DP1180 Material Calibration Between Sheet Metal Simulation and Prototype

L. I. U. Rongfeng and L. I. Dayong

Abstract One of the advanced high-strength steel materials, DP1180, is widely used in the automobile industry so as to satisfy lightweight demands in China mainland market in recent years. Formability and springback problems are very serious in manufacturing. To shorten die development lead time for hard material in mass production, sheet metal forming simulation and its accuracy are becoming essential. After conducting uniaxial tension, compression–tension experiment and fitting a database for real sheet, using Yoshida–Uemori material model in integrated sheet metal simulation system JSTAMP/NV, the sprinback evaluation result is improved to close with prototype result of one typical frame part. Through this study, it is found that proper material model and real material database have much influence on the simulation accuracy for DP1180 material.

Keywords Sheet metal simulation · Material model · Material database

Introduction

Advanced High-Strength Steel (AHSS) with ultra-high strength up to 1180 MPa by cold forming has been increasingly employed in automotive bodies so as to reduce the white bodies' weight and improve crashworthiness as well. The strong requirements from industries pushed the development of material makers to deliver more strong materials. On the other hand, it is a really big challenge for die shop and part suppliers because it is much difficult to design and make parts than usual. Simulation needs for AHSS are coming up and the problem is accuracy improving for formability and springback prediction. Generally, the material property and material model are important factors to improve simulation accuracy if not considering much

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of real manufacturing conditions. In this paper, there was a calibration between simulation and prototype focus on DP1180 material database and material models. First, there was an investigation in China mainland market. It was found that Bao Steel's DP1180 was a major AHSS material in mass production during the past 3 years. Then uniaxial tension and Compression–Tension (CT) experimental tests occurred in a particular test method. Based on those raw test data, a Yoshida–Uemori (YU) material database was fit for integrated simulation system named JSTAMP/NV. Simulation result compares between YU material model and scanned prototype panel. It was found that about 20% springback accuracy came up after material database and model calibration.

AHSS Questionnaire and DP1180 Material Test

In July 2019, a questionnaire survey occurred so as to find out the majority of AHSS makers and the most widely used AHSS materials in China market. Survey targets are OEM makers and major stamping part suppliers in mainland. There were 11 valuable feedbacks from 12 companies. It was found that 68% of OEM makers or suppliers had the experience to use AHSS during the past 3 years. For 980 and 1180 MPa grades, the survey shows that there are totally 24 kinds of AHSS materials and the thickness varies from 1.0 mm to 2.3 mm. Nineteen materials, about 85% of AHSS in current mass production, are come from Bao Steel and the others are imported from Japanese or American steelmaker outside mainland. In future, using local AHSS is a trend and the percentage is expected to be higher due to cost performance.

Considering most widely used AHSS material during past years, DP1180 steel from Bao Steel is studied. Test was conducted in professor Dayong Li's lab, located at Shanghai Jiaotong University. In order to measure the mechanical properties for material modeling, uniaxial tensile test, CT test, and Loading–Unloading–Loading (LUL) test are performed, respectively.

All CT test samples are machined along RD (rolling direction), and all tests are performed at the strain rate of 10^{-4}. The CT tests are conducted with the assistance of an anti-buckling device, which is shown in Fig. 2. The side support is provided by two plates, against which the springs act. In order to enlarge the compression range before buckling, an optimal specimen is utilized [1], as shown in Fig. 2. A 0.2 mm thick Teflon film is utilized on each side of the specimen to reduce friction force. A non-contact EIR laser extensometer (LE-05) is used to measure strain in the CT test, as shown in Fig. 1. The measurement of sample deformation over the gage length is realized by receiving the reflected signals from the two parallel tapes bonded to the edge of specimen. In the CT test, the specimens are compressed to a pre-strain and then reloaded reversely until fracture. The friction compensation of CT test procedure has been described in details [1].

Fig. 1 CT test device

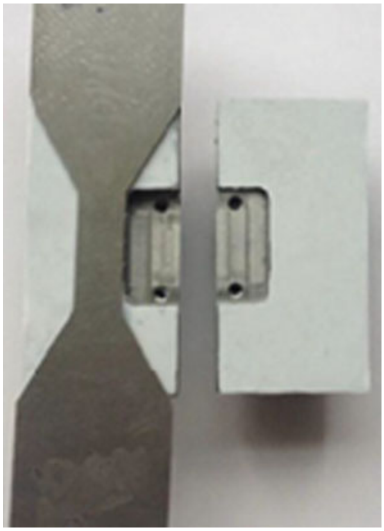

Fig. 2 CT specimen and jig

Figure 3 shows test uniaxial tension results. For three directions as RD, Transfer Direction (TD), and 45-degree (45°) direction, all curves show the different specimens and the fracture occurred at about 8% level. The 45° specimens seem to crack a litter earlier than RD and TD direction. The reproducibility of uniaxial test is pretty well.

In Fig. 4, the experimental curves for a typical LUL scheme of DP1180 are shown. Starting from 0, then loading to 2, 4, 6, and 8% engineering strain, each followed by an unloading–reloading loop. Due to nonlinearity of the unloading and reloading, significant hysteresis loops exist, corresponding to the variation of elastic modulus.

