DUBOKO VUČENJE PODNICA

FORMING PROCESS OF THE FLOOR

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Ključne riječi: *duboko vučenje, debelostjena ploča, parni kotao*

Sažetak:

U ovom radu prikazane su osnove procesa dubokog vučenja za proizvodnju čepova parnih kotlova iz debelostjenih materijala. Također, prikazana je analiza naprezanja koja se pojavljuju u procesu dubokog vučenja - naprezanje, naprezanje usljed sile trenja i unutarnje naprezanje zbog premještanja materijala su također prikazani. Nakon toga izrađene su neke matematičke formule kako bi se pronašla ukupna naprezanja koja se pojavljuju u materijalu tijekom procesa dubokog vučenja a koja su potrebna za proračun snage.

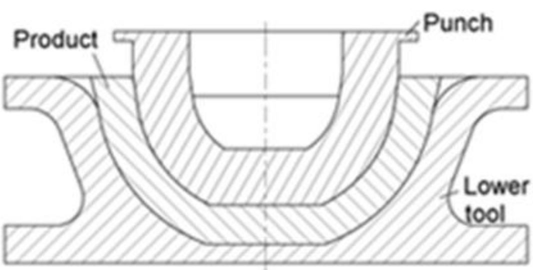
Abstract:

In this paper the basics of a deep drawing process for the production of a thick plate steam boiler end caps are shown. Also the analysis of stresses which appear in the deep drawing process are shown – bending stress, frictional stress and inner stress due to displacement of material are also shown. Afterwards some mathematical formulations are made in order to find total stresses which appear in the material during the forming process which are needed for the force calculation.

1. INTRODUCTION

The production of thick plate steam boiler end caps is usually performed in one or more work travels on hydraulic presses. The designer of hydraulic presses and the engineer responsible for deep drawing of products should be aware of the amount of deep drawing force in the process.

So far, the empirical and theoretical expressions have shown to have very different results. In order to examine deep drawing forces which appear in the deep drawing process, a tool shown in Figure 1. was used.



