 0,51 | 0,963 | 1,02 |
| $r_{20}$ | | 0,55 | 1,003 | 1,04 |
| Mean plastic anisotropy ($r_m$) = 0,864 | | | | |
| Coefficient of planar anisotropy Δr = - 0,198 | | | | |

## TECHNOLOGY OF DEEP DRAWING

Final product (Figure 3) is a cup used as a special casing nozzle for a prototype of a device for applying grout in masonry walls.

Tooling is custom made (Steel 58 - 61 HRC) to form parts of given configuration. Drawing tooling is located on a 160 ton press, with maximum ram speed of 150 mm/s. Typical drawing speed [10 - 11] for steel blanks

**Figure 3** Final product a special casing used in a grouting prototype

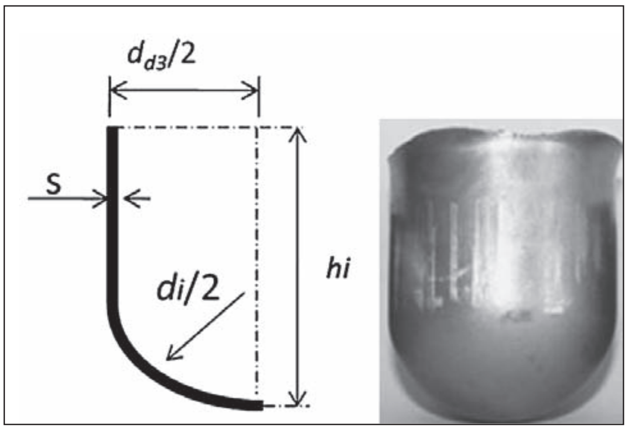


**Figure 4** Shape of cylindrical object, used for height calculation equation (3) [13]

ranges from 91 mm/s to 253 mm/s, speed of 150 mm/s was used in forming of the cup. Drawing was performed without blank holder as it is planned to be used in production process. Strip of sheet metal was introduced into the tooling and centring of blank for drawing operation was performed by cutting operation.

Required dimensions of the final product are $h$ = 36 mm, $d_i$ = 34,5 mm. Blank size was calculated with the use of equation (5) ([12], Figure 4) and has a thickness of 2 mm. Difference from final shape as shown in Figure 3 is caused by additional special deformation on a lathe machine.

$$h_i = 0{,}25 \cdot \frac{D^2}{d_i}. \quad (5)$$

The calculated ideal round blank was $D$ = 70,48 mm and $D$ = 71 mm selected. The second step was determining the optimal number of draws required. After experimental testing a crack occurred in first draw (Figure 5), therefore drawing in several steps was introduced as the proper procedure.

Selected draw ratio for first draw was $\beta$ = 1,66 and from (6) resulting $d_0$ = 43 mm. For second draw a coefficient of $\beta$ = 1,136 was used, resulting was $d_1$ = 38 mm. Third draw was selected in order to achieve required dimensions and therefore $\beta$ = 1,11 was used and final dimension were $d_2 = 34{,}5^{+0.3}$ mm.

$$\beta_{actual} = \frac{D}{d} \quad (6)$$

Diameter - wall thickness ratio is $d/s$ = 17,25. Permissible ideal ratio for steel first draw [9] is $\beta \approx$ 1,85 - 1,72, therefore $\beta_{actual} > \beta_{perm} \approx$ 2,29 > 1,72. Theoretically steel material is produced with $\beta \approx$ 1,85 - 1,72, in the first draw and $\beta \approx$ 1,33 - 1,28 in secondary draws, however experiment showed that for material X5 CrNiMo 17-12-2 a bigger safety factor was required.

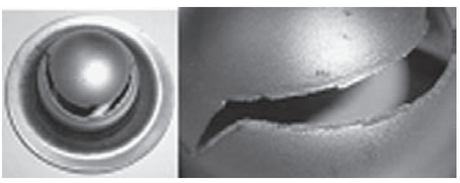

**Figure 5** Calculation with one draw resulted with crack therefore evidence that $\beta_{max}$ was exceeded

The outside diameter of the final part must be within a certain tolerance. Therefore draw ring diameter ($d_p$) is equal to the minimum outside diameter of the final part. Therefore, for first and second draw tolerances were selected from [10] and the ring diameters are:

$$d_{p1} = 43^{+15}_{-10}\ \text{mm},\ d_{p2} = 38^{+15}_{-10}\ \text{mm},\ d_{p3} = 36{,}5^{+15}_{-10}\ \text{mm}$$

Drawing clearance is calculated from (7) $z$ = 3 mm.

