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Effect of Bottoming on Material Property during Sheet Forming Process through Finite Element Method

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Abstract. Metal forming is one of the conventional manufacturing processes of immense relevance till date even though modern manufacturing processes have evolved over the years. It is a known fact that material tends to return or spring back to its original form during forming or bending. The phenomena have been well managed through its application in various manufacturing processes by compensating for the spring back through overbending and bottoming. Overbending is bending the material beyond the desired shape to allow the material to spring back to the expected shape. Bottoming, on the other hand, is a process of undergoing plastic deformation at the point of bending. This study reports on the finite element analysis of the effect of bottoming on the material property during the sheet forming process with the aim of optimising the process. The result of the analysis revealed that the generated plastic strains are in the order between 1.750e00-1 at the peak of the bending and 3.604e00-2, which was at the early stage of the bending.

1. Introduction

Sheet metal forming process is one of the fundamental techniques employed in metalworking. This is one of the common manufacturing processes on the shop floor of a fabrication yard, where sheet metal are often formed and bent into thin and flat pieces. Sheet metal forming processes are classified as a conventional forming process, which applies forces to piece of sheet metal to modify the geometry of the material instead of material removal. The applied load to the material stresses it beyond its yield strength causing the material to plastically deform but not to fail. In this state, the sheet can be bent and stretched into different configuration and shapes [1].

The bending process is applied in the sheet metal forming operation to bend and fabricate curvature shapes such as electronics part. Most of the bending activities are not only employed in the bending process but are found in other many sheet-metal forming manufacturing processes such as the deep drawing process, the U-tube bending and the flanging process. One of the major drawbacks of the bending process is the development of spring back, which is believed to have affected many of the working process parameters such as the material property, bending angle, bending radius, bending stroke [2], [3]. Considerable studies have been conducted with the aim to investigate and reduce the amount of spring-back.

In the past, sheet metal bending processes are dependent on the designer's experience and involve trials and errors to obtain the desired result [4]. Trial and error can involve adjustments made to the machine tools and process control to compensate for variation in material and unexpected parameters [5]. Many analytical models proposed to study spring-back in bending use simple beam or plate bending theory [6]. Some of the research conducted includes the study into the spring-back of CK67 steel sheet in V-die and U-die bending processes [7]. The studies into the spring-back control of sheet metal air bending process [8] and the investigation of the variation of elastic modulus during plastic deformation and its influence on spring-back [9[. Also the prediction of spring-back in the wipe-bending process of sheet metal using the neural network [10], the determination of spring-back of stainless steel sheet metal in the V-bending die [11] and the study into spring-back prediction, compensation, and optimisation using numerical analysis [12].

Several studies have been conducted on sheet metal forming [8]-[11] by different researchers to date, through this the application of this cut across different industrial applications. It is believed that bending is one of the applications used in metal forming process in many industries and observed that springback as one of the problems associated with bending process [13]. The process of validating the experimental results in qualifying the amount of springback in a U-bending process demand that both experimental and numerical investigation be conducted on the effect of punch speed on the amount of springback in U-bending of auto-body steel sheets [14]. They use SPCC and DP780 steel sheet for both the experimental and finite element analysis and the experimental results show that the amount of springback for SPCC during the bending process decreases but that of DP78 increases as the punch increases.

Furthermore, other research conducted was a study on finite element analysis of punch height effect on the V-bending angle, and the results showed that the effects of punch height on the bending angle could be theoretically clarified based on the material flow analysis and the stress distribution analysis [15]. Considering all the research work conducted in metal sheet bending and forming, the V-bending operation and finite element analysis has been widely investigated experimentally but using U-bending (Figure 1) to study the effect of bottoming on the material property during the sheet forming process is scarcely researched. This paper presents the effect of bottoming on the material property during the sheet forming process using finite element method

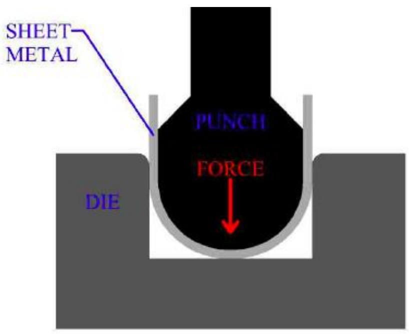

Figure 1: Schematic of U-bending Process [16]

