Characterising the Effect of Springback on Mechanically Formed Steel Plates

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Abstract— In the bending operation, springback causes geometrical inaccuracies of bent parts. To curb springback, various factors such as bending parameters and material properties need to be considered. This paper reports the effects of springback on mechanically formed steel plates. Experimental work using circular bending was conducted to analyse the effect of springback on the formed steel sheets. The sheets were bent using a punch and die having a radius of curvature of 120 mm. In addition, the formed samples were characterized through microstructure, microhardness and tensile results. The results revealed an error due to springback of 4.24%. Furthermore, the Vickers microhardness of the formed samples compared to the parent materials shows an increase of 6% while the Ultimate Tensile Strength also increased by 7%. The effects of strain hardening resulting from the bending process led to the increased hardness and strength of the material. The formed samples had elongated grains when compared to the equiaxed grains of the parent material. The increase in the grains can be attributed to the stretching of the material during the bending process.

Keywords— Mechanical forming, springback,

I. INTRODUCTION

SHEET metal bending plays a very important role in the manufacturing industry. As the industry develops, the size of the components being produced gets smaller and tolerances on them gets tighter. The geometrical accuracy of a bent part is crucial in determining the quality of the component [1]. Analysis of the process of sheet metal bending reveals a phenomenon called springback. Springback is the term used to describe the elastic recovery of sheet metal after a bending operation [2]. Problems relating to springback do not only affect formed components, but also affect the design of the bending tools such as the forming dies. When a sheet undergoes a bending operation, usually on presses, it is deformed to a certain degree and takes the shape of the die. However, as soon as the die is removed, the sheet recovers slightly towards it original shape. In other words, the sheet does not maintain the final radius of curvature of the load condition, but it recovers elastically to a much larger final radius of curvature. According to Ling [1] and Verma [3], springback often affects the design of the forming dies. Because of springback complications, die designs are only finalized after fabrication and testing of multiple prototypes [1]. Thus designers have significant problems because they must correctly calculate the amount of springback which will occur during the bending procedure so that an anticipated part profile can be achieved. A parametric study conducted by Ling [3] in order to reduce the time spent on manual corrections of the die showed how the inclusion of a step in the die can reduce the springback. Besides affecting the bending tools, springback largely affects the dimensional accuracy of the bent sheets. With respect to the sheets, springback negatively affects the bending angle and the bend curvature of the sheet [4]. As technology in the automotive industry develops, manufacturers want to make part for high and advanced high strength steels. However, punching sheets made from high strength steels exhibits poor formability and a high amount of springback [3]. However, determining how much springback a sheet will exhibit is of great importance in the manufacturing industry. This kind of problem is encountered especially by sheet-metal working companies. Bending inaccuracies will only result in costly reworking of the components. This is a cost that can be avoided if a manufacturer can predict the behaviour of the sheet after bending. Part shape errors due to springback are usually considered to be a manufacturing defect in the sheet metal forming process. Therefore, springback is generally referred to as the undesirable change of part shape that occurs upon removal of constraints after forming [5]. It is a geometrical change which happens after unloading, due to the occurrence of primarily elastic recovery of the part. This paper therefore reports the effect of springback on mechanically formed steel plates.

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II. EXPERIMENTAL SET UP

The 2 mm steel sheets were bent to a radius of curvature of 120 mm using a suitable mould. Both the punch and the die had a radius of curvature of 120 mm. The punch was of a convex shape and the die was of a concave shape. Polyurethane material was used in the bending procedure to prevent friction and surface heating. The optimised force used in the bending procedure was 30 N. The experimental set up of the tests is presented in Figure 1.

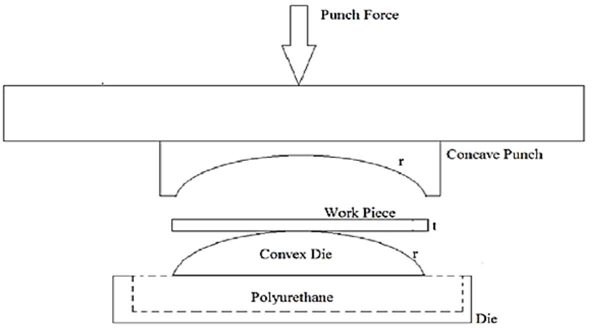

Figure 1: Sheet metal bending using a concave punch and convex die

The geometry of the sheet after bending and the parameters used in determining the springback are shown in Figure 2.

