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Simulation of press-forming for automobile part using ultra high tension steel

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Abstract. In recent years, ultra high tension steel has gradually been used in the automobile industry. The development of press-forming technology is now essential by reason of its high productivity and high product quality. In this study, tensile tests were performed with a view to understanding the material properties. Press-forming tests were then carried out with regard to the behaviors of spring back and deep-drawability, and manufacturing a real product. The ultra high tension steel used in the experiments had a thickness of 1 mm and a tensile strength of 1000 MPa. Finally, simulations of spring back, deep-drawability and manufacturing a real product in ultra high tension steel were conducted and evaluated in order to calculate the optimum-press-forming conditions and the optimum shape of the die. FEM with non-linear and dynamic analysis using Euler-Lagrange's element was used for the simulations. It is concluded from the results that (1) the simulations conformed to the results of the experiments (2) the simulations proved very effective for calculating the optimum press conditions and die shape.

1 Introduction

In the 21st century, all industrial products, automobiles, personal computers, cellular phones and so on, must be manufactured with attention to both energysaving and environmental considerations. Recently, magnesium alloys have been used for those products. [1] However, some parts of the products are gradually being changed to ultra high tension steel because of the low productivity and low reliability of magnesium alloys; whereas the ultra high tension steel is greater strength than 1000 MPa; it has high reliability and high recyclability, and products made from it have the advantage of being very light in weight. However, press-forming this material is difficult because of its high yielding stress and low ductility: particularly, the thinner the work piece, the larger its spring back. In addition, manufacture of the molding die requires many corrections of the die, and so it is very difficult to reduce manufacturing costs or to shorten the period of development for new products. [2–4]

In this research, simulation of press-forming for automobile part using high tension steel was investigated. Tests at various temperatures and tensile speeds were firstly performed in order to understand the behavior of the material. Press-forming tests were then performed with the purpose of understanding the behaviors of spring back and deep-drawability, and the conditions governing the manufacture of real products. Finally, simulations of the previous press-forming tests on the ultra high tension steel were conducted and evaluated. FEM (LS-DYNA) with non-linear and dynamic analysis using Euler-Lagrange's element was used for the simulations. The efficacy of these simulations for calculating optimum press conditions was evaluated. In addition, these simulations were used to achieve the optimum design of a press mold for this material and evaluated for practicability.

2 Material behavior of ultra high tension steel and analytical model

2.1 Material behavior

Tensile tests at various temperatures and tensile speeds were performed. The test piece material was CHLY 980 [5] produced by NKK Co. Ltd. The test piece conformed to standard No.13 (JIS Z 2201) with a gauge length, width and thickness of 50 mm, 12.5 mm and 1.0 mm respectively. The tests were carried out at temperatures of 293 K, 423 K and 523 K. Tensile speed was normally $8.3 \times 10–2$ mm/s; however, at 293 K tensile speeds of $8.3 \times 10–2$ mm/s, 0.25 mm/s, 1.0 mm/s and 2.0 mm/s were used.

The dependences of tensile strength and elongation on temperature are shown in Fig. 1, for test pieces at three different orientations relative to the sheet material's rolling direction. In the figure, "0 rad" indicates that the length of the test piece is parallel to the rolling direction. Elongation is constant from 293 K to 423 K, reaching 60% at 523 K. Rolling direction influences both tensile strength and elongation by about 10% and 15% respectively.

The relationships between actual stress and strain temperatures are shown in Fig. 2. Strain was measured by displacement of the cross head. True stress was measured from the tensile load and the cross-section area of the necked part of the test piece. Test piece orientation was 0 rad to the rolling direction. It can be seen that temperature had very little influence.

The relationship between stress and strain at four tensile speeds is shown in Fig. 3. Temperature is 293 K. Test piece orientation is as in Fig. 2. Tensile speed ranges from $8.3 \times 10–2$ mm to 2.0 mm/s. These speeds were used for the punch speed in the previous experiments. This range of tensile speeds did not influence the relationship between stress and strain. The strain rate had is no influence in this region and was therefore neglected in the later simulations.

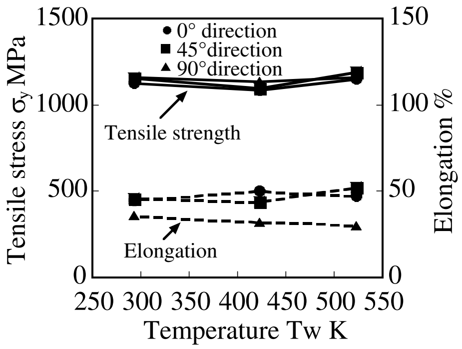


Fig. 1. Relationships between temperature of test piece and tensile strength and elongation.