$$z = 1{,}5 \cdot s \quad (7)$$

The smallest necessary force [12 - 15] in order to achieve the necessary product was calculated because the holders were not used. The required force was calculated from equations (8 - 13) $F_M$ = 19 101 N with the data experimentally obtained (Table 2). $A_0$ = 282 mm$^2$; $\beta$ = 1,65; n = 0,3015; C = 1111,65 MPa; $\sigma_{fsr}$ = 463 MPa.

$$F_M = 0{,}71 \cdot \sigma_{fsr} \cdot A_0 \cdot \ln(0{,}7 \cdot \beta_1) \cdot \frac{1}{\eta_p} \quad (8)$$

$$\sigma_{fsr} = \frac{R_p + \sigma_{fFM}}{2} \quad (9)$$

$$\sigma_{fFM} = C \cdot \varphi^n_{FM} = C \cdot (\ln 0{,}7 \cdot \beta_1)^n \quad (10)$$

$$A_0 = \pi \cdot s \cdot (d_1 + s) \quad (11)$$

$$\beta_1 = D_0 / d_1 \quad (12)$$

$$\eta_1 = 0{,}7 \quad (13)$$

Tooling was designed with *Solidworks* software and a 3D simulation of tooling and the product was created with calculated dimensions for every draw. Figure 6 shows tolling designs for required operations of deep drawing.

Future operations include combination of the model with *Solidcam* module that prepares the model for milling operations. Because of the complex relationship that occurs in deep drawing, the stress-strain state cannot be explained only by analytical procedure [13]. Several factors are deemed significant in a multi - redrawing process:

- Punch profile: $d_{p1}$ and $d_{p2}$ and $d_{p3}$.
- Die profile: $d_{d1}$, $d_{d2}$ and $d_{d3}$.
- Top - ram pressure: $F_{FM} \cdot 1{,}3$ = 24,831 kN.
- Lubrication type: Mineral oil for steel, (μ - 0,14 - 0,16) [12].

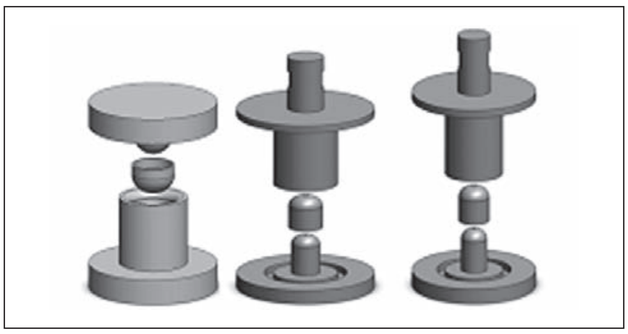

**Figure 6.** Tooling for first, second and third draw

## CONCLUSION

In this paper an investigation of material behavior under specific process parameters was monitored. Chemical composition testing has been done with metal spectrometer and the given material X5CrNiMo 17-12-2 was within specified tolerances. Also the tensile test for mechanical properties was conducted. Yield strength has been measured as average 306 MPa which is by 66,6 MPa higher than specified in standard [14]. Tensile strength of investigated material was an average of 519 MPa instead of 530 – 680 MPa that is specified by standard for selected material. For the tested material the production process of a deep drawing of a cup was presented.

Process parameters were calculated for inner tolerances; the tools design was made with *Solidworks.* Improvements in material savings were made from selecting a proper deep drawing procedure. Deep drawing tooling was designed by calculated specifications. Estimation of final shape and surface behavior for material X5CrNiMo 17-12-2 has been done. Process uncertainties were caused by five process parameters: error punch and die profile, top ram force, lubrication type and number of draws. The tooling was prepared for production process with specified material. Critical radiuses for first drawing were adjusted in order to remove wrinkling and fracture.

Further extended research and analysis will be based on a numerical investigation of this process and material.

## List of Symbols:

| | |
|---|---|
| Current drawing ratio | $\beta$ |
| Drawing clearance / mm | z |
| Yield strength / MPa | $R_{p02}$ |
| Tensile strength / MPa | $R_m$ |
| Blank diameter / mm | $D$ |
| Trimming supplement / mm | $\Delta h$ |
| Punch diameter / mm | $d_p$ |
| Force / N | $F$ |
| Elongation, at break / % | $A_{80}$ |
| Hardening exponent | n |
| Flow stress / MPa | $k_f$ |
| Stress / MPa | $\sigma_{fsr}$ |

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**Note:** The responsible for the English language is K. Mance, Rijeka, Croatia.