2. Experimental Methodology

The mechanical forming technique is one of the different manufacturing processes employed in the fabrication of sheet metals to form different shapes and part. The process often involved bending and shaping of sheet metals using different technics. Sheet metal bending is the plastic deformation of the work over an axis, creating a change in the part's geometry. In some cases, the bending produces small change in sheet thickness while some instance it does not produce any change in the thickness of the material. It is important to highlight that in the process of making the desired geometry, bending can be used to impart strength and stiffness to sheet metal, change a part's moment of inertia, and to eliminate sharp edges [17].

Sheet metal bending is based primarily on the phenomenon of tension and compression within the materials. Mechanical Engineering principles of metals, especially regarding deformation, are an important factor to understanding sheet metal. The effect that material properties will have in response to the conditions of manufacture will be a factor in sheet metal process design. Usually sheet metal bending is mostly performed at room temperature, however, at times some form of heat are applied to either warm or hot work the material at some temperature other than room condition [17]. The introduction of moderate temperature often improves the material property and help to enhance the bending of some hard materials. Traditionally, sheet bending process mostly employs a punch and die setup for the shaping or bending or forming to be achieved. The different types of punch and die geometry and fixtures have made the bending to be unique to an operation; this may be viewed as a drawback of this process when compared to other modern manufacturing processes. Figure 2 shows a schematic of a representation of a simple sheet metal V-bending configuration.

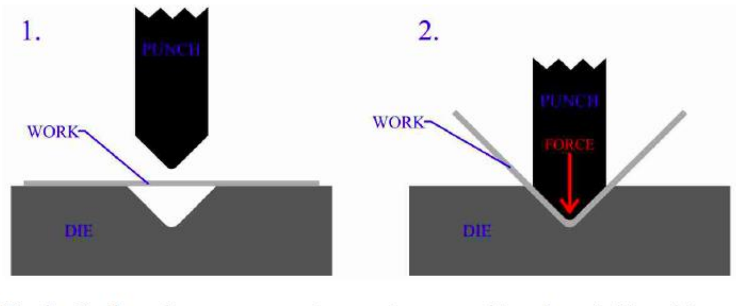

Figure 2: Schematic of V-bending setup [17]

In general, we may consider a whole U-bending process into two steps, loading and unloading. In the loading step, a sheet metal is being bent into the die until the punch moves down completely so that its shape is formed closely to the die shape. During this step, the workpiece undergoes elastoplastic deformation and temperature increases under frictional resistance. Owing to this thermo-mechanical relaxation, the dimension of the final product, particularly the bending angle, becomes different from that of the product before unloading. This dimensional difference is called the elastic recovery phenomenon, and particularly the bending angle alternation is denoted by spring-back. Figure 3 may illustrate the spring-back amount and the negative spring-back is also called spring-go.

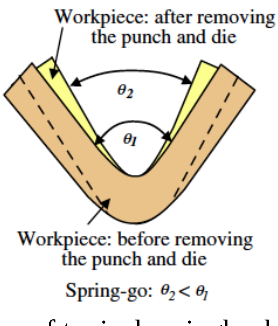

Figure 3: Illustration of typical springback phenomenon [13]

Sheet metal bending and forming are long standing manufacturing processes in the fabrication of different shapes despite the drawbacks of spring back. The improvement of the processes over the years has contributed immensely to the relevance of such a traditional manufacturing process to diverse areas of applications. Some of the techniques developed to overcome the effects of spring back include over bending, stretch forming and bottoming. The amount of spring back is quantified, and the sheet metal is over bent to a smaller bend angle than needed. Recovery of the material from spring

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back results in a calculated increase in bend angle. This increase makes the recovered bend angle exactly as what was originally planned. Stretch forming, on the other hand, is a metal bending technique that eliminates most of the spring back in a bend. Subjecting the work to tensile stress while bending will force the elastic region to be plastically deformed [13].