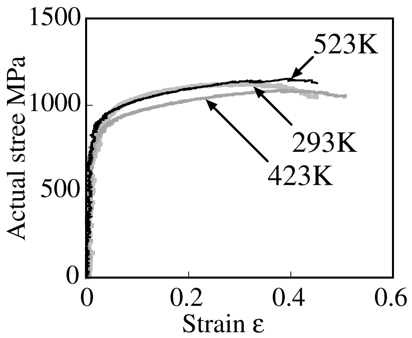


Fig. 2. Relationship between actual stress and strain on test piece at various temperatures.

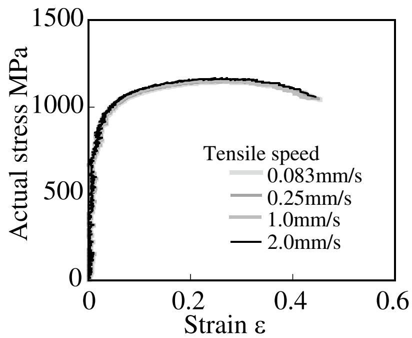


Fig. 3. Relationship between stress and strain on various tensile speeds (Workpiece temperature is 293K).

2.2 Analytical model

The simulations used non-linear dynamic FEM analysis using LS-DYNA. In LS-DYNA, an analytical model – in this case equation (1) was used to express the previous behavior of the ultra high tension steel.

$$\sigma_y = (A + B\varepsilon^N) \tag{1}$$

where σ_y is yield stress, ε is strain and A, B and N are constants. These values were calculated in accordance with Fig. 2 and are shown in Table 1. In the table the relationships between the temperature of the test piece and the yield stress or limit of elongation are also shown. The analytical model incorporating both yield stress and limit of elongation was used to judge whether the press-forming was successful or not in the simulation using LS-DYNA.

Table 1. Each constant and limit value of fracture for the ultra high tension steel.

Johnson/Cook's constants			limit value of fracture		
A –	B –	N –	σy Mpa	ε –	Tw K
550	1070	0.3	1149	0.451	293
			1115	0.506	423
			1277	0.603	523

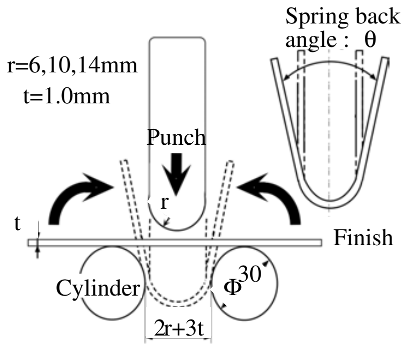


Fig. 4. Experimental set-up of bending test.

3 Simulation of spring back

Bending tests with supports at three points were first performed to understand the phenomenon of spring back. Then simulations using LS-DYNA with the analytical model were used to calculate the phenomenon, and the efficacy of the simulations was evaluated.

The experimental set-up is shown in Fig. 4. The material of the test piece was identical to the previous test. The test piece conformed to standard No. 3 (JIS Z 220) with a gauge length, width and thickness of 200 mm, 15 or 30 mm and 1.0 mm respectively. Test piece orientation was 0 rad to the rolling direction. The tests were carried out at temperatures of 293 K, 423 K and 523 K. Punch speeds were 5 mm/s, 15 mm/s and 120 mm/s. Two sheets of teflon, 0.05 mm thick, were placed on both surfaces of the blank for lubrication. The simulation model had 3584 nodes and 2342 elements, and its shape and size were very similar to the experimental equipment.

Both experimental and calculated results with respect to the bending tests are shown in Fig. 5. The influences of the radius of the punch, the temperature of the test piece, and the punch speed could be calculated very accurately in the simulation: the accuracy of the simulations was about 85%. The reaction forces of the punch in the simulations are compared with those in the experiment in Fig. 6. The forces in the experiment and the simulations corresponded very well. Therefore, the simulations were effectively used in preparing the press for real production at optimum capacity.

