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INFLUENCE OF THE FRICTION COEFICIENT ON SPRINGBACK EFFECT OF A U-SHAPED PART MANUFACTURED BY TAILOR WELDED STRIPES

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Geometria finală a unei piesei obținută prin procesul de deformare plastică la rece, realizată din table sudate subțiri este afectată de fenomenul de revenire elastică. Această lucrare își propune să demonstreze influența condițiilor de lubrifiere asuprea fenomenului de revenire elastică. Încercări experimentale şi simulări numerice au fost efectuate cu diferite valori ale coeficientului de frecare, menținându-se constanți ceilalți factori de influență ai procesului de ambutisare. Profilul pieselor obținute experimental a fost realizat cu ajutorul unul scaner 3D. Simulările au fost realizate cu ajutorul programului de element finit ABAQUS. In partea finală a lucrării este prezentată o comparație între rezultatele obținute experimental şi cele obținute prin simulare.

This paper deals with some experimental and numerical tests related to tailor welded stripes forming and springback. Final shape of the parts manufactured by TWB is seriously affected by springback effect. This paper is trying to prove the important role that friction coefficient has on the springback reduction. Experimental and numerical tests have been carried out using different friction coefficients and maintaining constant all other parameters. The experimental resulted parts were measured using a 3D scanning machine. The simulations have been done using ABAQUS software. A comparison between the experimental and simulation results are presented in the final section of this paper.

Keywords: tailor welded blanks, springback, lubrication conditions

Introduction

Recently, the automobile industries have been trying to develop various types of model and high-quality low-cost cars to meet the customer's requirements and to find new ways of establishing this goal effectively. For the purpose of achieving the above presented objectives, different methods using various welding processes (such as laser-welding, mash seam-welding processes, etc.) were developed. A tailor welded blank consists of two or more sheets that have been welded together in a single plane prior to forming. The sheets can be identical, or can have different thicknesses, mechanical properties or surface coatings [1].

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Friction between sheets and tool plays an important role in sheet metal forming since fracture, wrinkling and weak spots are strongly influenced by frictional behaviour. In finite element model simulation of sheet metal forming, the Coulomb friction model, in which a constant model is assumed, is generally used. However, the frictional behaviour depends upon local contact conditions, such as local surface roughness, pressure and relative speed of contact surfaces.

The techniques of numerical analysis applicable for sheet metal forming have been considerably developed for the last several years. However, accurate prediction of the springback remains elusive [2]. In finite element method (FEM) models of metal forming, the roughness has usually been assumed to be constant; even though it is commonly observed that sheet drawn under tension over a tool radius results in the surface becoming shiny, indicating a major change in surface morphology.

Many studies presents a wide range of information about the formability and failure patterns of welded stripes. A wide range of information about the formability and failure patterns of tailor-welded stripes and the springback of non-welded sheet metal parts has been presented. However, the springback characteristics of tailor-welded stripes have hardly been found [3–5].Published results on springback prediction of tailor welded stripes are minimal. The welding line is insignificant influenced when it is placed perpendicular to the direction of the deformation force [6].

Since the springback is also affected by the material properties, such as Young's modulus and initial yield stress, the process design for tailor-welded stripes is more complicated than a homogenous stripe. Though novel approaches relating to the formality of tailor-welded stripes are available, the change of springback due to the characteristic of each process should be verified by finite element method [7–10].

In this study, the tailor welded stripes (joined together without taking in consideration the welding line) with two types of material having the same thickness, are used to investigate springback characteristics in U-shape bending.

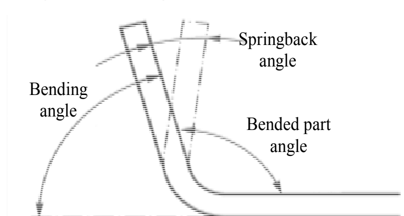

Fig. 1. Scheme of the bending process and springback

Springback (Fig. 1) is mainly influenced by the punch and die profile radii, initial clearance between punch and die, friction conditions, rolling direction of the materials, blankholder force, material properties (elastic modulus, Poisson's coefficient, constitutive behaviour in plastic field) etc. [11–13]. The purpose of this study was to investigate the friction coefficient influence for minimizing the springback effect of the tailor-welded stripes. To achieve this goal, simulation and experimental test were carried out with different friction conditions.

