6. Međunarodno znanstveno-stručno savjetovanje **SBZ 2011**
SUVREMENE TEHNOLOGIJE I POSTUPCI PRI IZRADI TLAČNE OPREME, ZAVARENIH METALNIH KONSTRUKCIJA I PROIZVODA
Slavonski Brod, 26. – 28. listopad 2011.

IZBOR OPTIMALNOG STROJA, IZBOR OPTIMALNIH PARAMETARA PROCESA I UTICAJ ZAGRIJAVANJA MATERIJALA NA POTROŠNJU ENERGIJE

OPTIMAL MACHINE CHOICE, OPTIMAL PARAMETER WINDOW AND INFLUENCE OF MATERIAL HEATING ON ENERGY CONSUMPTION

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Ključne riječi: trening, zavarivanje, kondicijski trening, psihološki trening

Key words: Training, welding, conditioning, psychological training

Sažetak: Trening se zavarivača danas svodi na stjecanje znanja i uvježbavanje vještine. Sve većom automatizacijom jednostavnijih procesa zavarivanja podiže se nivo zahtjeva za zavarivačima koji osim svoje vještine i znanja moraju i fizički i psihički biti spremni za različite uvjete rada. Rad se bavi dijelom treninga zavarivača u kojemu oni podižu svoju fizičku sposobnost da u određenim položajima tijela mogu više puta ponavljati vrlo precizno određene pokrete i da pri tome imaju mirnu ruku. Rad se također bavi i problematikom psihološkoga treninga za jednostavnije savladavanje cjelokupne problematike na koju nailaze u svojemu poslu.

Abstract: Today's welder training is reduced to knowledge acquisition and skills practice. The ever growing automation of simpler welding processes raises the demand level for welders who, beside their skills and knowledge, also have to be physically and psychologically fit for different working conditions. This paper deals with the part of welder training in which they raise their physical ability to very precisely repeat certain moves several times in specific body positions and to keep a steady hand while performing that action. The paper also deals with the problem area of psychological training for simpler mastering of all the problems they come across in their work.

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1. INTRODUCTION - SPRINGBACK AFTER BENDING

The bending process was first subjected to a theoretical investigation by Ludwik. Today bending processes are mostly investigated through FEM methods, and planned experiments in order to make conclusions of sheet metal behavior during bending. Nevertheless when examining spring back with FEM methods it is supposed that sheet metal retains the uniaxial state of stress. R. Hill used plasto-mechanic equations of equilibrium in carrying out his observations of the bending process. F. Proks expands the use of these equations to the material with linear strengthening. More recent works rely on the mentioned works (FEM), whose authors perform experiments in order to test the theoretical equations which describe process of bending. The expression

$$K = \frac{r_u}{r_{u,r}} = \frac{r_i + s_0/2}{r_u + s_0/2}$$

is called the springback ratio; where r_i – internal radius before unloading, mm; r_u – internal radius after unloading, mm; s_0 – sheet thickness, mm.

If K is known from experiment (Figure 1.), the springback angle is easily determined to be

$$\rho = \alpha - \alpha_r = \left(\frac{1}{K} - 1\right)\alpha_r . \text{ [1]} \qquad (1)$$

It should be emphasized that the upper equation applies only to pure moment bending. If there are combined loads in the process of bending, then conditions are much more complicated for different bending processes.

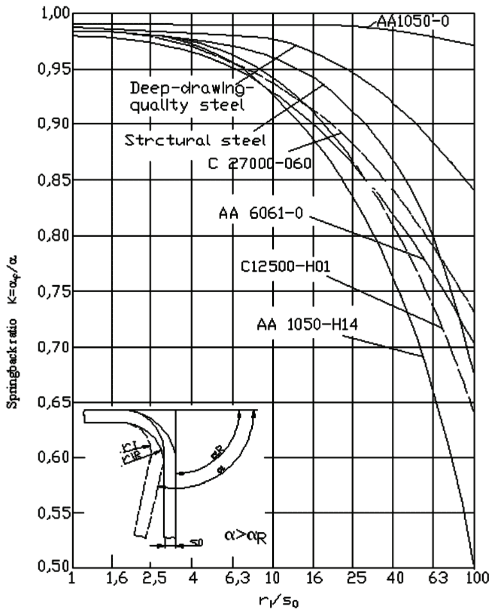

Figure 1. Springback ratio of different work materials as a function of bend radius [1]