4 Simulation of deep drawing

A 784 kN capacity hydraulic press was used for deep drawing cylindrical blanks. The relationship between forming

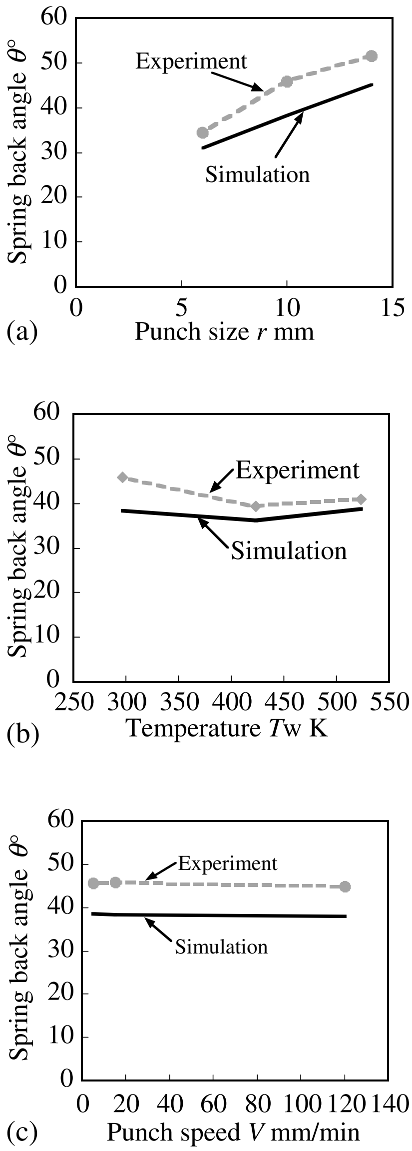


Fig. 5. Experimental and calculated results. (a) Influence of the punch size, (b) Influence of temperature of the test piece, (c) Influence of the punch speed.

conditions and limit drawing ratio (LDR) was investigated. A blank holder force of 39.2 kN was created by oil hydraulics. The punch was 60.4 mm in diameter with a 6.0 mm corner radius. The die opening was 62.5 mm in diameter with a 6.0 mm corner radius. The blank was a 1.0 mm-thick disc of ultra high tension steel (CHLY 980(5) produced by NKK Co. Ltd). Two sheets of teflon, 0.05 mm thick, were placed on both surfaces of the blank for lubrication. Temperatures of the blank were 293 K, 373 K and 523 K. Punch speed was 2.0 mm/s.

The simulation model for deep drawing with ultra high tension steel is shown in Fig. 7. The model consists of a punch, a die, a blank holder and a blank of the same size as the experimental mold. A quarter model of the experimental mold was used to shorten the calculation time. The punch, the die and the blank holder are defined as rigid bodies (no deformation) in the simulation. The die is perfectly fixed and both the punch and the blank

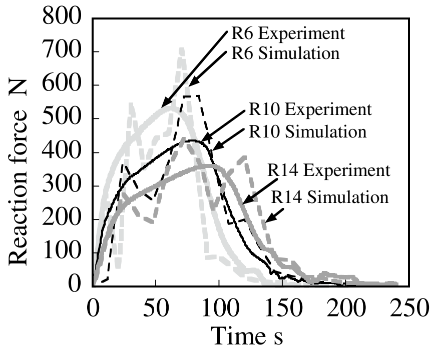


Fig. 6. Reaction force of the punch in the bending tests (experiment and simulation).

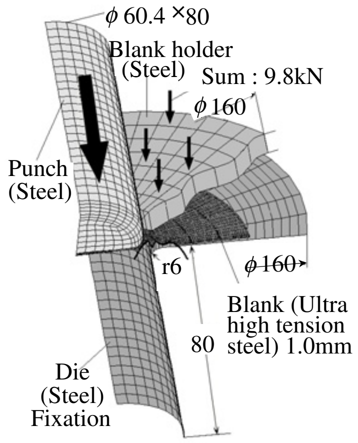


Fig. 7. Schematic view of model for deep-drawability in FEM.

holder can move only axially. Blank holder force is 9.8 kN (a quarter of 39.2 kN). The coefficient of friction between the blank and the blank holder or the die is 0.05, which is the experimental value [6]. Blank thickness is 1.0 mm. It is modeled as a solid element with flow stress dependent on strain in the manner proposed by equation (1). The simulation using LS-DYNA was used to calculate the deep drawing, and the efficacy of the simulation was evaluated.

The results of the comparison between the previous experiment and the present simulation of deep drawing are shown in Fig. 8, where the symbol ○ means success while × means fracture of the blank during deep drawing. In the experiment, DR values (= blank diameter / punch diameter) of 2.0, 2.1 and 2.2 were used. In the simulation, DR values were increased from 1.5 to 2.3 in steps of 0.1. The solid line is the border between success and fracture in the experiments and the painting region is the border in the simulations. When the temperature is at 423 K, the limiting DR value increases slightly and a deeper product is formed. The difference between the experiment and the simulation is about 85%. This is due to the latent error of the FEM software used and the latent error in the dispersion of material properties.