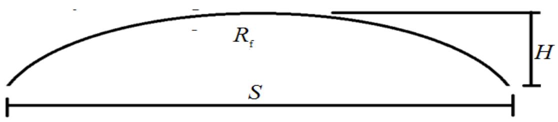

Figure 2: The geometry of the sheet after bending

The resulting error due to springback of the sheets was calculated using the initial bend radius of the sheets before springback and the final radius of the sheets after springback using equation 1.

$$R_f = \frac{H}{2} + \frac{S^2}{8H} \qquad (1)$$

Where R_f is the final sheet radius after springback, S is the chord length H is the perpendicular line segment to S which intersects the highest point of R_f.

The percentage change in the radius of the sheets due to springback was calculated using equation 2 which gives the resulting error due to springback.

$$\%\text{Change in curvature radius} = \frac{\text{Final Radius} - \text{Initial Radius}}{\text{Initial Radius}} \times 100 \qquad (2)$$

The formed sheets were sectioned at the point of maximum deformation and characterized. For the microstructural analysis, the parent material and formed samples were mounted using hot mounting resin and prepared in accordance with the standard procedure of metallographic sample preparation of steel and etched with 2% nital solution to reveal the microstructure. The Olympus BX51M optical microscope was used for the analysis. For the hardness test, the Vickers Microhardness Tester model MH-3 was employed according to ASTM 384 with a load of 300g and the spacing between indentations was 2 mm. The measurements were taken at 0.5 mm from the formed surface and a dwell time of 10 seconds was used. The tensile samples were tested in accordance with ASTM E-8. A servo-hydraulic Instron 8801 tensile testing machine was used to conduct the tests. An extension rate of 0.5 mm/min and a gauge length of 50 mm were used.

III. Results and Discussion

3.1 Springback results

Eight samples were formed for consistency and the percentage error due to springback was calculated for each of them using equation 1 and an average was calculated which is the average springback error. The results are displayed in more detail in Table 1.

Table 1: Springback results

Sample No	Final radius (mm)	h (mm)	S (mm)	Springback error (%)
1	124.34	37	177	3.62
2	125.54	36.5	177	4.61
3	125.54	37	178	4.61
4	124.30	37	177	3.62
5	125.54	37	178	4.61
6	125.54	37	178	4.61
7	125.50	37	178	4.61
8	124.34	37	177	3.62
Average				**4.24**

The smallest error due to springback was found to be 3.62% and the largest error due to springback was found to be 4.61%. It should be noted, however, that all the results are between 3.62 and 4.61%. From the results obtained, the average error due to springback was found to be 4.24%.The sheets sprung back to a radius of curvature that was greater than the desired 120 mm. When considering the circular bending procedure that was conducted, it should be noted that the sheets underwent a bottoming stage. That is ensuring full contact between the punch and the die. During the punching procedure, it was ensured that all the samples came into full contact with the cavity of the concaved punch and were in full contact with the convex die. Because of the bottoming stage, it can be concluded that the initial bend radius of the sheets was 120 mm since both the punch and die have a radius of 120 mm. If bottoming was not part of the punching procedure, the error due to springback would have been greater than 4.24%. This is because bottoming reduces springback [10].

3.2 Microstructural characterisation

Typical microstructures of the parent material and the formed samples are presented in Figure 3(a) and (b).

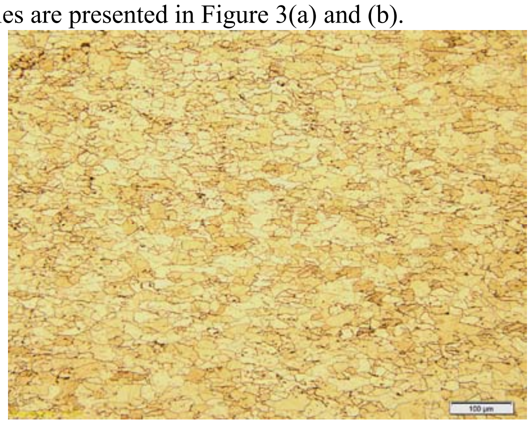

Figure 3 (a): Microstructure of the parent material

Figure 3 (b): Microstructure of the formed material

It was observed that the grains of the microstructure of the parent material are equiaxed. Equiaxed grains in metals can be as a result of a number of factors which may include forming operations such as hot rolling and heat treatment procedure such as tempering while the microstructure of the formed samples revealed elongated grains. The elongated grains can be attributed to the effects of the tensile stresses that acted on the outer concaved side of the sheet metal during the bending procedure. In other words, stretching of the material occurred during the bending procedure. This was verified through the comparison of the grain sizes of the parent material to the formed samples.

