Study on deformation characteristics of tailored blanks having thickness distribution by successive forging process

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Abstract. Tailored blanks are used in car body-in-white parts for the purpose of reducing weight and improving safety. The reduction of weight in a car decreases the fuel consumption and global emissions. In this study, the deformation characteristics of tailored blanks having thicknesses distribution produced by successive forging were analysed using finite element method. The successive forging produced tailored blanks without joining similar to tailor rolling by means of presses. The blank was locally and repeatedly compressed using upper and lower punches hence compression load is small. The punch geometry was varied to understand the deformation behaviour of the blanks for feeding interval of 10 mm. Waving was observed on the sides of the tailored blanks. The width of the blanks after successive forging increases as the punch width increases and when using an inclined punch.

1. Introduction
Nowadays the demand of lightweight vehicle is increasing due to environmental concern as lightweight vehicle leads to reduced fuel consumption and global emission. Tailored blanks are semi-finished parts that are found in the car body-in-white for the purpose of weight reduction. Tailored welded blanks are generally produced by joining two or more sheets of different material, thickness or coating together by welding process. Welding and thickness differences of tailor welded blanks lead to reduced formability [1]. The sudden change in thickness increases stress concentration and decreases the formability of the tailor welded blank. The non-uniform material deformation of thin and thick blanks and the weld line movement of tailor welded blanks lead to tearing during forming [2].

Tailored rolled blanks on the other hand are tailored blanks having thickness distribution produced by rolling process without the need of joining. These blanks are produced by adjusting the roll gap between rollers to achieve the desired thickness distribution [3-4]. The continuous thickness variation at the transition zones reduces the stress concentration hence improves formability. Han et al. [5] investigated the manufacturing process of tailor rolled blanks having thickness distribution in longitudinal and latitudinal directions. Tailor rolled blanks however, are costly and the supply is limited.

Tailored blanks having thickness distribution in the longitudinal direction was also produced by successive forging [6]. The thickness was controlled by varying the feeding interval and also utilizing the elastic deformation of the tools and press. T. Kuboki et al. [7] produced blanks for micro parts by controlling the feeding interval using successive compression. S Jirathearanat et al. [8] analysed the successive forging process in producing tailored blanks having thickness distribution using wedge-shaped tool. This study analysed the deformation characteristics of tailored blanks having thickness...
distribution under different punch geometry by finite element method. The effect of successive forging on the compression load, thickness change and surface quality were observed.

2. Approach of successive forging of tailored blanks having thickness distribution

Figure 1 shows the steps in successive forging process. It is a repetitive process where a small area of sheet metal is compressed at a time. After compression (see Figure 1(a)), the upper punch is retracted to allow for the feeding of the sheet (see Figure 1(b)) for the next compression (see Figure 1(c)). These steps are repeated until the desired length of compression is achieved. The feeding interval was 10 mm.

Finite element analysis was conducted using ABAQUS to understand the successive forging process and the deformation behaviour of the tailored blanks. To model the successive forging process, for the first compression, the upper punch compressed the blank as shown in Figure 2. Then both of the punches were retracted while the next set of punches move towards the sheet for the second compression. The second set of punches was located 10 mm apart from the first punches based on the feeding interval. The total number of compression was five. The stroke was set to 0.8 mm. The tools were modelled to be rigid while the sheet was elastic-plastic. The sheet was divided into solid hexahedral elements. The material for the blank is Stainless Steel 304 and the properties are as listed in Table 1. The initial length of the blank was 100 mm while the width and thickness of the blank were 20 mm and 3 mm, respectively.

Figure 1: Steps in successive forging process

Figure 2: Successive forging process model
Table 1: Material properties

| Properties              | Value  |
|-------------------------|--------|
| Density (kg/m$^3$)      | 7900   |
| Young’s modulus (GPa)   | 193    |
| Yield Strength (MPa)    | 215    |
| Poisson’s ratio         | 0.29   |

The simulation was conducted for three different conditions as illustrated in Figure 3. For condition 1, the punch width was 30 mm and the punch will compress the entire sheet in the width direction. Both conditions 1 and 2 used flat punches while condition 3 utilized inclined punch. The flat punch width was varied between 5 to 15 mm for condition 2 while for condition 3 the inclined punch angle were varied for $\alpha = 30^\circ$ and $45^\circ$.

![Condition 1](w=30mm) ![Condition 2](w=5,10,15mm) ![Condition 3](alpha=30 and 45)

Figure 3: Successive forging conditions for feeding interval 10 mm

3. Result and discussion

The simulation result for blank after successive forging process for condition 1 is shown in Figure 4. The blank was compressed five times with constant punch stroke. The thickness after compression was 2.2 mm. Waving was observed on both sides of blank causing uneven width distribution due to increase in number of compression and large deformation in the thickness direction. $W_1$ is larger than $W_2$ and $W_3$ because the first compression involves large initial contact area as compared to the following compressions. Hence the compression load is high for the first compression while the load is reduced for the next compression as shown in Figure 5.

![Condition 1](w1=24.48mm w2=23.39mm w3=21.27mm)

Figure 4: Simulation result of blank after successive forging process (condition 1)
Figure 5: Compression load of blanks after successive forging process (condition 1)

Figure 6 shows the simulation result for blanks after successive forging process for condition 2 (flat punch with width 10 mm) and condition 3 (inclined punch with 45° angle and width 10 mm). The reduction in thickness occurred at the centre of the blanks and waving on both side of the blanks are minimum as compared to condition 1. The inclined punch produced more spreading with less elongation. The inclined punch allows more material to flow towards the side of the blank and hence increases the width.

![Simulation result of blanks after successive forging process for conditions 2 and 3](image)

Figure 6: Simulation result of blanks after successive forging process for conditions 2 and 3

Figure 7 shows the width of the blanks after successive forging for different punch width and angle. As the punch width increases the spreading of the blank increases. The inclined punch shows larger width distribution after five compressions as compared to the flat punch.

![Cross section](image)

(a) Condition 2 (flat punch with width 10 mm)

(b) Condition 3 (inclined punch with 45° angle and width 10 mm)
4. Conclusion
Simulations on successive forging of tailored blanks having thickness distribution by finite element analysis have been conducted. Three forging conditions with different punch geometry were studied to understand the deformation characteristics of the tailored blanks. During successive forging, the compression load is small due to small contact area between punch and blank. However, waving was observed on both sides of the blanks. Waving was reduced for conditions 2 and 3 due to smaller punch width. This uneven width distribution will be further investigated in the future study. The blank spreads more as the punch width increases and when using an inclined punch.

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