Figure 9 shows for the distribution of strain in the blank with a final stage 2.2 DR value. At this point, the stress in the blank is a safe value. However, strain in the blank is 0.45(45%), which is at the limit of elongation, and fracture

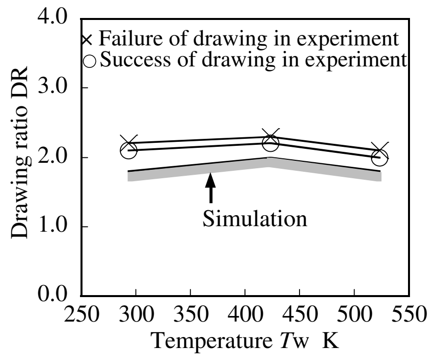


Fig. 8. Relationship between die temperature and DR value in the experiment and the simulation (Punch temperature 353 K).

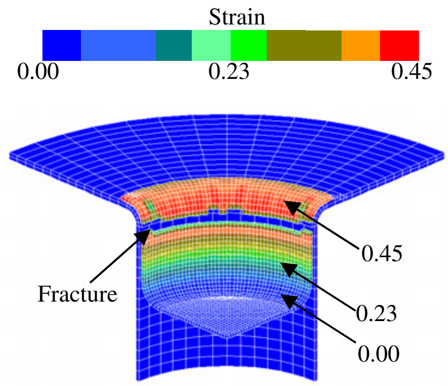


Fig. 9. Strain distributions in the simulation of deep drawing (FEM simulation).

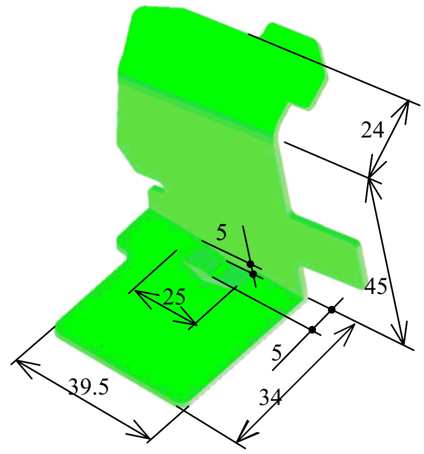


Fig. 10. Schematic view of the product.

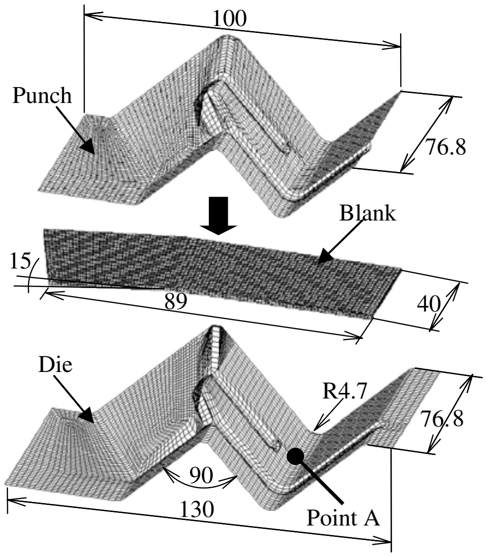


Fig. 11. Schematic view of model for press forming in FEM simulation.

occurs. In this condition, no further increase in drawability could be gained by further changes of temperature in either the die or the punch. Thus, from this simulation, the limited DR value is 2.0, caused by the limit to elongation in the blank. It can be understood from these figures that the optimum drawing conditions and the optimum die shape and size for a deeper product can be decided by investigation of the distribution of both stress and strain shown in Fig. 9 in conjunction with the tensile strength and elongation data. The simulation of the deep drawing of the ultra high tension steel blank was been effective in determining the optimum drawing conditions. The results of the simulation will enable both cost and preparation time to be decreased.

5 Simulation of manufacture of automobile product by press-forming

Finally, the relationship between the experiment and the simulation of the manufacture of an automobile product by press-forming was investigated to evaluate the industrial efficacy of the simulation.