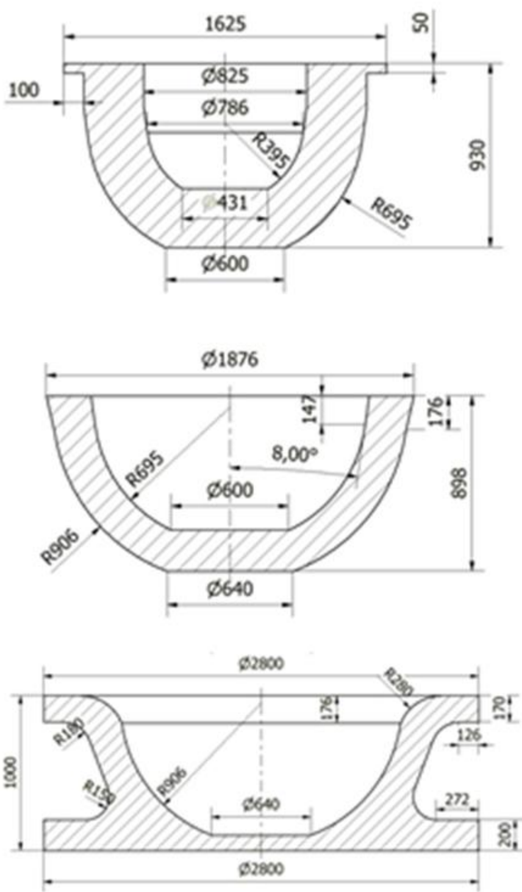


Figure 1. *Experimental tool geometry and dimensions*

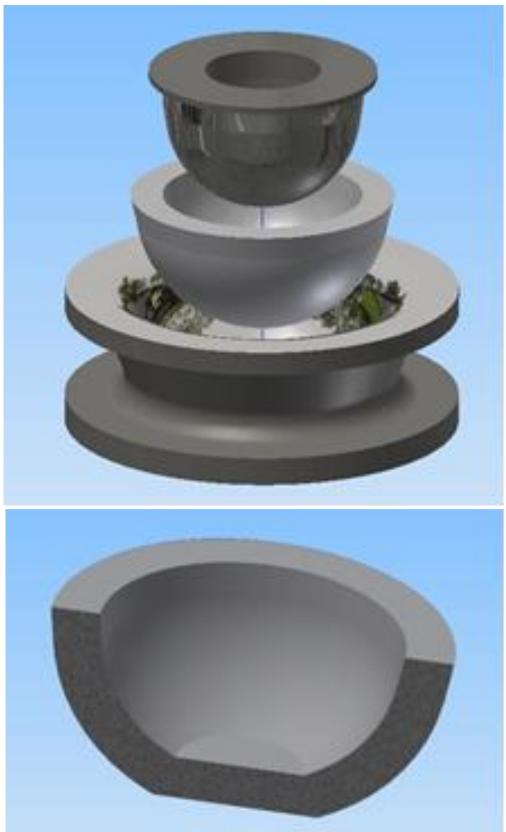


Figure 2. *3D model of experimental tool and deep drawn product*

Deep drawing process is performed in such a way that first a thick metal plate (dimensions 2180 mm in diameter and 210 mm thick) is heated-up to forming temperature, and then it is formed with tools under the pressure of hydraulic press.

2. FORCE CALCULATION

In order to obtain the forming force needed for deep drawing process, it is necessary to understand which stresses act on infinitively small element which is shown in Figure 3 and Figure 4.

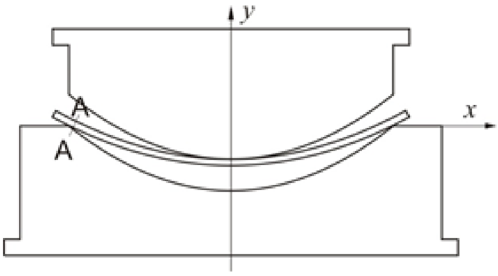


Figure 3. *Schematic illustration of bending of plate with marked A-A section [1]*

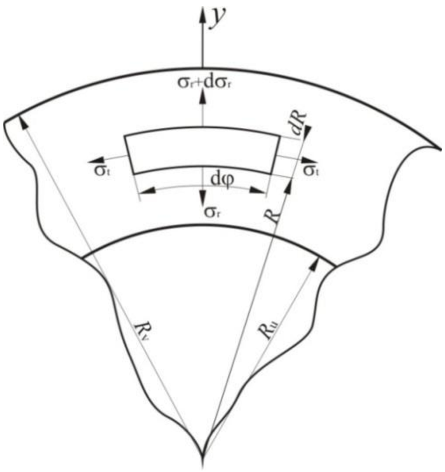


Figure 4. *Stresses which act in marked section A-A form Figure 3. [1]*

From Figure 3 it can be seen that section A-A is important for understanding stresses which act on the infinitive small element. This stresses are: plastic deformation stress σ_u, stress form friction over the edge σ_{fr} and bending stress σ_{bend} [1].

Total stress is calculated as:

$$\sigma_{tot} = \sigma_u + \sigma_{fr} + \sigma_{bend} \quad (1)$$

In order to obtain stress of plastic deformation σ_u it is necessary to use infinitesimally small element and forces acting on it which can be seen if Figure 4. [1]. From the condition that all forces in y direction are in equilibrium it can be written that:

$$(\sigma_r+d\sigma_r)(R+dR)s\cdot d\varphi-\sigma_r\cdot R\cdot d\varphi+2\sigma_r\cdot\sin(d\varphi/2)\cdot s\cdot dR=0 \quad (2)$$

Since expression $\sin\left(\frac{d\varphi}{2}\right)=\frac{d\varphi}{2}$ can be written for infinitesimally small angles and after dividing the expression (2) with thickness s it can be written [1]:

$$(\sigma_r + \sigma_t) dR + d\sigma_r \cdot R = 0 \tag{3}$$

In order to solve this differential equation (3) one additional expression must be introduced where k_f is forming stress:

$$k_f = \sigma_r + \sigma_t \tag{4}$$

After combining expressions (3) and (4) the solution of differential equation can be found as [1]:

$$\sigma_u = k_f \cdot \ln\left(\frac{R_v}{R_u}\right) \tag{5}$$

During the forming process, a plate is moving over the filleted edge with respective radius r_M and this plate needs to overcome the force of friction. This results in the larger stress near inner radius R_u which consists from bending and friction stresses.

