

ACTUAL PROBLEMS OF MODERN SCIENCE

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EXPERIMENTAL RESEARCH OF SPRING-BACK EFFECT DURING SEQUENTIAL FORMING WITH DIFFERENT INNER ANGLE, THICKNESS AND BENDING WIDTH OF BLANK

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Introduction

Steel sheet products and products from it are the most common product of metallurgical and machine-building enterprises [1–3], also, very stringent requirements are imposed of the geometric accuracy of these products [4–7]. Steel reinforcing cold-formed shapes are common products manufactured by enterprises specializing in the metal forming processes. Initial material for cold-formed shapes is galvanized cold-rolled flat steel with a thickness of 0,65 mm. to 2,0 mm. Issues of the development of a special of cold-formed dising and their production are constantly pay attention because of the effectiveness of their application [8–10]. Cold-formed shape is obtained during the blank forming process in the multi-roll roll-profiling mills. However, the bent parts after load relief elastically unbend and change the bending angle, which is characterized by the spring-back effect [11–13]. The influence of the strengthening effect on the geometric parameters and the magnitude of the parts springing formed in the die and various roll-systems was considered in works [14–22]. It is also known that the sheet blank is prone to springing at bending on multi-roll roll-forming mills [8, 15, 23–26]. The spring-back angle can be determined based on experimental analysis of the measuring experiments [27–30].

To date, there is no reliable information about the difference of the spring-back angle, which occurs when the flat blank is bending to a certain final angle for one or several passes. Also, the value of the initial blank width is not taken into account, although such oscillations essentially affect the energy parameters of bending. Failure is to not consider that the springing leads to inconsistency of the finite size of the shapes and defect formation between the roller space of the roll-forming mill stands [31–33]. There are also no mathematical dependences for determining the value of the spring-back angle at passes and at the end of the multi-pass bending, which

complicates the performance of the preventive prediction of the quality of cold-formed shapes.

The purpose of the work is to obtain the graphical and mathematical dependencies for descriptions of the resultative spring-back angle of the blanks at the multi-pass bending, taking into account the width of the blank, number of passes, and pre-bending angle at each preliminary pass.

Materials and methods

Investigations of bending at the bending of Steel 3 grade (0.14...0.22% C; 0.15..0.3% Si; 0.4...0.65% Mn; $\leq 0.3\%$ Ni; $\leq 0.05\%$ S; $\leq 0.04\%$ P; $\sim 97\%$ Fe) blanks were carried out on the crank-press model K116G (Fig. 1). As a working tool, were used bending die of U8 grade tool steel (0.76...0.83% C; 0.17...0.33% Si; 0.17...0.33% Mn; $\leq 0.25\%$ Ni; $\leq 0.027\%$ S; $\leq 0.03\%$ P; $\sim 97\%$ Fe) with heat-treated to hardness HRC 40...44 [34]. They were made for different angles of bending: 72° , 91° and 109° (Fig. 2). Radii : (i) – for die with a bending angle of 72° : upper die rin = 3 mm, lower die rout = 4,0 mm; (ii) – for die with a bending angle of 91° : upper die rin = 4 mm, lower die rout = 5,0 mm; (iii) – for die with a bending angle of 109° : upper die rin = 4 mm, lower die rout = 5,0 mm. The lower and the upper dies were fixed in the die block installed on the specified press.

Measurement of the shape parameters of the blanks was carried out by an angle-meter and a caliper, which has undergone metrological checking in due time. The length of the blanks were used is $L = 60$ mm (Fig. 3).



Fig. 1. Crank-press K116G, with 0.125 MN force



Fig. 2. Bending dies

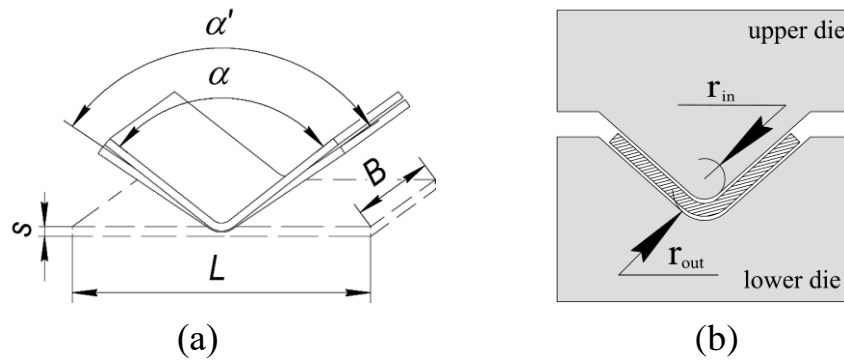


Fig. 3. Scheme of spring-back effect during blank (a) bending in die (b): L – the length of the blank; S – the thickness of the blank; B – the width of the blank; α – the angle of the die; α' – the angle after unloading

The blanks were divided into two groups with same sizes and quantity: the thickness of the blank – $S = 1$ mm: the width of the blank – $B = 20$ mm (5 samples), 40 mm (5 samples) and 60 mm (5 samples); thickness – $S = 1,5$ mm: the width of the blank – $B = 20$ mm (5 samples), 40 mm (5 samples) and 60 mm (5 samples); thickness – $S = 2$ mm: width of the blank – $B = 20$ mm (5 samples), 40 mm (5 samples) and 60 mm (5 samples).