1. Experimental tests concerning the influence of friction conditions

The tailor welded stripes used in the experiments were made from FEPO and E220 steel. Strips of 350×30 mm dimensions and 0.7mm thickness were cut from the metal sheet along and perpendicular to the rolling direction. The samples were cut at $0^o$and 90^o with respect to the rolling direction. Springback parameters that were observed during the tests are presented in Fig. 2:

- θ_1 – sidewall angle between real profile and theoretical profile;
- θ_2 – flange angle between real profile and theoretical profile;
- ρ – curvature radius of the sidewall.

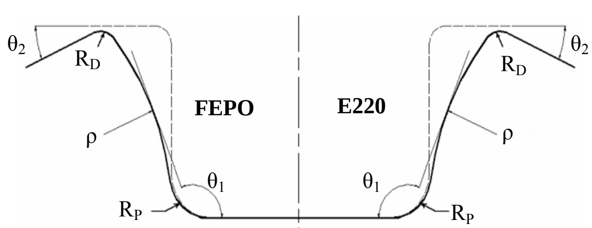

Fig. 2. Springback parameters

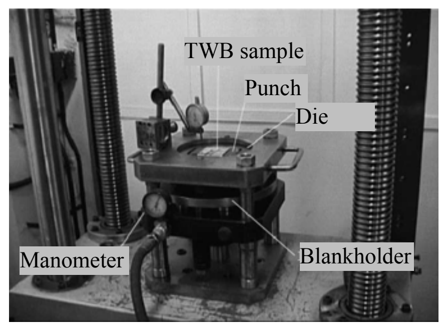

Fig. 3. Experimental device

The experimental researches were realized using a die for rectangular parts and a 10 kN blankholder force. The device is presented in Fig. 3. Tool geometry is presented in Table nr. 1. The forming force was generated using a mechanical tensile test machine. The profile of the obtained part and the parameters of springback were measured with a numerical controlled scanning machine Roland Model MDX-15, and the obtained data were processed with a CAD software

Table 1.

Forming device dimensions

Punch dimensions (mm)	78×120
Punch profile radius (mm)	10
Die opening (mm)	80×118
Die profile radius (mm)	5
Punch stroke (mm)	22

For the determination of the influence of friction conditions between specimen and tools on the parameters of springback, the experiments took place under the following conditions:

- the specimens, were cut out at an angle of 0^o to rolling direction;
- blank holder force F = 10 kN;
- the tests were carried out under dry friction (without lubrication) and with lubrication of the specimen and tools active surfaces.

Friction coefficient is considered 0.1 in the case of forming with lubrication of the tool and sheets and 0.177 in the case of forming without lubrication. The values of springback parameters are recorded in Table 2.

Table 2.

Springback parameters

	FEPO					
Friction coefficient	**Angle θ_1 [grd]**		**Angle θ_2 [grd]**		**Sidewall radius [mm]**	
	Theoretic value	Measured value	Theoretic value	Measured value	Theoretic value	Measured value
0.1	90	96.3	0	10.4	:	204.27
0.177	90	97.4	0	12.7	:	180.47
	E220					
Friction coefficient	**Angle θ_1 [grd]**		**Angle θ_2 [grd]**		**Sidewall radius [mm]**	
	Theoretic value	Measured value	Theoretic value	Measured value	Theoretic value	Measured value
0.1	90	99.1	0	14.3	:	132.32
0.177	90	100.7	0	17.2	:	106.79

The influence of the friction conditions on the parameters of springback is illustrated in Figs. 4, 5, 6. In Fig. 5 is presented the variation of the θ_1 angle, the angle between the sidewall and the bottom of the part. It can be observed that for both sides of the part better results are obtained in the case of forming without lubrication.