2. SPRINGBACK PROBLEM WITH SPHERICAL TANKS

Spherical tanks are used for the storage of liquid mediums, mostly in petrol industries for storage of oil derivates such as automobile fuel, airplane fuel, liquefied natural gas, oils, etc. Since spherical shape offers some advantages over other shapes such as their possibility to store medium with minimal thickness of tank, small needed volume and minimum cost price.

Figure 2. Segments of spherical tank are positioned and welded [2]

Figure 3. Segments of spherical tank positioned and welded together [3]

Spherical tanks are becoming fair more interesting for production as their radius increases. The shell of spherical tank consists of steel sheet, while the segments are assembled by welding in whole at the actual place Figure 2 and Figure 3.

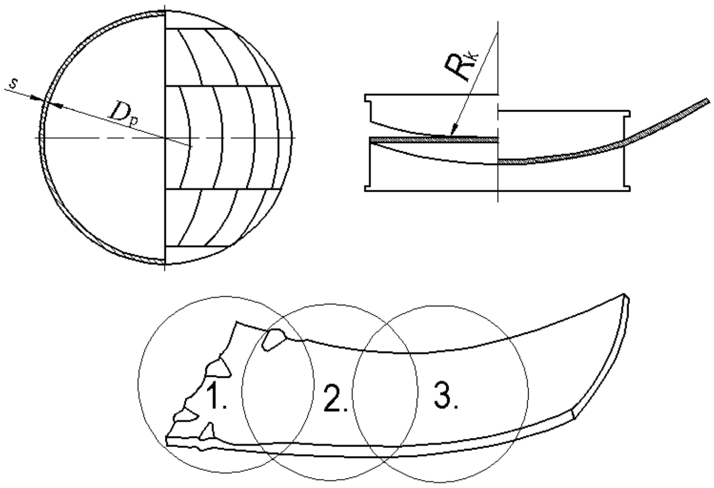

Figure 4. The bending of segment in tool

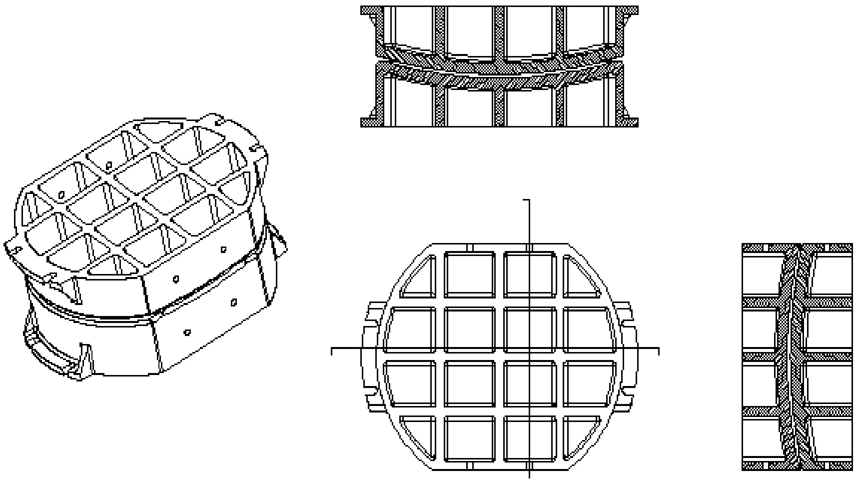

Figure 5. Tool Kt 5081 and Kt 5136

Figure 6: Forming of heated metal plate which is later used as a spherical tank segment

The bending separate parts are achieved in several indentations on hydraulic press and can be seen from Figure 4. Figure 5 presents tools Kt 5081 (R_k = 4925 mm) and Kt 5136 (R_k = 4500 mm). Figure 6 shows the process of forming (bending) of heated steel metal plate which is later on used as a segment of spherical tank.