The first group of blanks was exposed to one-pass bending. Bending of the blank was carried out in a die at a predetermined bending angle of 72° , 91° , and 109° , and the spring-back angle $\Delta\alpha = (\alpha' - \alpha)$ was measured (see Fig. 3).

The second group of blanks with same geometric sizes was subjected to a multi-pass bending (Fig. 4).

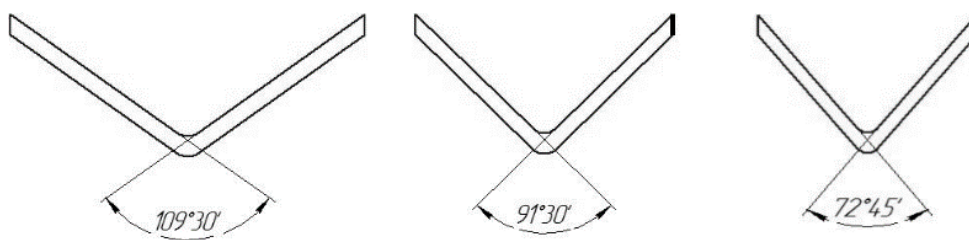


Fig. 4. Three-pass bending of blanks

That is, the blanks were first bent in a die with an angle of 109° and measured the bending angle. Further, bending upper and lower dies were changed, and the preformed bends were doped in a die with a 91° angle and measured the bending angle. Then they again changed the bending lower and upper dies, and the preformed bends were duplicated in a die at an angle of 72° , and measured the bending angle.

The measurements were carried out after each bend, which was carried out separated by passes, according to the developed method. Each experiment included at least five measurements. The processing of these experiments was carried out on the basis of the generally accepted method of dispersion analysis of the factor experiment in accordance with standard [35]. The standard methods based on the positions of probability theory and mathematical statistics are given in the specialized literature [36, 37], the experimental values of the basic parameters of forming are considered as random variables characterized by the normal distribution law and obtained as a result of measurements of equal accuracy.

Results of research

After the processing of the experimental information, dependence of the main parameters of the form change, which characterizes change of the spring-back angle during forming in the dies, was developed. The graphic dependences show the change of the spring-back angle – $\Delta\alpha$, depending on the width to thickness ratio (B/S) and the relative angle of the blank (β): $\beta = (180 - \alpha')/180$.

Examples of experimental graphics are shown in Fig. 5–10.

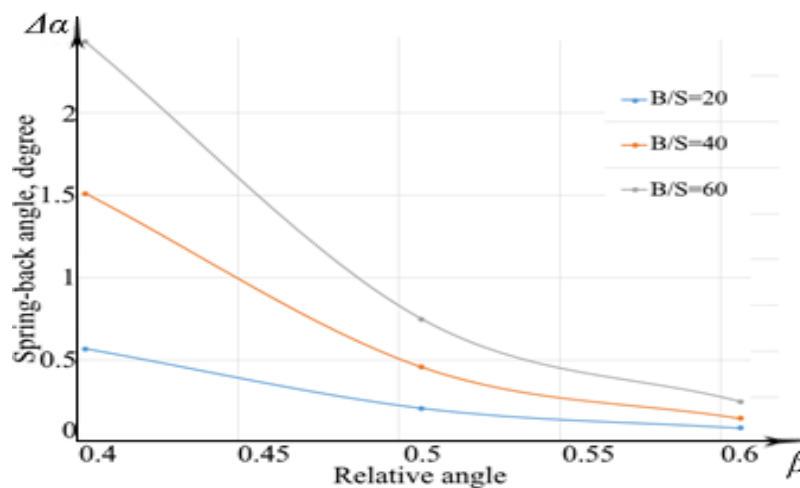


Fig. 5. Change of the spring-back angle, depending on the relative bending angle of the blank with a thickness $S = 1$ mm during one-pass bending

Analyzing the change of the spring-back angle, it is should be noted its overall growth with the thickness and width of the samples increasing.