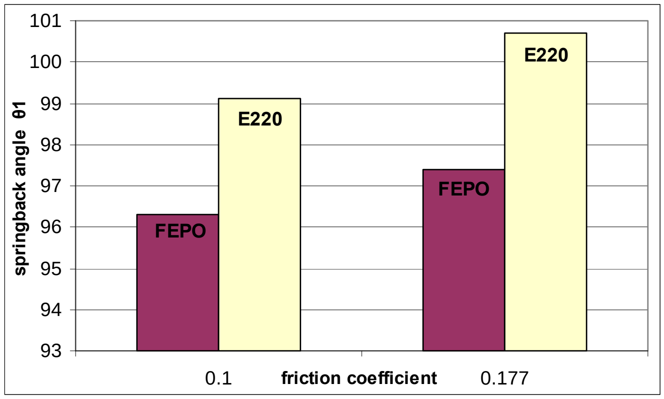

Fig. 4. Variation of angle θ_1

In Fig. 6 is presented the variation of the θ_2 angle, the flange angle of the part.

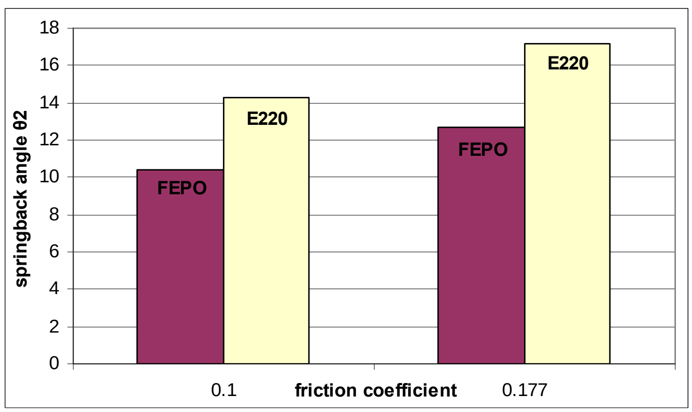

Fig. 5. Variation of angle θ_2

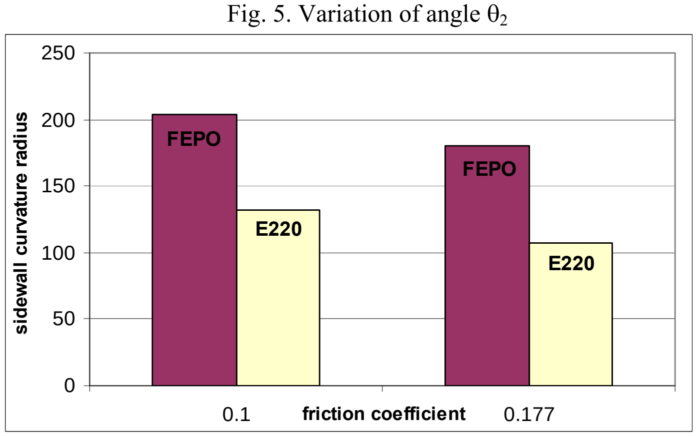

Fig. 6. Variation of sidewall curvature radius ρ

From the analysis of the graphics presented above, the following aspects can be observed:

- the modification of friction conditions leads to appreciable variations of springback parameters;
- the values of springback angles θ_1 (Fig. 4) and θ_2 (Fig. 5) are higher when using lubrication than in the cases of dry friction;
- the values of sidewall curvature ρ are higher in the case of dry friction (Fig. 6).

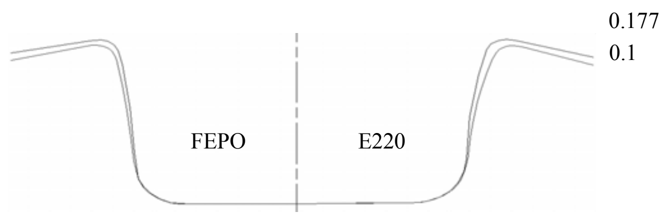

Fig. 7. Friction conditions influence on springback of TWBs

These observations lead to the conclusion that lubrication does not improve springback parameters in the case of U forming of tailor welded strips (Fig. 7).