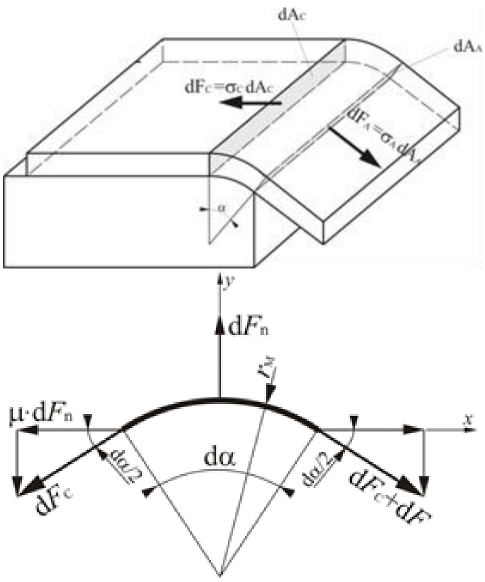


Figure 5. *Schematic illustration of a plate moving over filleted edge of the tool and forces acting on the infinitesimally small element. [2]*

If force dF_A increases for amount $dF = dF_A - dF_C$ there will be movement of sheet metal. By increasing the bending detail it can be shown that the forces which act on the bended surface looks like in Figure 5. Elementary band shown in Figure 5. has length $dl = r_M \cdot d\alpha$ [2].

From Figure 5., if all forces are set to be in equilibrium, and their values projected on x, and y axis, two equations can be written.

$$\sum X = 0$$

$$(dF_C + dF) \cdot \cos\frac{1}{2}d\alpha - dF_C \cos\frac{1}{2}d\alpha - \mu dF_N = 0 \tag{6}$$

$$\sum Y = 0$$

$$dF_N - (dF_C + dF)\sin\frac{1}{2}d\alpha - dF_C \sin\frac{1}{2}d\alpha = 0 \tag{7}$$

Since it can be written that:

$$\sin\frac{1}{2}d\alpha \approx \frac{1}{2}d\alpha \qquad \cos\left(\frac{d\alpha}{2}\right) \approx 1 \tag{8}$$

Expressions (6) and (7) can be written as:

$$dF - \mu dF_{\mathrm{N}} = 0 \tag{9}$$

$$dF_{\mathrm{N}} - dF_{\mathrm{C}} \cdot d\alpha = 0 \tag{10}$$

When this two equations are combined it follows that:

$$dF = \mu dF_{\mathrm{C}} \cdot d\alpha \tag{11}$$

Total accession of force for the finite bending angle can be written as:

$$\int_{dF_{\mathrm{C}}}^{dF_{\mathrm{A}}} \frac{dF}{dF_{\mathrm{C}}} = \mu \int_{0}^{\alpha} d\alpha \tag{12}$$

By integration of expression (12) it can be seen that the force of friction for one volumetric element at the end of the arc can be written as:

$$\Delta F = dF_{\mathrm{A}} - dF_{\mathrm{C}} = dF_{\mathrm{C}}\left(e^{\mu\alpha} - 1\right) \tag{13}$$

Then it can be written that:

$$\sigma_{\mathrm{fr}} = \frac{\Delta F}{\Delta A},\ \mathrm{MPa} \qquad \sigma_{\mathrm{fr}} = \sigma_{\mathrm{u}}\left(e^{\mu\alpha} - 1\right),\ \mathrm{MPa} \qquad \sigma_{\mathrm{fr}} = k_f \cdot \ln\left(\frac{R_{\mathrm{v}}}{R_{\mathrm{u}}}\right)\left(e^{\mu\alpha} - 1\right),\ \mathrm{MPa} \tag{14}$$

Bending stresses in the steam boiler cap will be positive in the outer tensile zone, and negative in the inner compressive zone in front of neutral plane.

This stress will increase with the thickness of the plate, and it will decrease with larger radius r_{M}.

Bending stress can be calculated with the following expression [2]:

$$\sigma_{\mathrm{bend}} = k_f \cdot \frac{s}{4r_{\mathrm{M}}},\ \mathrm{MPa} \tag{15}$$

This, combined with the expressions (1,5,12) leads to the following expression used for the calculation of total stresses in the material during forming [2]:

$$\sigma_{\text{tot}} = k_f \left(\ln\left(\frac{R_\text{v}}{R_\text{u}}\right) \cdot e^{\mu\alpha} + \frac{s}{4r_\text{M}} \right),\ \text{MPa} \quad \textbf{(16)}$$

Since total stresses are known, the forming force can be calculated with the following expression:

$$F_{\text{tot}} = A_\text{A} \cdot \sigma_{\text{uk}},\ \text{N}$$
$$F_{\text{tot}} = 2 \cdot R_\text{v} \cdot \pi \cdot s \cdot k_\text{f} \left(\ln\left(\frac{R_\text{v}}{R_\text{u}}\right) \cdot e^{\mu\alpha} + \frac{s}{4 \cdot r_\text{M}} \right) \quad \textbf{(17)}$$

There are several more expressions with which the forming force can be calculated and for the purposes of this work only two of them will be mentioned.