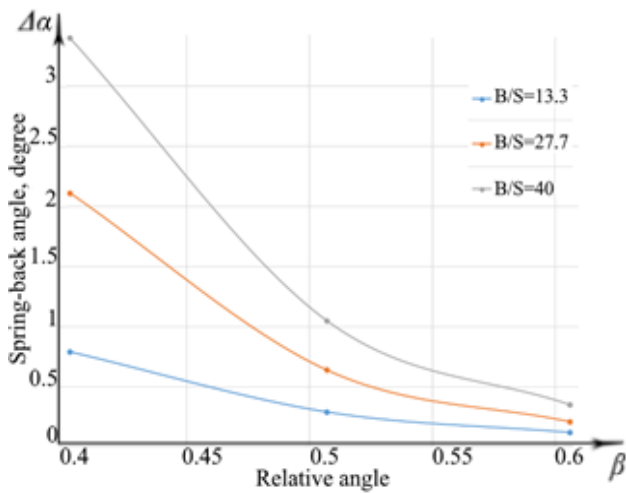


Fig. 6. Change of the spring-back angle, depending on the relative bending angle of the blank with a thickness $S = 1.5$ mm during one-pass bending

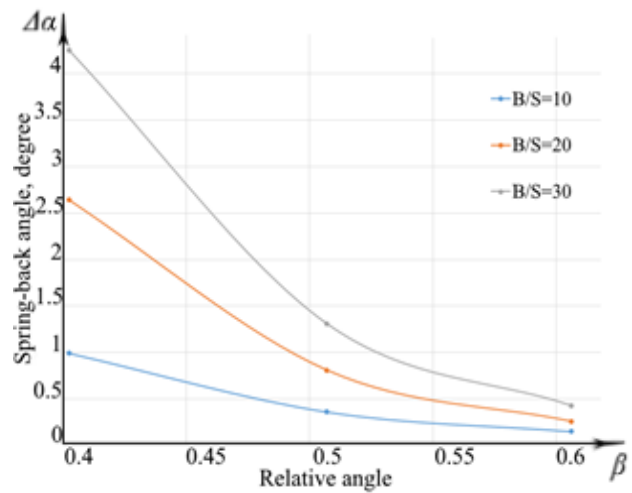


Fig. 7. Change of the spring-back angle, depending on the relative bending angle of the blank with a thickness $S = 2$ mm during one-pass bending

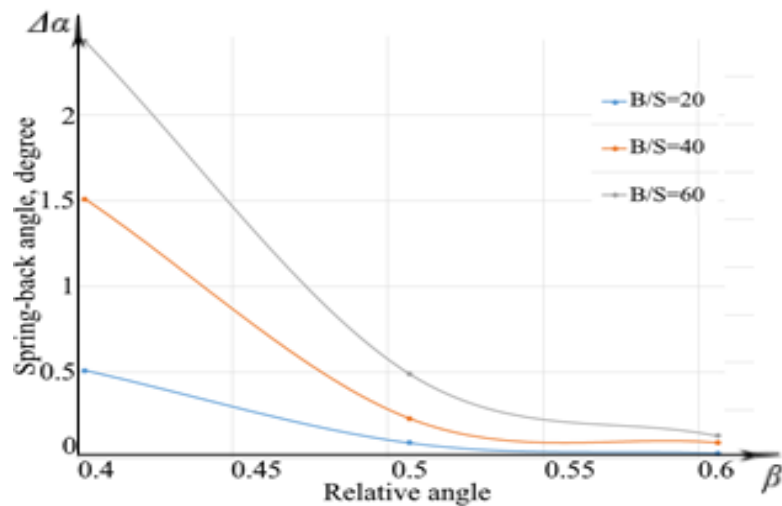


Fig. 8. Change of the spring-back angle, depending on the relative bending angle of the blank with a thickness $S = 1$ mm during multi-pass bending

As it is established, during deformation of blanks with thickness $S = 2$ mm, springing occurs more intensively. It should also be noted for the blank with a width $B = 60$ mm. Bending of the blank $S = 1$ mm is accompanied by less intensive springing, compared with the blanks $S = 1.5$ mm, $S = 2$ mm. It should also be noted for blanks with a width $B = 20$ mm.

Experiments data are shown in Figs. 5–10 were processed in the MS Excel package using the "Analysis ToolPak" macros and using a linear, logarithmic and exponential regression model. As a result of the data processing of the experiment it was found that the linear model does not give adequate results for any of the cases,

because the calculation on it gives a big difference between experiment and calculation.