3. MATHEMATICAL INTERPRETATIONS OF RESULTS OBTAINED BY EXPERIMENTS IN PRAXIS, AND NUMERICAL SIMULATIONS OF BENDING OF SEGMENTS FOR SPHERICAL TANKS

The experiments were conducted using the plates ∅2000 × 16 mm of material NIOVAL 47.

Using the various equations necessary bending force was calculated, and on the machine bending force for bending of the circular plate (Figure 4) was set as as F_{q00s} =1.185 MN [4, 5]. The plate bended with 1.185 MN had wrinkles at the edge of height up to 2 mm. Because of that reason the plate had to be calibrated [4]. The calibration force can be calculated using the expression

$$F_k = k \cdot F_{q00s} \,. \tag{2}$$

In order to compute the calibrating force it is necessary to obtain experimentally the amount of coefficient of calibration k for relevant dimensions. Experimentally k coefficient was determined, for the plate with dimensions ∅2000 × 29 mm coefficient of calibration k is k = 2, and for the plate with dimensions ∅2000 × 16 this value is k=2,5. Comparing the values of coefficient of calibration k it can be seen that its value is greater when the plate thickness is smaller. It is because during the bending process the wrinkles tend to form themselves more if the thickness is smaller. On that way, for the plate with dimensions ∅2000 × 20 mm, it can be supposed using the above obtained experiments that
k = 2,34.

The factors that have the most significant influence on the amount of mechanical spring-back are: calibration forces, plate material, punch radius, punch motion, plate thickness and plate diameter. In order to research the influence of punch radius R_k, plate thickness and plate diameter, according to technological and productivity conditions it was used experiment's factor plan.

Experiments were conducted using randomized distribution in attempt to avoid systematic errors. The considered factors were: punch radius 4500 and 4925 mm, plate thickness 16 and 29 mm, plate diameter 1800 and 2000 mm. Using all above mentioned considerations, it can be on the basis of experimental and industrial researching determined the law for coefficient of mechanical spring-back of calibrated plate with constant plate diameter K^{II}. It can be determined using expression [4, 5]:

$$K^{\mathrm{II}} = \frac{1}{0{,}768304 + 0{,}0906276\, R_{\mathrm{p}}} \quad \text{and} \quad R_k = K^{\mathrm{II}} \frac{D_p}{2} \tag{3}$$

For technological usage it is recommended that the calculation of K^{II} is done by using the equation (3). For instance, in the case of the plate with 2000 mm diameter, bending plate radius 7 m (shell diameter of spherical tank 14 m) and plate material NIOVAL 47 this coefficient of mechanical spring is 0,1406.

For numerical simulation, one quadrant of bending tool was modeled and same is shown in Figure 7.

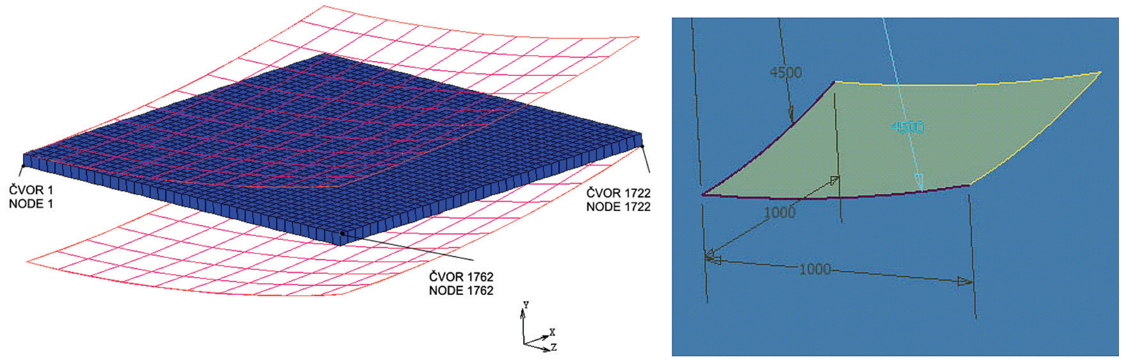

Figure 7. FEM model which was used in numerical simulations

From Figure 7, it can be seen that tool is modeled in two parts. The upper tool was defined as rigid body, and its path was controlled as a function of time. Contact table was defined in order to manage contact problems. Lower tool had same geometry as upper tool, and also was described as rigid body, but unlike upper tool it had no motion described. Between tools, a mesh which represents sheet metal plate was modeled. For this purpose a 3D mesh, of 1600 elements was used. Elements have been described as solid model, with option of "assumed strain" and element type 7.