A schematic view of the real product used for investigation is shown in Fig. 10. The product is both bent and contracted in area in this process: a blank workpiece is first produced and the subsequent procedures involve bending, perforating and folding. There are seven processes in all. The blank was a 1.0 mm-thick disc of ultra high tension steel (CHLY 980(5) produced by NKK Co. Ltd). A 784kN capacity press with servo control was used to press form the product. Punch speeds were 78 mm/s and 330 mm/s, and there was a stoppage for 1 sec. at the dead point. The lubricant was No. 30 motor oil with 30%wt of sulfide of molybdenum. The temperature of the blank was 293 K.

The simulation model for press-forming the real product is shown in Fig. 11. The model consists of a punch, a die and a blank of the same size as the experimental mold. The punch and the die are defined as rigid bodies (no deformation) in the simulation. The die is perfectly fixed and the punch can move only up and down. The coefficient of friction between the blank and the die is 0.10, which is the experimental value [6]. Blank thickness is 1.0 mm. It is modeled as a solid element with flow stress dependent on strain in the manner proposed by equation (1). The simulation using LS-DYNA was used to calculate the deep drawing, and the efficacy of the simulation was evaluated.

The results of the comparison between the experiment and the simulation regarding the shape of the bend are shown in Fig. 12. The shape was measured by a coordinate

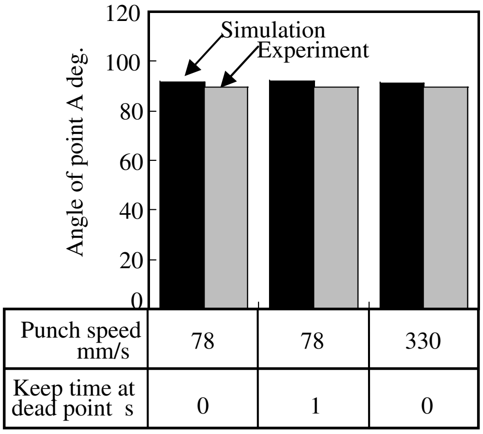
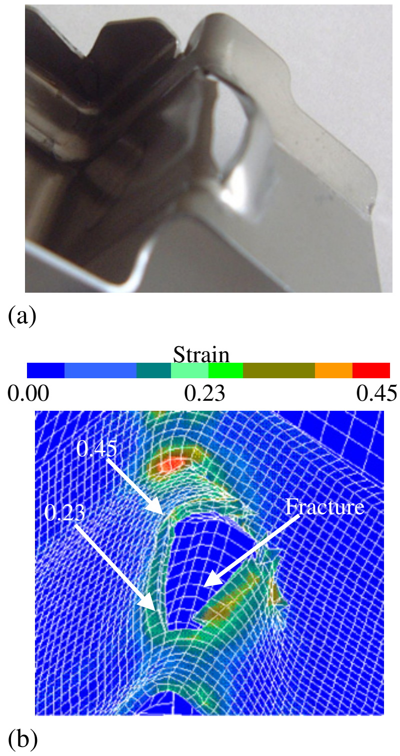


Fig. 12. Accuracy of the product in the measurement and the calculation.



0.45

Fig. 13. Facture of contraction area in the product. (a) Photograph of fracture, (b) Strain distributions on the simulation for press forming in FEM simulation.

measuring machine. The punch speed and stoppage time had no influence at the dead point. The difference between the experiment and the simulation is about 5%.

The results of the comparison between the experiment and the simulation in terms of the contraction of area are shown in Fig. 13. Fracture occurs in all products under various press conditions in both the experiment and the simulation. In the simulation, the stress on the periphery of the fracture is 1150 MPa and the condition of fracture is perfectly satisfied.

The elongation of the material is about 45% and very small, and the stress was suddenly increased by a small change of strain. Therefore, this contraction, which was marked by a large degree of deformation, was caused by the material's lacking both strength and elongation.

Finally the contraction was broken by this lack of strength, as shown in Fig. 13. There is no simple way to repair the product such as changing the temperature of the blank or changing the punch speed because of the material properties. In this case, the design of the product and the die should be changed in order to manufacture a perfect product.

Thus the simulations described in this paper have the following: shortening of the development period for the new product; developing the product with high confidence; simulating the optimum design of the optimum conditions for press-forming without error or repair.

6 Conclusion

Simulation of press-forming of ultra high tension steel has been conducted and evaluated in order to calculate the optimum press conditions and optimum design of a forming model. It is concluded from the results that (1) the simulation conformed to the results of the experiments. The difference between experiment and simulation was roughly from 5% to 10%, (2) the simulation proved very effective for calculating the optimum conditions regarding both press and die.

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