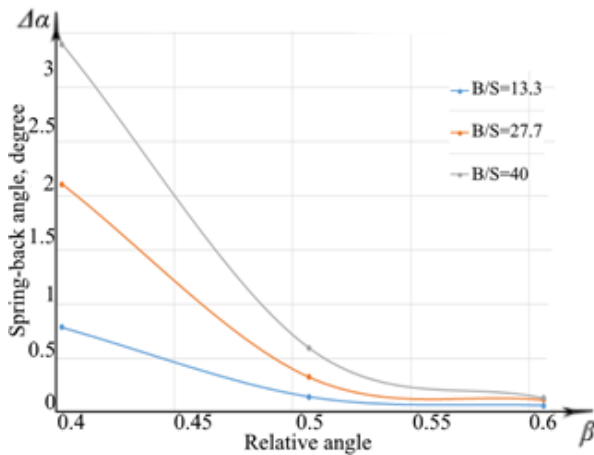


Fig. 9. Change of the spring-back angle, depending on the relative bending angle of the blank with a thickness $S = 1.5$ mm during multi-pass bending

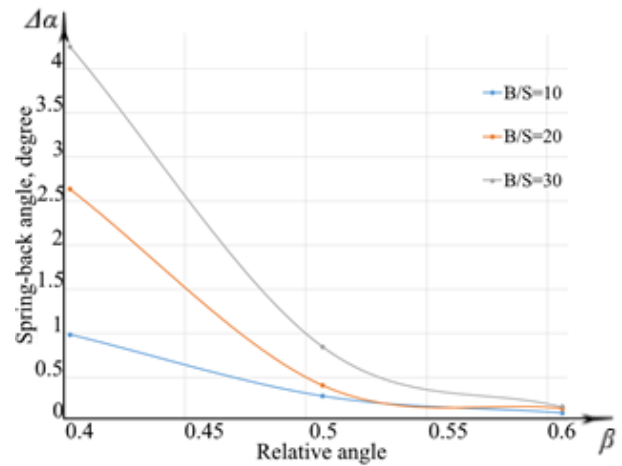


Fig. 10. Change of the spring-back angle, depending on the relative bending angle of the blank with a thickness $S = 2$ mm during multi-pass bending

For the case when only the data of one-pass bending ($n = 1$) are taken into account, the logarithmic model has been found to be the most adequate and correct:

$$\ln(\Delta\alpha)_{\ln.mod1} = -3.09683 + 0.5481 \cdot \ln(B/S) - 4.5735 \cdot \ln(\beta),$$

for which the correlation coefficient is equal to 0.77744; coefficient of linear determination is equal to 0,5969; the adapted determination coefficient is 0.5663; standard error is 0.7111.

For the case of multi-pass bending ($n = 1, 2, 3$), the logarithmic model was also found to be the most adequate and correct.

$$\ln(\Delta\alpha)_{\ln.mod1-3} = -39.3727 + 0.2121 \cdot \ln(B/S) + 43.8989 \cdot \ln(\beta) - 14.2823 \cdot \ln(n),$$

for which the correlation coefficient is 0.8702; the linear determination coefficient is 0.77573; the adapted determination coefficient is 0.7256; standard error is 0.6290.

For the case when the data of one-pass and mulyt-pass bending ($n = 1, 2, 3$) are taken into account, it is found that the result is the most adequately and correctly describes the exponential model:

$$\ln(\Delta\alpha)_{exp.mod} = 3.8389 + 0.0115 \cdot \exp(B/S) - 2.3813 \cdot \exp(\beta) + 0.1182 \cdot \exp(n),$$

for which the correlation coefficient is equal to 0,5822; the linear determination coefficient is 0,3390; the adapted determination coefficient is equal to 0,2993; The standard error is 0.9469.

Conclusions

1. As a result of the analysis in literary sources, lack of information has been found to take into account the spring-back angle at the multi-pass bending of the blank. It is shown that during calculating the shape change and predictive prediction of the quality of bending shapes it is necessary to take into account the properties of the blank material, as well as the angles of the pre-bending and the ratio of the width and thickness of the blank.

2. The method of experimental research for the spring-back angle at the multi-pass bending is developed. Was shown the expediency of using methods of direct measurements of geometric sizes of blanks after bending at different angles, taking into account the thickness and width of the blank, as well as the necessity of applying statistical methods and methods of regression analysis to obtain analytical dependencies.

3. The graphic dependences of the spring-back angle is built on such relative indicators of the bending process as the relative bending angle (β) and width to thickness ratio (B/S) of the blank, which makes the calculation of experiments more versatile. After analyzing the graphs obtained, that we can conclude that the spring-back angle significantly decreases with increasing number of pre-bends. The magnitude of the spring-back angle increases with increasing the thickness and width.

4. With the aid of regression analysis, mathematical models were developed to predict the bending angle at the design of technological processes at the stage of calculations and designing of technical documentation (manuals).

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