ADVANCED TECHNOLOGIES AND MATERIALS VOL. 45, NO. 1 (2020)
DOI: 10.24867/ATM-2020-1-005

ADVANCED TECHNOLOGIES & MATERIALS

http://journal-atm.org

Experimental Identification of the Springback Angle During the Sheet Metal Processing of Wider Range of Materials Assisted with Rapid Tooling

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ABSTRACT

The parts obtained by sheet metal forming technology can be classified as a percentage in the most common parts of assemblies and sub-mechanisms of mechanisms. The basic problem that occurs when making sheet metal parts using bending process, is the elastic return. The elastic return coefficient that can be used as a correction coefficient in the bending process is necessary to be determine for the used material, as well as for the processing conditions. All this led to high cost of the processing tool. On the other hand, rapid tooling constantly increasing its present in the processing presses. One of the biggest advantages of the rapid tooling is reduction of the cost and processing time of the final product. In this paper, the experimental identification of the elastic return coefficient for three different materials (Al-alloy, non-alloy steel and stainless steel) was performed, as well applicability of rapid tooling on sheet metal bending. The experiments covered a range of bending angles from 65° to 135°. It has been found that depending on the type of material and the bending angle, the elastic return coefficient can vary considerably. It also turned out that its value is significantly influenced by the geometry of the punch. All elements made using additive technology, successfully performed work tasks without the occurrence of destruction.

Key words: *Rapid tooling; Sheet metal; Bending; Springback.*

1. INTRODUCTION

With the noticeable intensive development of techniques and technologies used in the design of new products, the term "modern way of designing" is indispensable. In other words, the designed product is going to be composed of parts that are obtained from a wide range of available production technologies, starting with casting, plastic processing, cutting, and even sheet metal processing technology.

Once is talked explicitly about sheet metal processing technology a conclusion can be reached that it is one of the most applied technologies. From computers, automobiles, aviation industry, etc., a large percentage are parts that are obtained by sheet metal processing technology.

A complete understanding of this technology is the basis for its successful application. One of the basic problems that occur with the mentioned technology is the elastic return angle (springback) which is a consequence of the physical/mechanical properties of the used materials [1, 2]. In order to effectively overcome this problem, it is necessary to perform detailed tests for the used materials, in order to properly prescribe the sheet metal forming technology, which can be classified in several directions.

- The first direction is the research of elastic return using special sheet metal holders [3, 4].
- The second direction refers to the examination of the influence of the shape geometry on the effect of elastic return [5, 6].

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Received: 28 August 2020; Accepted: 30 September 2020

- Directions refer to the compensation of the bending angle with a larger bending angle are the next one [7, 8].
- The last one is the examination of the warm bending effect on the elastic return angle [9-11].

2. FUNDAMENTALS OF THE PROCESS

In this paper, an experimental investigation of elastic return angle during sheet metal bending that is assisted with rapid tooling was conducted.

2.1 Sheet metal processing

Sheet metal bending represents one of the ways to plastically shape metal sheets to form the final desired geometry of the part. One of the main disadvantages of metal sheet bending is the presence of an elastic return angle.

Elastic return of material after the sheet metal bending process is an unavoidable phenomenon that is a function of the type of material to be bent, the value of the punch radius r_2, and the thickness of the sheet metals. Its appearance is conditioned by the existence of return elastic and plastic deformations in the bending zone. As a consequence, after the bending process, there will be a significant deviation of the measured geometry of the part from that required by the technical documentation (Fig. 1) [12].

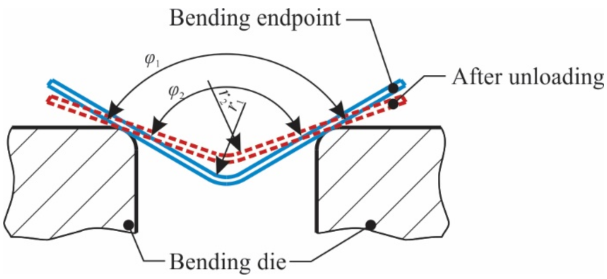

Fig. 1 *Change in bending angle due to elastic return.*

To compensate for the elastic return angle, it is necessary to perform experimental identification of the elastic return coefficient K for the desired material, bending radius, and bending angle, according to the expression [13]:

$$K = \frac{\varphi_2}{\varphi_1} \tag{1}$$

2.2 Rapid Tooling

The cost of the production tool in a large percentage affects the final product cost. In a large number of cases, a long period of production is required for specific tool production. In those cases, widespread production technologies are necessary to be included.