The expression for calculation of forming force according to DIN norm [3]:

$$F_{\text{tot}} = 2 \cdot R_\text{u} \cdot \pi \cdot s \cdot R_\text{m} \left(\frac{R_\text{v}}{R_\text{u}} - b \right),\ \text{N} \quad \textbf{(18)}$$

$b = 0,6 \ \rightarrow$ coefficient

And the expression for the calculation of forming force according to Tomlenov [3]:

$$F_{\text{tot}} = (1{,}5 \div 2) R_\text{m} \cdot \ln\left(\frac{R_\text{v}}{R_\text{u}}\right) \cdot \pi \cdot R_\text{u} \cdot s,\ \text{N} \quad \textbf{(19)}$$

According to Siebel's expression, the forming force can be calculated as [3]:

$$F_{\text{tot}} = 1{,}3 \cdot \pi \cdot R_\text{v} \cdot s \cdot R_m \cdot \ln\left(\frac{R_\text{v}}{R_\text{u}}\right),\ \text{N} \quad \textbf{(20)}$$

3. EXPERIMENT

For the experiment, a steel plate of 2800 mm in diameter and 210 mm of thickness was used. During the forming plate was coated with graphite mixed with mineral oil. The temperature of heating of a steel plate was 1100°C and by the time the steel plate was mounted on the tool the temperature has dropped to 1040°C.

At the end of the forming process the temperature of the steel plate was 920°C.

The time needed for the plate to be extracted from the furnace and until the end of the forming process was 10-13 minutes. The forming process was performed in the 50 MN forming hydraulic press. In the production a 23 steam boiler caps were made, and maximal forming force was 28,6 MN.

Maximal difference of forming force in the production of 23 boiler caps was 2 MN.

Since material was heated to the medium temperature of 970°C, the forming stress and the tensile stress were assessed to 76 MPa according to the manufacturer data.

With the above mentioned data, and the use of Figure 1. (from which R_u = 695 mm, R_v = 906 mm), the forming force F_{tot} can be calculated.

From (17):

$$F_{tot} = 2 \cdot 906 \cdot \pi \cdot 210 \cdot 76 \left(\ln\left(\frac{906}{695}\right) \cdot e^{0{,}2\cdot1{,}57} + \frac{210}{4 \cdot 280} \right)$$

$$F_{tot} = 50022389\ \text{N} \approx 50\ \text{MN}$$

From (18):

$$F_{tot} = 2 \cdot 695 \cdot \pi \cdot 210 \cdot 76 \left(\frac{906}{695} - 0,6 \right) = 49037842 \ \text{N}$$

$$F_{tot} \approx 49 \ \text{MN}$$

From (19):

$$F_{tot} = 2 \cdot 76 \cdot \ln\left(\frac{906}{695} \right) \cdot \pi \cdot 695 \cdot 210 = 18477886 \ \text{N}$$

$$F_{tot} \approx 18,5 \ \text{MN}$$

From (20):

$$F_{tot} = 1,3 \cdot \pi \cdot 2 \cdot 906 \cdot 210 \cdot 76 \cdot \ln\left(\frac{906}{695} \right) = 31314033 \ \text{N}$$

$$F_{tot} \approx 31,3 \ \text{MN}$$

4. CONCLUSION

In this paper the basics of a deep drawing process for the production of a thick plate steam boiler end caps are shown. Theoretical analysis of stresses which appear in the deep drawing process are shown – bending stress, frictional stress and inner stress due to displacement of material are shown.

These stresses are described, and some mathematical formulations are made in order to find total stresses which appear in the material during the forming process. Later the expression for the calculation of the forming force is shown. Also some other experimental formulations from the literature are presented. These expressions were used for the calculation of the deep drawing force, and later the results were compared to the experimentally obtained force values in the production of boiler end caps.The results show that the closest amount of force can be calculated with the expression (20). The difference in the results is from large amount of assumptions and simplifications used in the formulation.

Also some other forces exists in the forming process, and stresses which are caused by this forces needs to be further investigated by FEM methods in order to better understand the deep drawing process.

5. REFERENCES

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