Table 1. Mechanical properties of different materials used in simulations

Steek	Yield strength R_{p02}, MPa	UTS R_m, MPa	A_{10}, % min	Flow curve $k_f = f(\varphi)$
NIOVAL 47	450	570-750	18	$588+700\cdot\varphi^{0,07}$
TstE355ML	345	470-630	22	$750\cdot\varphi^{0,12}$
TstE690Q	690	770-940	14	$1084\cdot\varphi^{0,07}$
TstE890Q	890	940-1100	11	$1220\cdot\varphi^{0,05}$

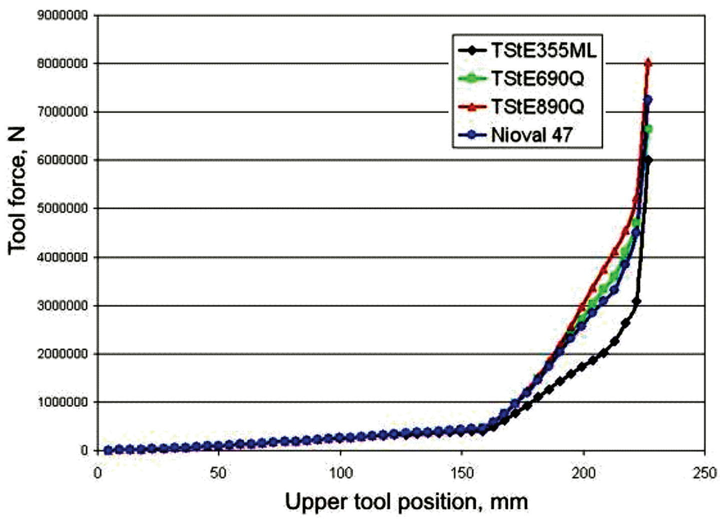

Figure 8. Force on the upper tool as a function of tool position

With the same model, different material flow curves were defined in order to investigate material behavior during the process of bending. In MSC.MARC Element type 7 is an eight-node, isoparametric, arbitrary hexahedral. As this element uses trilinear interpolation functions, the strains tend to be constant throughout the element. This results in a poor representation of shear behavior. The shear (or bending) characteristics can be improved by using alternative interpolation functions.

This assumed strain procedure is flagged through the geometry option. [6]

Figure 8 shows results – a force on the upper tool as a function of tool position. In the first part of the tool motion, forces on the tool are similar for different materials which are interpreted as elastical loading. In the second-central part of the diagram materials show different behavior and in the last part they show different forces required for the production of the part. These high forces are called calibration forces which are necessary for the reduction of springback, and the reduction of wrinkles which appear during bending process.

4. MACHINE CHOICE AND HEATING

Optimal machine choice should be based on choosing machine with highest efficiency. Since the amount of springback is dependant on the amount of calibration force as shown, it is necessary to use hydraulic press for bending which can produce required calibrating force. It is shown that calibrating force can be several times bigger than the bending force. Pressure vessels can be made either by cold metal forming, or materials can be heated (Figure 9).

Figure 9. Heated and formed segment of spherical tank

If material needs to be heated on specific temperature, it is necessary to use a lot of energy. For material heating furnaces are used. When metal material is heated, work-hardening stress is reduced, so tool force, and energy needed for metal forming are reduced too. Calculations of bending force for material at elevated temperatures are very complex and only approximations can be made because of differing material properties which change with temperature. Energy needed for heating up material is considerably higher than energy needed for material deforming. As an example for cold metal upsetting of mild steel with diameter d_0 = 50 mm and h_0 = 65 mm (≈ 1 kg) to h_1 = 20 mm it is necessary to input $6{,}3\times10^3$ N·m (J) of work. For hot upsetting of same cylinder heated on 1473 °C it is necessary about $6{,}3\times10^2$ N·m of work, and about $8{,}5\times10^5$ N·m for heating material up, with heath efficiency 25 %. So in this particular example process of hot metal forming requires 135 times higher energy input than process of cold metal forming.

