Analysis of tailor-rolled blanks having thickness distribution by finite element analysis

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Abstract. Tailored blanks have been widely applied in car body-in-white parts due to its ability to optimise weight for the purpose of reducing global emission. Tailor welded blanks are produced by joining sheets having different thicknesses by welding. However, stress concentration is induced due to sharp change in thickness and the heat affected zone has its microstructural and properties changed. Tailor rolled blanks on the other hand are semi-finished parts produced by rolling process where no joining is required. The continuous thickness transition reduces the sharp change in thickness. In this paper, the deformation behaviour of stainless-steel workpiece produced by rolling is being investigated under two different conditions using finite element analysis. Narrow profiled and grooved rolls were utilized for the production of tailored blanks with profile in width direction. The material flow and the thickness distribution were investigated during the rolling process for both sets of rolls.

1. Introduction

The weight of automobiles is growing steadily to fulfil the risen demand of cars with high performance, safety structure, additional comfort and large space. As the weight of automobiles increases, fuel consumption as well as the global emission are also increasing. Cars are among the road transport that contributed significantly on the CO₂ emissions [1]. Hence, the request for producing lightweight cars is growing nowadays due to the negative effect of automobiles on the environment.

Tailored blank is one of the approaches in achieving lightweight cars. Tailored blanks are semi-finished parts that are produced by joining sheets having different thicknesses, material and coatings prior to its forming process. Tailored blanks are widely used in car body-in-white for the purpose of weight reduction and safety improvement. The application of tailored blanks in car body parts such as roof rails, center pillar, and etc has shown a significant reduction in the weight of a car. Generally tailored blanks having thickness distribution are produced by joining sheets having different thicknesses together by welding and these blanks are called tailor welded blanks [2]. Localized area requiring high strength or stiffness are made thicker while other areas are made thinner. However, due to the sharp change in thickness from joining, stress concentrations are high and hence formability are reduced.

Gautam and Kumar [3] investigated the formability of tailor welded blanks and uniform thickness blanks of high strength steel. The limiting dome height of the tailor welded are smaller compared to the uniform thickness blank. Karami et al. [4] examined the formability of tungsten inert gas (TIG) and friction stir
welded sheet metals. The formability of the welded joints of carbon steel reduces due to grain growth and microstructural change due to heat effected zone.

Tailor rolled blanks has been used to overcome these problems. Tailor rolled blanks are blanks having thickness variation produced by rolling process. The thickness variations are controlled by changing the gap between rolls. The continuous thickness transition between thick and thin areas eliminates the stress concentration. Tailored rolled blanks have shown good potential in reducing weight and improving crashworthiness of automobile such as center-pillar and cross beam. Han et al. [5] produced tailor-rolled blanks having thickness distribution in both longitudinal and latitudinal directions for an automobile door. Optimization of the thickness distribution of a car part can increase the energy absorptions during impact [6]. Meyer et al. [7] on the other hand increased the maximum drawing depth of a tailored-rolled blanks by controlling the thickness distribution during deep drawing process. Compared with a uniform sheet thickness, tailor rolled blanks offer weight saving and improvement of formability. Kopp and Bohlke [8] develop a strip profile rolling process to control the thickness distribution of the sheets in the width direction where material flows laterally.

Stainless steel has been applied in various applications including aerospace and automobile, medical and construction due to its corrosion resistance. The understanding of the deformation behaviour and material flow of tailor rolled blanks made of stainless steel is important in achieving a desired rolled product in both longitudinal and latitudinal directions. This paper investigates the effect of rolling process on the deformation behaviour of stainless-steel blanks having thickness distribution using a narrow-profiled rolls. Two different rolling conditions were analysed to observe the thickness distribution as well as the flow of material during the rolling process.