Stretch forming cannot be performed for some complex bends and very sharp angles. The amount of tension must be controlled to avoid cracking of the sheet metal. Stretch forming is a process often used in the aircraft building industry. Bottoming is a bending process where the punch and the workpiece bottom on the die. This makes for a controlled angle with very little spring back. The tonnage required on this type of press is more than in air bending. The inner radius of the workpiece should be a minimum of 1 material thickness [18].

3. Mechanics of Sheet Metal Bending Process

An understanding of the material properties, characteristics and behaviours of metal, is necessary for a good insight into the mechanics of sheet metal bending. The elastic and plastic deformation of the sheet metal is necessary and also that the bending sheet metal produces localised plastic deformation and essentially with no change in the sheet thickness, depending on the type of operations and does not create a metal flow that may affect the region close to the bend. The force required to perform a bend is largely dependent upon the bend and the specific metal bending process because the mechanics of each process can vary considerably. Proper lubrication is essential to control forces and has an effect on the process. In punch and die operations, the size of the die opening is a major factor in the force necessary to perform the bending. Increasing the size of the die opening will decrease the required bending force. As the sheet metal is bent, the force needed will change. Usually, it is important to determine the maximum necessary bending force, to access machine capacity requirements [16].

Some of the important factors influencing the mechanics of bending include material, sheet thickness, width over which bend occurs, the radius of the bend, bend angle, machinery, tooling and specific metal bending process. Bending a sheet will create forces that act in the bend region and through the thickness of the sheet. A schematic of the mechanics of sheet metal bending is shown in Figure 4. The material towards the outside of the bend is in tension, and the material towards the inside is in compression. Tension and compression are opposite forces, therefore when moving from one to the other, a zero region must exist. At this zero region, no forces are exerted on the material. When sheet metal bending, this zero region occurs along a continuous plane within the part's thickness, called the neutral axis. The location of this axis will depend on the different bending and sheet metal factors. However, a general approximation of the location of the axis could be 40 % of sheet thickness, measured from the inside of the bend. Another characteristic of the neutral axis is that because of the lack of forces, the length of the neutral axis remains the same. Fundamentally, to one side of the neutral axis, the material is in tension, to the other side, the material is in compression. The magnitude of the tension or compression increases with increasing distance from the axis [16], [19].

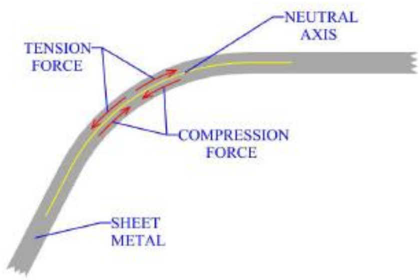


Figure 4: Schematic demonstrating the mechanics of Sheet Metal Bending [16]

4. Finite Element Formulation

The finite element method as applied to the sheet metal bending and U-bending, in particular, is to evaluate the effect of bottoming using a U-bending approach considering the plastic strain and Von-Mises stress developed in the process of and bottoming in particular. Marc software, 2015 version was employed for the FEM analysis. The geometry of the steel was defined in Mentate Marc, a plain strain element was used, and the material properties and boundary conditions were setup. The schematic diagram of the U-bending process and the dimension is shown in Figure 5. The finite element setups of the deformable and rigid bodies are shown in Figure 6 as defined in Marc mentate.