For heating up material CmHn is used as a fuel. As a product of burning CmHn following gasses arise:

$$CmHn \Rightarrow CO+CO_2+H_2O+O_2+N_2+SO_2$$

Certain gases combine and create new gases:

$$S+O_2 \Rightarrow SO_2\ ,H_2O + SO_2 \Rightarrow H_2SO_4$$

If there are too much of these gases, they create adversely consequences. In order to obtain protective environment for safe metal forming at elevated temperature it is necessary to perform material heating according to diagram of furnace atmosphere balance (Figure 10).

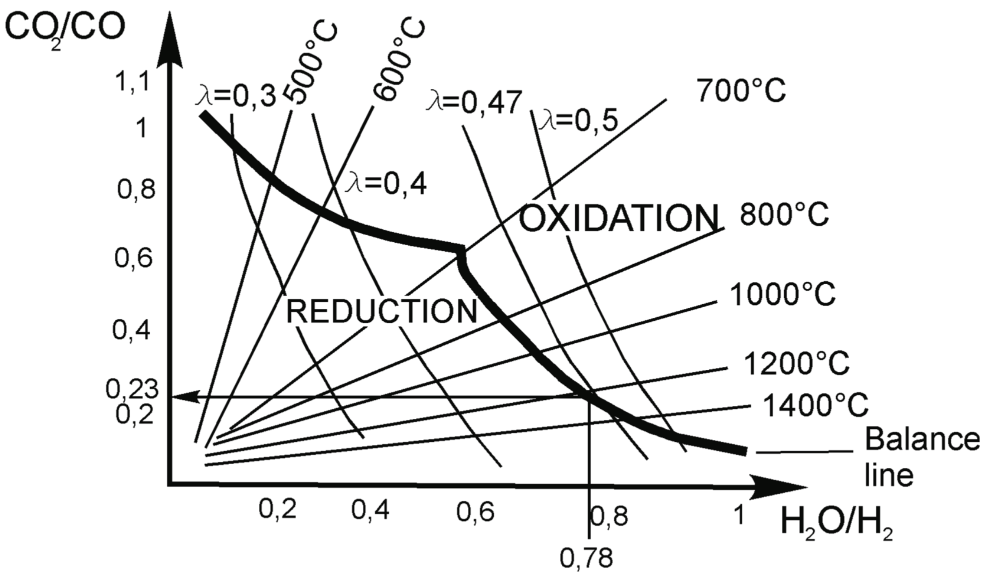

Figure 10. Furnace atmosphere gas balance [1]

From Figure 10 one can see that regardless of usage of this diagram, harmful gases exit to atmosphere, and pollute environment. Although natural gas is the least "dirty" fuel, sometimes it is recommended to use the process of cold metal forming instead. For other complicated products and different materials it is advisable to use metal forming at elevated temperatures in order to produce parts of desired quality – for instance in military industry for battle tanks and all kinds of weapons, for space missions, sports, etc.

Engineer should always take into account the effects of metal oxidization at elevated temperatures since these oxides can get into material (product) and they are potential places of fracture.

5. CONCLUSION

Although natural gas is the least "dirty" fuel, sometimes it is recommended to use the process of cold metal forming. For other complicated products and different materials it is advisable to use metal forming at elevated temperatures in order to produce parts of desired great quality for instance in military industry for battle tanks and all kinds of weapons, for space missions, sports, etc. Engineer should always take into account the effects of metal oxidization at elevated temperatures since these oxides can get into material (product) and they are potential places of fracture. Engineer should consider the most environmental friendly energy resources used for the metal heating-up before metal forming. Natural gas is certainly one of the cleanest energy resources and it is widely applied in various technological processes.

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