2. Analysis by finite element method of the influence of friction conditions

The simulation of U-shape part forming was made using finite element method. The objective is to create a model that allows an accurate prediction of springback intensity, stress and strain state at the end of the forming process. The analyzed geometrical parameters are sidewall radius ρ and springback angles θ_1 and θ_2. In order to validate the model, the results of the FE analysis were compared with the experimental results.

The material was modelled as elastic-plastic, where elasticity is considered isotropic and plasticity is modelled as anisotropic using Hill quadratic anisotropic yield criterion.

In this simulation, fine mesh technology was applied to interested regions such as the punch profile radius and the tailor-welded strip model to improve the accuracy of the analysis for the springback.

The geometrical model is presented in Fig. 8. The initial dimensions of the sheet were 350 mm length, 30 mm width and 0.7 mm thickness. The sheet was modelled as deformable body with 400 shell elements (S4R) on one row with 5 integration points through the thickness. The tools (punch, die and blankholder) were modelled as analytical rigid because they have the advantage of reduced calculus efforts and a good contact behaviour. Rigid body movements are controlled by reference points.

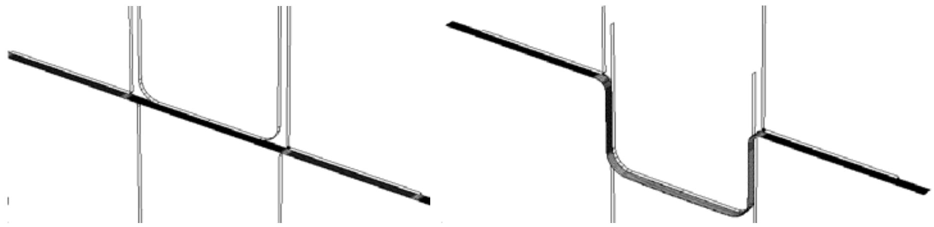

Fig. 8. Geometrical model

The boundary conditions imposed to the tools were intended to describe the experimental conditions as accurate as possible. For contact conditions a modified Coulomb friction law combined with penalty method was used.
For determination of the influence of friction conditions between specimen and tools on the parameters of springback, the simulations have been done under the following conditions: the sample model is loaded with the material characteristics corresponding to 0^o rolling direction; blank holder force F = 10 kN; the simulations were carried out under dry friction (friction coefficient is 0.177) and with lubrication (friction coefficient 0.1) of the specimen and tools active surfaces.

The variations of springback parameters (θ_1, θ_2, ρ) as function of friction coefficient are presented in Table 3.

Table 3.

Springback parameters

	FEPO					
Friction coefficient	**Angle θ_1 [grd]**		**Angle θ_2 [grd]**		**Sidewall radius [mm]**	
	Theoretic value	Measured value	Theoretic value	Measured value	Theoretic value	Measured value
0.1	90	98.8	0	12.2	:	254.46
0.177	90	99.2	0	13.8	:	203.93
	E220					
Friction coefficient	**Angle θ_1 [grd]**		**Angle θ_2 [grd]**		**Sidewall radius [mm]**	
	Theoretic value	Measured value	Theoretic value	Measured value	Theoretic value	Measured value
0.1	90	99.2	0	17.1	:	162.51
0.177	90	101.4	0	18.4	:	103.34

The influence of the friction conditions on the parameters of springback is illustrated in Figs. 9, 10, 11.