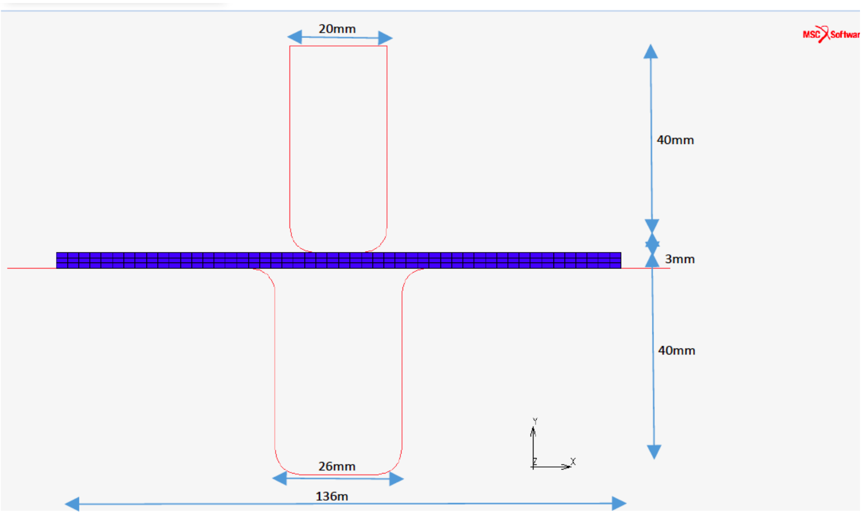


Figure 5: Schematic of U-bending Process and dimensions

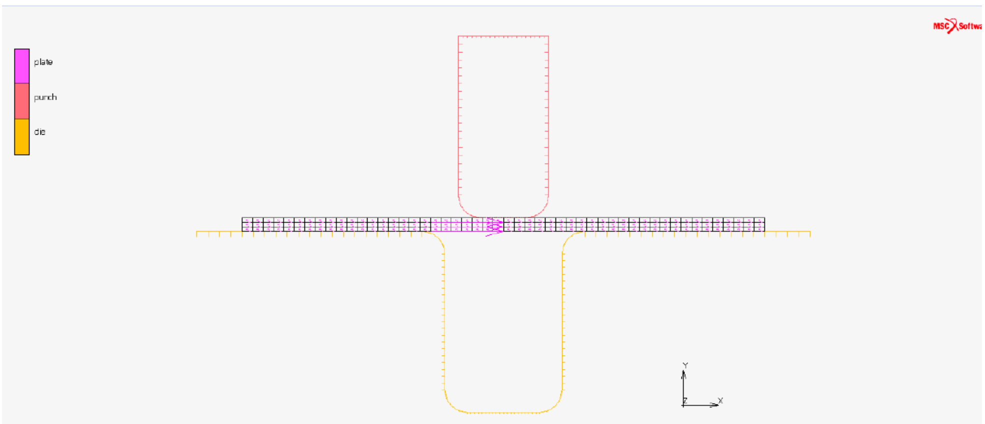
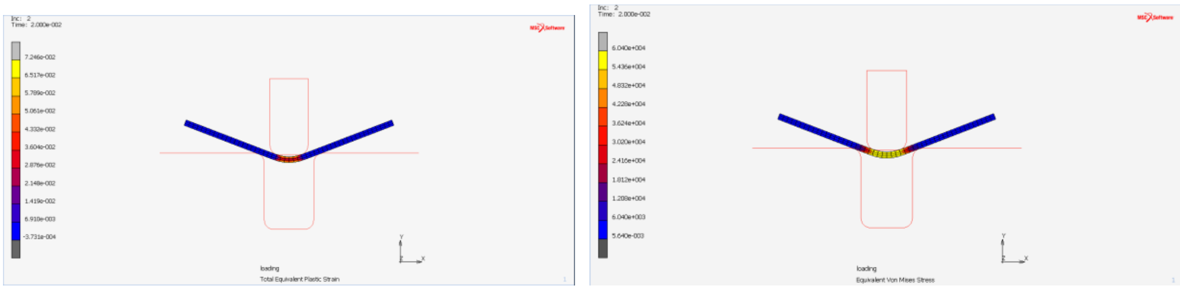