The measurement tool on the optical microscope was used to measure the grains. Six individual grains were measured and the results of the measurements of the parent material and the formed samples are presented in Table 2.

	Grain Size	
Points	**Parent material (μm)**	**Formed samples (μm)**
1	42.15	98.51
2	37.99	97.81
3	35.92	87.7
4	50.32	83.76
5	38.13	76.82
6	46.78	76.26
Average	41.88	86.81

The average grain size of the parent materials was determined to 41.88 μm. The average grain size of the formed samples was found to be 86.81 μm. The increase in the grain sizes of the formed samples compared to the parent material shows that the material was plastically deformed due to the bending operation.

3.3 Microhardness characterisation

The average microhardness value of the parent material was found to be 108 Hv while the formed samples were 115 Hv. The increase in the microhardness of the formed samples compared to the parent material can be attributed to strain hardening resulting from the bending process. However, it is confirmed that there is no metallurgical notches in the formed samples.

3.3 Tensile results

Three parent material specimens were used for the tensile tests and the average mechanical properties were determined. The stress-strain curves are presented in Figure 4.

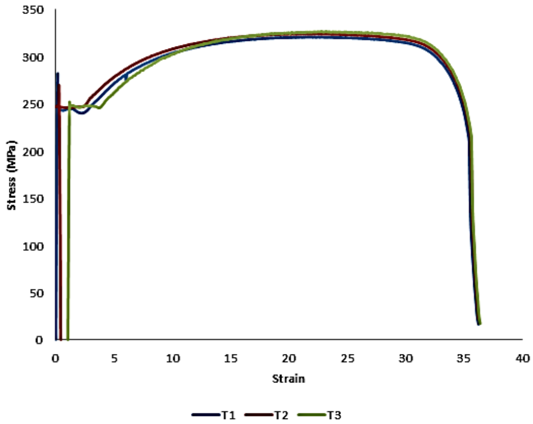

Figure 4: Stress-Strain curves of the parent material

From the graph, it was observed that the material exhibited a ductile behaviour. The average percentage elongation was 37.80% and the Ultimate Tensile Strength of the material was found to be 328 MPa. The effect of the deformation process and springback were determined by comparing the mechanical properties of the formed samples to the parent materials. According to Knupfer and Moore [24], the Ultimate Tensile Strength UTS can be related to the Vickers hardness value by the following equation:

$$\mathrm{UTS} = 9.81\left(\frac{\mathrm{HV}}{2.9}\right)\left(\frac{\mathrm{n}}{0.217}\right)^{\mathrm{n}} \quad (3)$$

Where n is the strain hardening coefficient and HV is the Vickers microhardness value. For annealed low carbon steel the strain hardening coefficient n is 0.21. The estimated increases in the mechanical properties of the material after bending are presented in Table 3.

Table 3: Estimated values

Property	Parent material	Formed sample	% Increase
Microhardness	108	115	6
Calculated UTS	362	386	7

The percentage increase in the microhardness value and the ultimate tensile strength was 6% and 7% respectively. Thus the bending process and the subsequent springback of the samples gave rise to the improved mechanical properties. In line with the strain hardening phenomena the strength and hardness of the material increased.

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IV. CONCLUSION

The effect of springback and the resulting properties of mechanically formed steel plates have been presented and discussed. It was found that the 2 mm formed sheets exhibited an average springback of 4.24%. In other words, the springback caused a forming error of 4.24%. Due to the springback error, the desired radius of curvature of 120 mm could not be achieved. From this stand point, it can be concluded that springback causes geometrical inaccuracies in sheet metal forming. It was also found that the percentage increase in the grain size as a result of the bending process was found to be 107.30%. The microhardness and the UTS of the formed samples were also improved compared to the parent material. To reduce the error due to springback in this case, over-bending can be considered as a method of compensating for the springback. A reduction in the radius of curvature of the mould is also required to obtain the desired 120 mm curvature.

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