EFFECT OF TEMPERATURE ON AMOUNT OF SPRINGBACK IN CYLINDRICAL BENDING PROCESS OF STAINLESS STEEL SHEET

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Abstract

To determine the value of springback coefficient of sheet metal the cylindrical bending tests were conducted. The experimental tests of bending process were carried out using special device which allows to measure the value of sheet springback. As a test material we used the AMS 5604 alloy sheet metal with a sheet thickness of 1 mm. The numerical simulations by finite element method of the cylindrical bending tests were conducted using LS-Dyna program. The simulations were conducted at the ambient temperature (20 °C) and at elevated temperatures: 400 °C, 500 °C, 600 °C, 650 °C and 700 °C. The results indicated that the value of springback coefficient of the sheet decreases with the increasing of temperature. Furthermore, during the bending process at analysed temperature the linear variation in sheet thickness is observed. The forming temperature value influences the value of limit strains of the sheet and determines the final shape of product.

Keywords: Bending, cylindrical bending test, springback, stainless steel, warm forming

1. INTRODUCTION

Springback is a phenomenon in which the metal strip unbends itself after a forming operation. Most materials can be bent to quite a small radius, but a problem is to control the shape of the bend workpiece [1]. In general, a bend workpiece will recover elasticity i.e. springback on unloading, so that the bend quality is heavily dependent on the springback, which is a function of material properties and process parameters such as Young's modulus, yield stress, strain hardening abilities, plastic anisotropy, thickness and die geometry [1, 2].

Research on the phenomenon of springback during the bending process has been carried out for several decades. Wang et al. [3] described a mathematical model of deformation of the sheet bending plane giving the ability to predict springback and the maximum bending force on the punch and the die. Huang and Leu [4] have conducted experimental studies for steel sheets, and have described the influence of process variables such as the radius of the punch, the radius of the die, punch speed, friction coefficient, normal anisotropy and others on the V-bending process. An analytical model providing spring action was proposed by Kim and al. [5]. Song et al. [6] discussed the prediction of the springback phenomenon with the use of such methods as the analytical model and numerical simulation using the finite element method. Fei and Hodgson [7] studied the effect of the selected parameters influencing the steel springback in the bending process. Garcia-Romeu et al. [8] conducted experiments of bending metal sheets of aluminum and stainless steel to achieve different bending angles. Ragai et al. [9] discussed the impact of sheet anisotropy on the steel springback in the bending process with the use of the finite element method. Chen and Koç [10] analyzed the spring of high-strength steels (AHSS) using the finite element method. The basic features on springback during the warm and hot formation of high strength steels have been clarified experimentally by many authors [e.g., 11-13]. It has been discovered that the springback value is reduced when the temperature is higher than 450 °C. Next to the temperature, an influence of other material parameters, such as elasticity, yield strength, and hardening process parameters such as load, sheet thickness, a matrix angle have been tested and new models have been created in order to accurately predict the springback phenomenon of the material [14].

The aim of the experimental and numerical studies was to determine the springback coefficient value of the AMS5604 stainless steel sheet in a wide temperature range: from the ambient temperature to the temperature of 700 °C. Experimental studies have been conducted on a special device that allows to measure the sheet springback. The numerical simulations have been carried out with the use of the finite element method in the LS-Dyna software.

2. MATERIAL

Experimental tests have been carried out for the AMS 5604 stainless steel sheet with a thickness of 1 mm. Steel of this type is applied in manufacturing products operating at temperatures up to 320 °C. The mechanical properties of the test sheet were determined in a uniaxial tensile test. The tests were conducted on the testing machine UTS-100 at ambient temperature (20 °C) and at temperatures of 400 °C, 500 °C, 600 °C, 650 °C and 700 °C. During the tensile test the following values have been determined: the yield point $R_{p0.2}$, ultimate tensile strength R_m, percentage elongation A_r, percentage elongation A_{50}, the coefficient of normal anisotropy *r,* strain hardening parameters, i.e. the *n* exponent and the *C* coefficient. The results of the uniaxial tensile test, after the statistical analysis, are summarized in **Table 1**. The effect of temperature on the change in the course of stress-strain curves is shown in **Figure 1**. The average values of the individual parameters X_{av} were calculated based on the results of tensile tests for samples of different orientations relative to the rolling direction of the sheet according to the relationship:

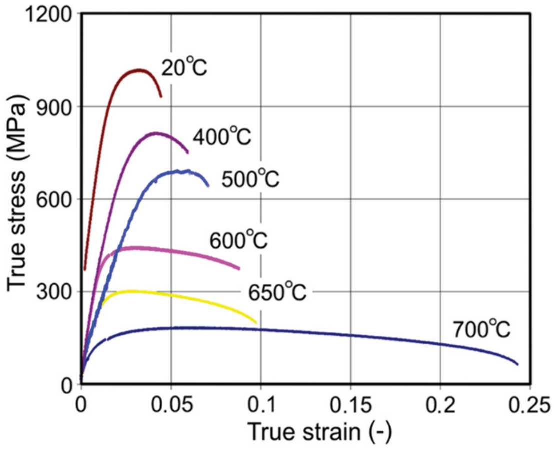

Figure 1 Comparison of the AMS5604 stress-strain curves obtained at different

$$X_{av} = (X_0 + 2\ X_{45} + X_{90})/4 \quad (1)$$

The change in Young's modulus and the Poisson's ratio, depending on the temperature of the measurement are shown in **Table 2**. The value of Poisson's ratio increases with an increase of the temperature, while in the case the Young's modulus an inverse relationship was observed.

Table 1 Mechanical properties of the AMS 5604 sheet

Temp. (°C)	$R_{p0.2}$ (MPa)	R_m (MPa)	A_r (-)	A_{50} (-)	*R* (-)	*C* (MPa)	*n* (-)
20	904	1061	0.040	0.058	0.90	3436	0.373
400	642	815	0.044	0.059	-	2607	0.362
500	537	694	0.052	0.071	0.96	1346	0.306
600	324	464	0.029	0.090	-	714	0.178
650	276	361	0.040	0.117	-	578	0.149
700	173	224	0.118	0.435	1.50	309	0.134

The analysis of results (**Table 1**) allows to find significant differences in the way of flow and mechanical parameters of the material of the tested sheets, depending on the temperature at which the test of uniaxial bumping was conducted:

- the yield point and the ultimate tensile strength decrease monotonically with an increase of testing temperature,

- exceeding of the testing temperature above 500 ºC resulted in a very substantial reduction in the tendency of the material to strain hardening.

Table 2 The effect of the temperature on both the Young's modulus *E* and the Poisson's ratio *v* for the AMS 5604 sheet

Temp. (°C)	273	293	373	473	543	673	773	873	973
E (GPa)	213	212	207	199	193	166	158	150	142
v (-)	0.284	0.2845	0.285	0.289	0.293	0.298	0.303	0.31	0.317

3. EXPERIMENTAL PROCEDURE

Samples with dimensions of 20 x 60 mm were bent freely on the testing machine using a special stamping tool. The radius of the punch and the radius of the inner surface of the die was 27.8 mm and 30.2 mm, respectively. After unloading the samples (in the case of the warm formed samples after they are cooled down) the measurements of the bending angle and the radius of the sample rounding at the bending point were carried out using the LM6 projector (Microtechnica) equipped with the Quadra Check 200 measuring meter (Metronics Inc.) with a tenfold magnification. The bending tests were carried out under the following conditions:

- cold bending (at ambient temperature),
- bending with inductively heated sample - die and punch unheated.

When warm bending the sample was heated outside the bending tool, and after obtaining the required temperature it was quickly moved and bent to a specific angle. The heating temperature of the samples during warm forming was selected on the basis of the results of the tensile test, indicating the best plastic properties of the material heated to the temperature of 500 °C [11]. The value of the springback coefficient K was defined as the relationship of the bending angle after unloading γ_s to the bending angle under the load γ_b. The value of bending angle was determined from the following relationship:

$$\gamma = arctg\left(\frac{2h}{w}\right) \tag{2}$$

where: h - height of the bent sample, w - spacing of the die bearings (w = 60 mm).

4. NUMERICAL MODELING

Numerical simulations of the bending process by using the finite element method (FEM) was conducted in the LS-DYNA software. The shape and dimensions of the bending numerical model reflected the geometry of the real tools (**Figure 2**). The tools in the FEM model were modeled as a non-deformable bodies, such an assumption allowed to present their geometry in a numerical model using the external surfaces (**Figure 3**). The sheet model was digitized using 300 shell elements with five integration points through the sheet thickness. The deformed material was treated as elastic-plastic, isotropic with nonlinear strain hardening described by the Hollomon equation. Isotropic properties of the material were defined assuming the Huber-Mises-Hencky's criterion of plasticity. The elastic properties of the material were defined by introducing to the LS-DYNA the curves of changes of the value of Young's modulus and the Poisson's ratio depending on the temperature as reported in **Table 2**. In the conditions of elevated temperature, the sheet, before the process of bending, was heated to the desired temperature, the temperature established for tools equals to 20 °C. The values of emissivity coefficient ε and the thermal conductivity ratio k were 0.8 and 80 W / m^{2}K, respectively.