Figure 6: Schematic of the finite element setup of the deformable and rigid body

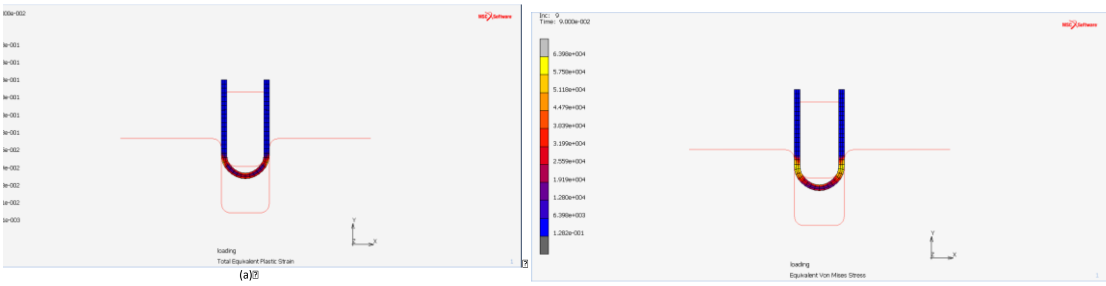
5. Result and Discussion

It is expected in a bending operation that both tensile stresses and compressive stresses are overcome for the desired shape to be achieved. When the bending is eventually achieved, the locked-in stresses cause the material to spring back towards its original position. Springback phenomena are seriously dependent on the material and the type of bending process employed, but the good story is that spring back can always be compensated for in any bending operation. The static analysis was conducted and completed with plain strain elements in constant time stepping, over thirty steps for loading and ten for unloading. The resulting deformation was described by the movement of the punch into the plate at different stroke lengths (2 mm, 9 mm and 20 mm). The contour plot at the stroke of 2 mm for the plastic strain and the Von Mises stresses is shown in Figure 7. (a) and (b) respectively. Both the equivalent plastic strain and the Von Mises Stress were measured during the bending and bottoming in particular to evaluate the effect on the material property. The punch at a stroke of 2 mm generated a plastic strain of 3.604e-2 and Von Mises stress of 6.040e+4 Pa. At this stage of the process, the plastic strain is compressive in nature while the Von Mises stress is tensile.



(a) (b)

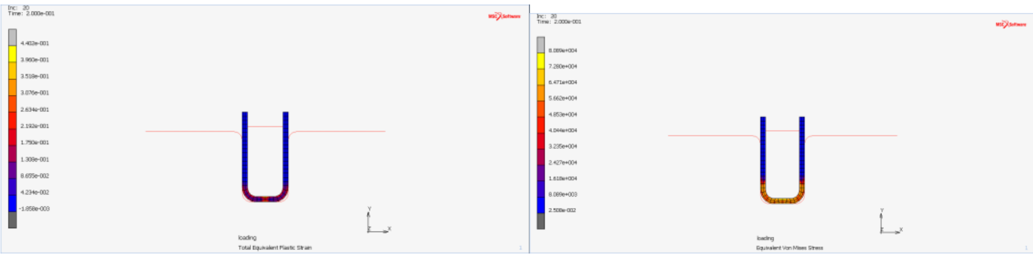
Figure 7 (a) and (b): Contour Plots showing the Equivalent Plastic Strain generated at a stroke of 2 mm



(a) (b)

Figure 8 (a) and (b): Contour Plots showing the Equivalent Plastic Strain generated at a stroke of 9 mm

As the punch stroke increases, there was significant changes in both the plastic strain and Von Mises stress. At a stroke of 9 mm, the plastic strain was still compressive (6.024e-2) but more tensile in nature, the Von Mises stress distribution shown on the contour plot indicated that there is stress distribution along the side wall of the U-bend (5.758+e4Pa) and the bend radius (1.919+4 Pa). Furthermore, It is important to highlight the significant role of the punch in a bending operation because the bend radius depends on the punch, material properties and the thickness of the material. When a sheet material is bent, the sheet stretches in length over the outside edges of the bend in tension and inner bend radius in compression. This consequently induces stresses and strains into the sheet metal as the punch presses, causing a permanent deformation of the material. The Contour plot showing the Equivalent Plastic Strain generated at a stroke of 20 mm is shown in Figure 9. A plastic strain of 1.75e-1 and Von Mises Stress of 5.662e+4 Pa were recorded at the end of the loading with the punch bottoming the material inside the die. The bottoming of the plate in the die was the reason for the increase and the tensile nature of the Von Mises Stress.



(a) (b)

Figure 9 (a) and (b): Contour Plots showing the Equivalent Plastic Strain generated at a stroke of 20 mm

The significant role of the punch in a bending process indicates that the deformation measured from the bending angle increased the stroke length. More interestingly are the measured strains (Equivalent Plastic Strain) induced into the sheet during the bending, strain being the response of material to the applied load. It is, therefore, important to consider these responses closely.

6. Conclusion

The finite element analysis of the sheet metal forming was conducted and completed using the Marc Mentate, MSC software version 2015. The study established that bottoming during a sheet bending process might increase the strain and the stress. This may have a consequential effect on the material property when a large magnitude of stresses and strain characterise the process.

7. Acknowledgement

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