With the exponential increase of the additive technologies in the production processes, production time and cost can be reduced. However, not so rare, in some cases, production tools are produced using additive technology (Rapid Tooling), Fig. 2 [14]. The main dilemma of using rapid tooling is its applicability in the production process.


Fig. 2 *Example of Rapid Tooling.*

3. EXPERIMENTAL SETUP

Sheet metal bending experiments were conducted on an eccentric press ILR EP-P-50. As the used eccentric press provides the possibility of defining the value of the length of the working stroke of the press, for the purposes of experiments, it was necessary to identify the actual length of the working stroke of the press. The main reason was to evaluate the exact bending angle of the specimen. In order to identify stroke length a displacement sensor HBM W80, based on the principle of an inductive half-bridge, was used. The sensor body is firmly attached to the press body, while the moving part of the sensor is attached to the slide plate. The acquisition system consisted of a universal four-channel amplifier HBM Quantum MX440B device which had the function of signal amplification, as well as its A/D conversion, while a PC and QUANTUM CATMAN software were used to monitor and record the measured results (Fig. 3) [15].

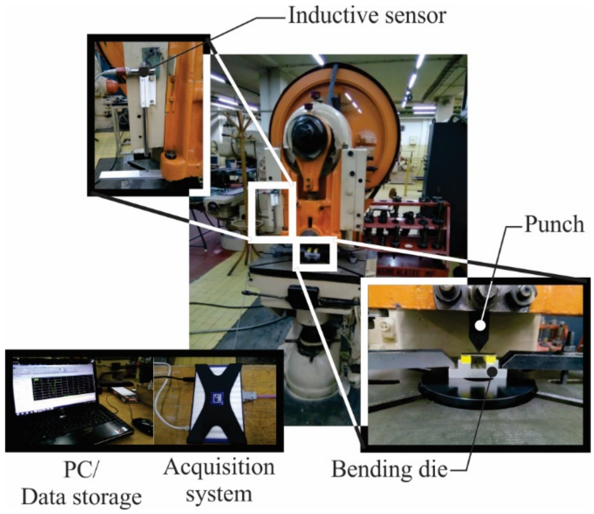

Fig. 3 *Experimental setup.*

The tool is designed to be modular. This means that punch was made of two parts, punch holder and punch, and bending die were made of bending die holder and bending die inserts (Fig. 4) [12].

Punch holder, punch and bending die inserts were produced using Rapid Tooling. Tools were printed on a Markforged 3D printer, using Onylux filament.

Used punches wearied between the experiments, where three of them had the values of the tip radius R1, R3, and R4 mm.

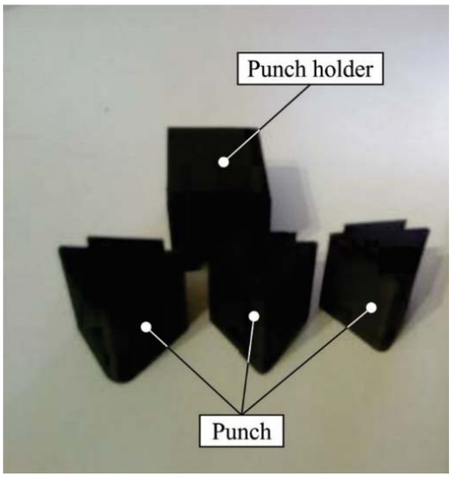

Fig. 4 *Interchangeable punches formed by additive technology.*

The tool, which consisted of punch holder, the punch and the bending die, was placed and attached to both the working table and the sliding plate of the press. Depending on the desired value of the sheet metal bending angle, the working table of the press, i.e. the bending die, was raised/lowered. In this way, a precise definition of the end position of the punch in relation to the bending die at the end of the working stroke of the press was achieved.
After the bending process, using a digital protractor, the achieve bending angle was measured (Fig. 5) [12].

Fig. 5 *Measurement of achieved bending angle.*

The experiments were performed on three different materials (aluminum EN 573-3, Č0545 and stainless steel EN 1.4016). All of the specimens were the same thickness of s=1.5 mm.
The experiments are based on the variation of the bending angle between the experiments. The bending angle was adopted to be around 65, 90, and 130°. The exact value of the bending angle differs between experiments and was calculated based on the value of the punch tip radius, sheet metal thickness, a stroke of the press, and the initial position of the punch relative to the bending die. In order to obtain the most accurate picture of the elastic return angle, all conducted experiments were repeated three times.