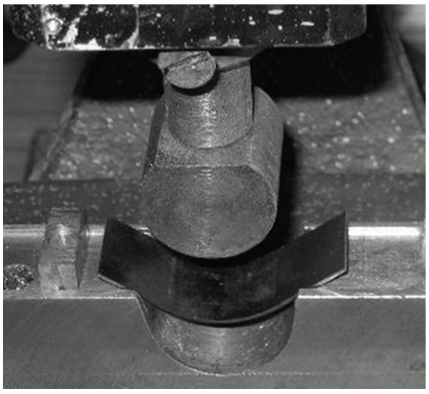

Figure 2 Tool for sheet bending

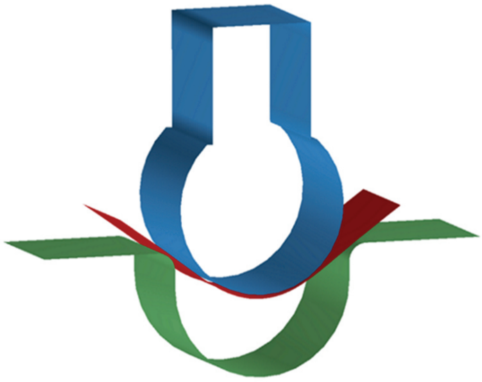

Figure 3 Geometry of tools in the numerical model of the bending process

5. RESULTS AND DISCUSSION

For the analyzed temperatures in experimental research the monotonic decrease of the springback angle with increasing bending radius was observed (**Figure 4**). In the temperature of shaping AMS5604 stainless steel, i.e. 500 °C, in all the range of bending radius, the values of springback coefficient are about 20-25 % smaller than the corresponding values of the springback angle set at ambient temperature.

The nature of changes in the intensity of the stresses in the sheet cross-section located at the contact point of the punch with the sheet is not clear for all bending temperatures (**Figure 5**). In the bending temperature of 400 °C the maximum value of the stress intensity is observed in the central region of the sheet. The largest value of the stress intensity of the sheet formed at the temperature of 800 °C is on the sample edge. For sheet bending temperature of 700 °C stress intensity distribution is uniform across the sample width. General trend to decrease the value of the stress intensity with an increase of temperature is visible.

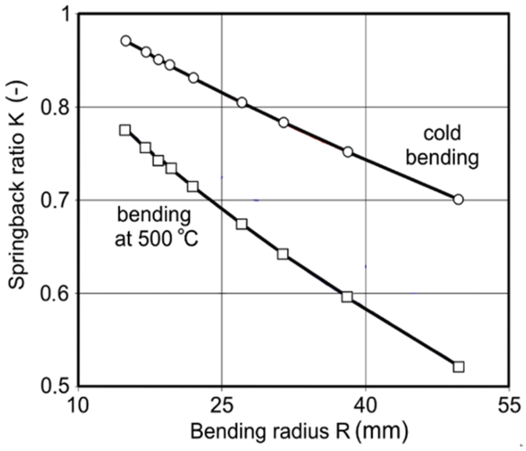

Figure 4 Influence of bending radius on the springback coefficient value

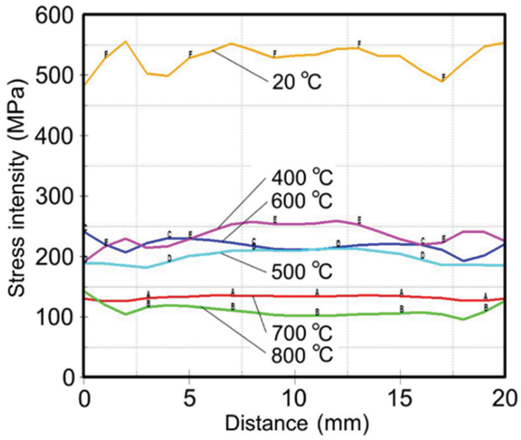

Figure 5 Distribution of stress intensity of the material after unloading in the symmetry plane of the sample

In contrast to the distribution of stresses intensity, an uneven distribution of sheet thickness in cross-section (**Figure 6**) and on the edge of the sheet (**Figure 7**) is visible. In the cross section of the sheet located at the contact point of the punch with the sheet one can observe a similar change in the sheet thickness for all analyzed forming temperatures. The greatest thinning of the sheet takes place in the vicinity of the side edges of the samples, while in the middle part one can notice the material swelling, i.e. an increase in the sheet thickness.