2. Rolling process
The rolling process was carried out by using Ansys software to understand the deformation behaviour and material flow of tailor rolled blanks under two different rolling conditions. The material of the workpiece was stainless steel and the properties are shown in Table 1. The thickness of the workpiece is 30 mm. Sets of rollers are designed to control the thickness distribution and material flow in longitudinal and latitudinal directions. The roll shape, geometry and movement are varied for each condition.

| Properties             | Value |
|------------------------|-------|
| Density (kg/m³)        | 7750  |
| Young’s modulus (GPa)  | 193   |
| Yield Strength (MPa)   | 210   |
| Poisson’s ratio        | 0.31  |

For the first rolling process (condition 1), a set of rolls are utilized as shown in Figure 1. To control the material flow in the width direction, narrow rolls are utilized. The rolls shape and geometry are depicted in Figure 2. The width of the rolls is smaller than the width of the workpiece and the rolls are located at the centre of the workpiece. The thickness of the workpiece is 30 mm, while the length and width are 186 mm and 94.6 mm, respectively. The distance between rolls is set to be constant. The displacement of the workpiece was 186 mm towards the rolls.
Figure 1: Condition 1

Figure 2: Rolls geometry for rolling process in condition 1 (in mm)

For condition 2, a set of rolls represented in Figure 3 was modelled. Each roll has the same shape and dimension. The rolls surface covers the width of the workpiece with a narrow groove surface at the centre as illustrated in Figure 4. The roll gap varies with the diameter of the roll at the center and at the sides. The initial workpiece has a uniform thickness of 30 mm with width of 85.4 mm and length of 186 mm. The workpiece was displaced 186 mm towards the rolls. During the rolling process, the gaps between the rolls are increase and hence no change of thickness will be observed at the centre of the rolled blank due to no contact between rolls and workpiece.

Figure 3: Condition 2
3. Result and Discussion

Figure 5 shows the finite element analysis of rolling process for the first condition. The narrow-profiled rolls moved towards the workpiece and compressing the centre portion along the way. Figure 6(a) and (b) shows the equivalent plastic strain of the workpiece and directional deformation in Y axis after the rolling process, respectively. The maximum equivalent plastic strain of 1.315 was observed at the centre of the workpiece of the rolled area.

Figure 5: Rolling process for condition 1

Figure 6: (a) Equivalent plastic strain distribution and (b) directional deformation in Y axis of rolled workpiece for condition 1
The geometry of the rolled workpiece is shown in Figure 7. Spreading was observed where the width increases to 121.6 mm while there is no significant change in length of the workpiece. Material flow transversely during rolling due to lower flow resistance in the lateral direction. The reduction in thickness was observed at the centre where the thickness is 13.8 mm while the thickness on the sides was not affected.

![Figure 7: Geometry of workpiece after rolling process for condition 1(in mm)](image)

The finite element analysis for condition 2 is shown in Figure 8. The workpiece moves towards the roll to obtain the thickness variation during rolling process. Halfway through the rolling process, the rolls gap is increased so no contact between the rolls and workpiece occurs. The equivalent plastic strain is shown in Figure 9(a) where the maximum equivalent plastic strain (0.938) occurs at the centre of the sheet where maximum thickness change occurred. The deformation in Y direction is shown Figure 9(b).

![Figure 8: Rolling process for condition 2](image)

![Figure 9: (a) Equivalent plastic strain distribution and (b) directional deformation in Y axis of rolled workpiece for condition 2](image)
Multiple thickness changes were observed for this rolling condition. Maximum change in thickness occurred at the centre along the length of the workpiece with thickness of 18.8 mm as represented in Figure 10. Both sides of the wall were rolled at the same gap with a thickness of 23.2 mm were observed. The width increases to 136.5 mm due to transverse material flow of the narrow profile at the centre of the rolls. Since the reduction in thickness is larger at the centre, material flows more in the lateral direction compared to the longitudinal direction.

Figure 10: Geometry of workpiece after rolling process for condition 2 (in mm)

Conclusion
Two different rolling conditions were investigated in this paper concerning the roll geometry for accessing the thickness distribution and material flow after rolling process. In each condition, the geometry of rolls was designed to control of thickness distribution of a stainless-steel workpiece. For both conditions it was observed that spreading of the rolled workpiece occur due to the narrow-profiled rolls. Hence a part requiring combinations of thickness with defined cross section in width direction can be achieved by rolling process with controlled flow of material.

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