4. RESULTS

Tables 1, 2, and 3, show the obtained values of the achieved bending angle φ_2 in relation to bend angle φ_1. The measurement results refer to three different materials (aluminum EN 573-3, Č0545 and stainless steel EN 1.4016). All these values are graphically represented in figs. 6, 7, and 8, depending on the specimen material.

Table 1 - *Measured values of achieved bending angle φ_2 in relation with bend angle φ_1 aluminum EN 573-3.*

Tool radius (Bend angle)	*Measurement, φ_2 [°]*		
	No. 1	*No. 2*	*No. 3*
R1 (φ_1=66.9°)	67.2	67.1	67.2
R1 (φ_1=89.6°)	90.2	90.1	89.8
R1 (φ_1=121.24°)	125.0	125.2	125.8
R3 (φ_1=68.37°)	73.9	73.6	73.1
R3 (φ_1=94.82°)	100.2	99.7	99.7
R3 (φ_1=130.72°)	137.7	138.5	138.6
R4 (φ_1=69.49°)	75.8	75.6	75.6
R4 (φ_1=95.76°)	102.9	102.8	102.7
R4 (φ_1=134.06°)	143.0	142.0	143.2

Table 2 - *Measured values of achieved bending angle φ_2 in relation with bend angle φ_1 steel Č0545.*

Tool radius (Bend angle)	*Measurement, φ_2 [°]*		
	No. 1	*No. 2*	*No. 3*
R1 (φ_1=66.9°)	67.8	68.4	68.1
R1 (φ_1=89.6°)	91.5	91.6	91.9
R1 (φ_1=121.24°)	125.9	126.0	125.7
R3 (φ_1=68.37°)	73.0	73.4	73.1
R3 (φ_1=94.82°)	100.1	99.9	100.1
R3 (φ_1=130.72°)	140.8	140.7	140.5
R4 (φ_1=69.49°)	74.6	74.5	74.8
R4 (φ_1=95.76°)	105.2	104.4	104.4
R4 (φ_1=134.06°)	146.0	146.0	146.5

Table 3 - *Measured values of achieved bending angle φ_2 in relation with bend angle φ_1 stainless steel EN 1.4016.*

Tool radius (Bend angle)	*Measurement, φ_2 [°]*		
	No. 1	*No. 2*	*No. 3*
R1 (φ_1=66.9°)	70.8	69.9	70.0
R1 (φ_1=89.6°)	94.5	94.6	95.0
R1 (φ_1=121.24°)	134.0	134.6	134.5
R3 (φ_1=68.37°)	77.0	76.3	76.2
R3 (φ_1=94.82°)	105.5	104.8	104.9
R3 (φ_1=130.72°)	147.9	147.3	148.3
R4 (φ_1=69.49°)	78.9	78.8	78.7
R4 (φ_1=95.76°)	110.0	110.1	110.5
R4 (φ_1=134.06°)	153.5	152.9	153.3

By analyzing the diagram shown in Fig. 6, which refers to the measured value of the achieved bending angle φ_2 in relation to bend angle φ_1 for aluminum EN 573-3, it can be concluded that with an increase of the value of punch tip radius, there is a decrease in the elastic return angle. Its value is not constant and depends on the bending angle of the sheet metal, which can be concluded from the Fig. 9, which shows the value of the elastic return coefficient *K*.
Compared to aluminum, steel Č0545 has a larger difference in the value of the elastic return angle with a change of the value of punch tip radius (Fig. 7). Likewise, the elastic return angle has higher values in relation to aluminum in the case of higher values of the bending angle. As the bending angle decreases, these values become almost identical for steel and aluminum.
When stainless steel EN 1.4016 is compared with the previous two materials, it is observed that it has the highest values of the elastic return angle (Fig. 8). This applies both to large values of bending angle and to smaller ones. In other words, compared to aluminum and steel, the elastic return coefficient for stainless steel has higher values, with a higher growth trend with increasing bending angle compared to the previous two materials, Fig. 9.