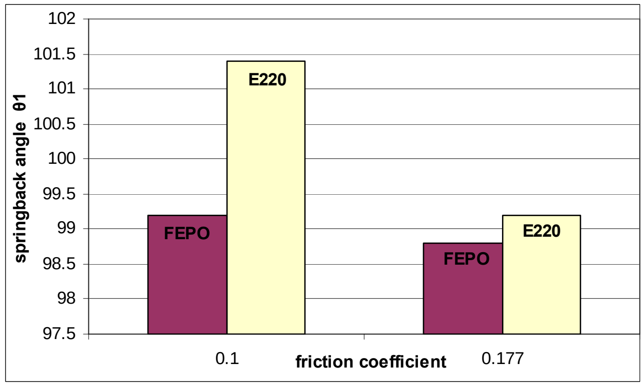

Fig. 9. Variation of angle θ_1

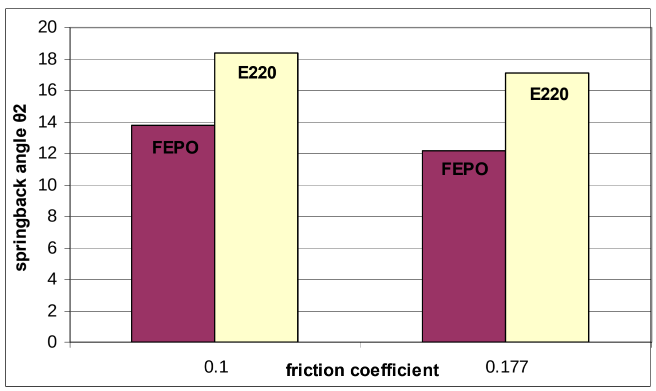

Fig. 10. Variation of angle θ_2

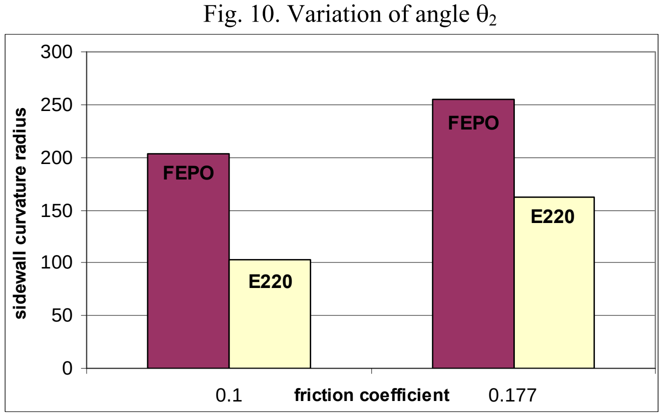

Fig. 11. Variation of sidewall curvature radius ρ

From the above presented results the following aspects can be remarked:

- the modification of the friction coefficient affects the springback parameters of the U-shaped part;

- the values of θ_1 and θ_2 angles attains higher values when the part made from TWBs is formed with lower friction coefficient;
- the sidewall radii ρ are smaller when the TWBs is formed with higher friction coefficient;
- the part area made from FEPO is not so much affected by the springback phenomenon in comparison with E220 steel area for both friction coefficients.

4. Comparison of the results obtained experimentally and by simulation

Analyzing the springback parameters variation charts obtained experimentally and by simulation, the results leads to the following conclusions:

- the tendencies are the same for both experimental or simulation results for every factor;
- the results of finite element analysis have a small tendency to overestimate the intensity of springback compared to experimental results (Table 4);
- the differences between the experimental and simulation test are caused by the assumed uniform blankholder pressure, which is not uniform in reality;

Table 4.

Springback parameters .

	FEPO					
Friction coefficient	**Angle θ_1 [grd]**		**Angle θ_2 [grd]**		**Sidewall radius [mm]**	
	Exp. test	Sim. test	Exp. test	Sim. test	Exp. test	Sim. test
0.1	96.3	98.8	10.4	12.2	204.27	254.46
0.177	97.4	99.2	12.7	13.8	180.47	203.93
	E220					
Friction coefficient	**Angle θ_1 [grd]**		**Angle θ_2 [grd]**		**Sidewall radius [mm]**	
	Exp. test	Sim. test	Exp. test	Sim. test	Exp. test	Sim. test
0.1	99.1	99.2	14.3	17.1	132.32	162.51
0.177	100.7	101.4	17.2	18.4	106.79	103.34

Conclusions

The following aspects stand out from the experimental researches of the influence of the rolling direction on springback parameters:

- the lubrication of specimens and tools active surfaces produced a small increase of springback intensity for both materials from TWB part;
- this phenomenon can be explained by the fact that lubrication lowers the friction coefficient allowing the material an easier flow into the die cavity.

It can be considered that the results generated by the analysis of springback phenomenon using finite element method are sufficiently accurate and can be considered valid. When properly used, simulation by finite element method can be considered a valuable tool in the study of the influencing factors of the springback phenomenon able to offer accurate data even from the design stage.

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