The value of the bending angle γ_s after unloading of the sample was determined from the coordinates of the four nodes located in the plane of the sheet symmetry (**Figure 8**). Although the values of mechanical parameters of the sheet material vary non-linearly depending on the test temperature (**Table 1**) the linear relationship (R^2 = 0.9891) between the bending angle γ_s and the value of the initial temperature of the sample was observed (**Figure 8**).

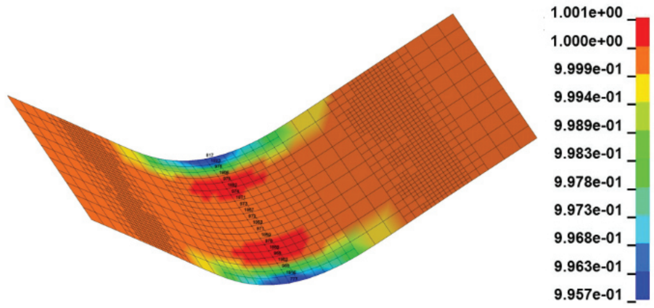

Figure 6 Distribution of sheet thickness (mm) after sheet unloading in the temperature of 500 °C

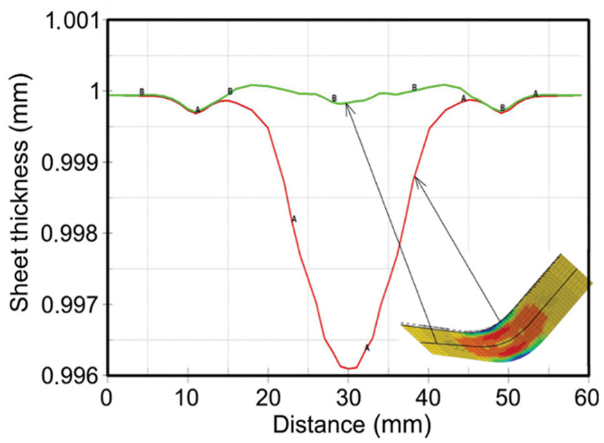

Figure 7 Thickness distribution of selected sections of the sheet after unloading; the test temperature = 400 °C

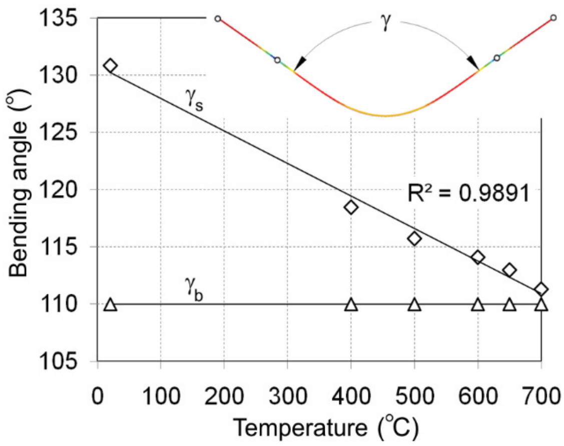

Figure 8 The influence of the temperature on the values of bending angles, punch stroke of 10 mm

6. CONCLUSION

The conducted experimental studies and numerical modeling of bending process of the flat samples of AMS5604 stainless steel sheet allow to draw the following conclusions:

- uniaxial tension test results clearly indicated the significant dependence of the temperature in the range of 20-700 °C on the mechanical properties of the material,
- the value of the yield point and the ultimate tensile strength decreased monotonically with increasing temperature,
- a significant decrease in the tendency to strain hardening was noticed (expressed by the value of the exponent of the work-hardening curve n) when the temperature exceeds 400 °C,
- with the rise of the temperature the value of the Poisson's ratio increases while in the case of the Young's modulus an inverse relationship was observed,
- received uneven distributions of stresses and sheet thickness on the width of the samples show that the plane strain state on the sample width assumed by a number of authors and simplification of the geometry of the numerical model for the 2D analysis is not justified.

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