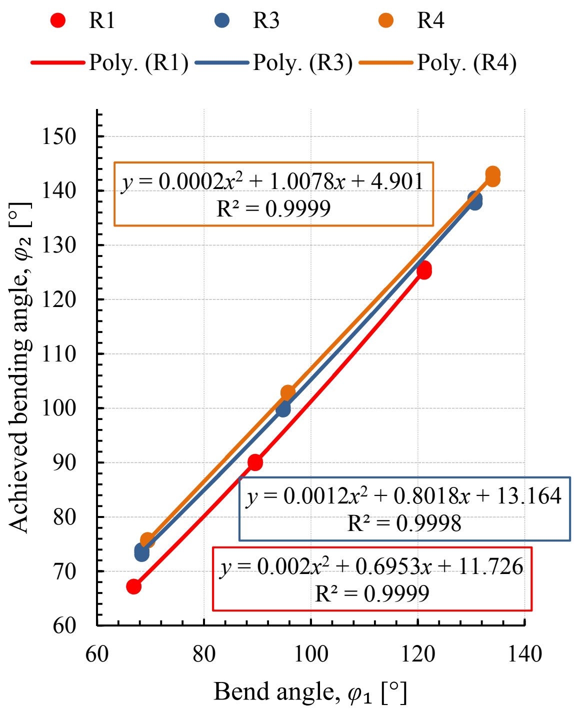

Fig. 6 *Ratio of achieved bending angle φ2 and bend angle φ1 for aluminum EN 573-3, for tools R1, R3 and R4 mm.*

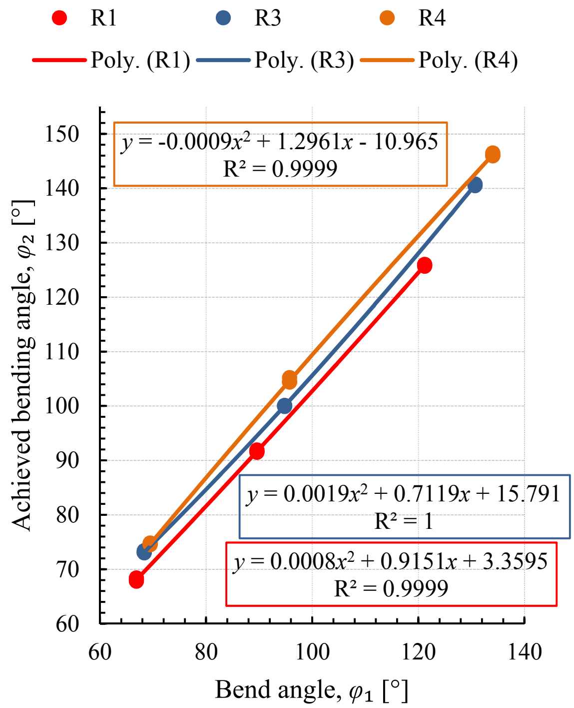

Fig. 7 *Ratio of achieved bending angle φ2 and bend angle φ1 for steel Č0545, for tools R1, R3 and R4 mm.*

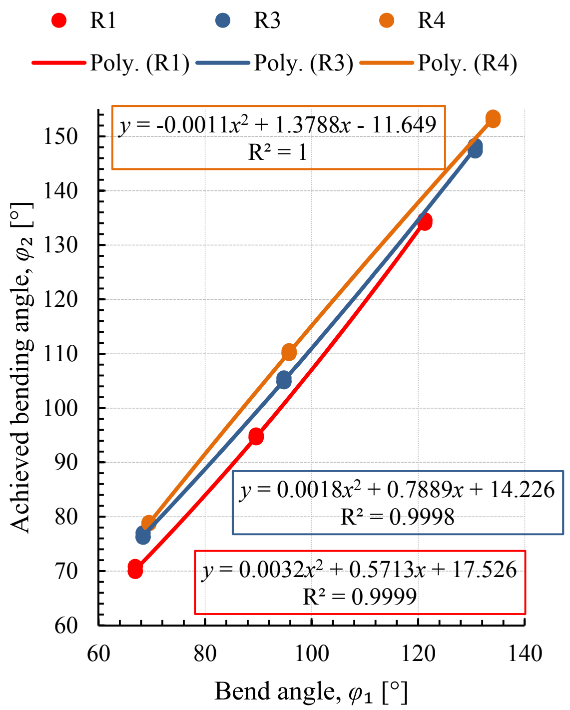

Fig. 8 *Ratio of achieved bending angle φ2 and bend angle φ1 for stainless steel EN 1.4016, for tools R1, R3 and R4 mm.*

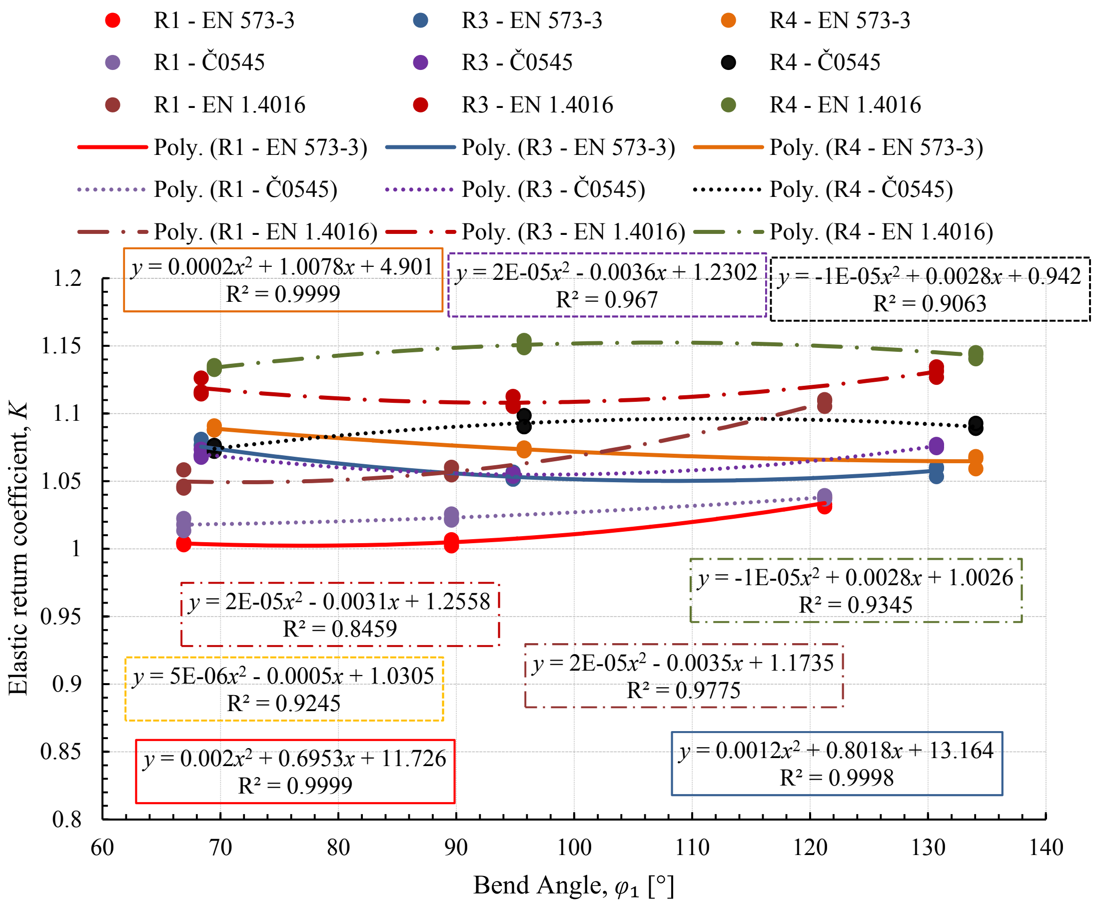

Fig. 9 *The value of the elastic return coefficient for three types of materials when using tools R1, R3 and R4 mm.*

5. CONCLUSION

- Depending on the type of used material, the values of the elastic return coefficient can vary considerably. In addition to the type of material, its change is also influenced by the bending angle of the sheet metal, as well as the geometry of the punch.
- In the case of aluminum, the value of the elastic return coefficient has a significantly lower value compared to steels.
- In the case of aluminum and steel at smaller bending angles of sheet metal, the elastic return angle has an approximately constant value, while for stainless steel these values are significantly higher and differ in the entire range of the tested bending angle.
- With the knowledge of the value of the elastic return coefficient for precisely defined processing conditions, it is possible to compensate for the bending angle for obtaining the desired geometry of the part.
- Rapid tooling can be successfully applied on the sheet metal bending, which can lead, not only to the reduction of the cost of the final product but also the cost-effectiveness of the production of complex shapes of sheet metal parts in small and medium production batches.

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