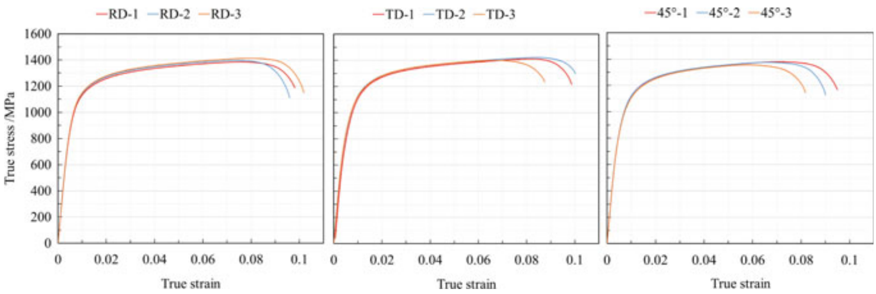

Fig. 3 True stain true stress curves of RD, TD, 45°

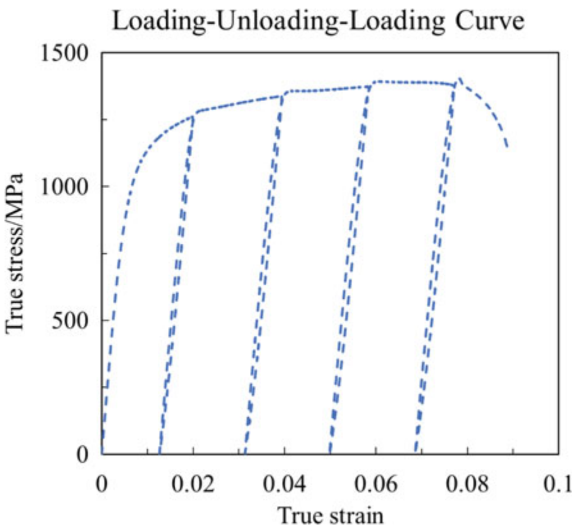

Fig. 4 True stain true stress curves of LUL test

CT experimental curves are shown in Fig. 5. Two percent pre-strain at compression at first and then unloading to 0, continuously tension until to fracture. It should be noted that bulking is occurred during compression because DP1180 is a very hard material. For the same reason, there are no other pre-stain levels in CT experiment in this paper.

In Fig. 5, CT test occurred at 2 % pre-stain, and crack strain became 10% which is higher than uniaxial test in RD, 45° and TD. The reason for this phenomenon is not clear and is going to be studied through more material tests in future.

The Lankford value of R is 0.592, 0.796, and 0.840 for RD, 45° and TD, respectively. All values are measured at 4% engineering strain using separate specimens from uniaxial and CT specimens.

The plastic strain-dependent Young's modulus was measured from the sequential LULexperiment (see Fig. 4). The variation of Young's modulus (slope of unloading

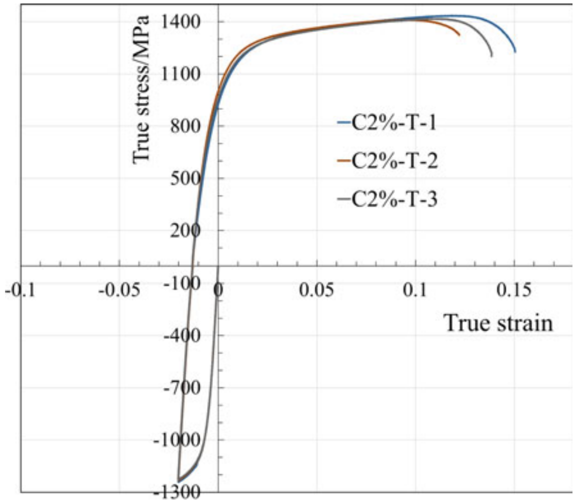

Fig. 5 True stain true stress curves of CT test at 2% pre-strain

stress–strain curve) is expressed by the following Eq. (1) which is suggested by Yoshida [2]:

$$E = E_0 - (E_0 - E_\alpha)(1 - \exp(-\xi \varepsilon)) \quad (1)$$

where *E*o denotes Young's modulus for a virgin material and *Ea* is its asymptotic value at an infinitely large plastic strain. It is a material parameter representing the variation of Young's modulus with increasing the effective plastic strain ε. Material constants in Eq. (1) were determined from *E* versus ε diagram (see Fig. 6) and they are listed in Table 1.

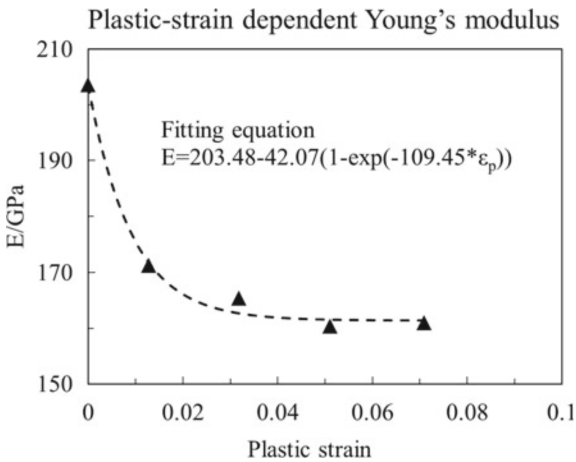

Fig. 6 Plastic strain-dependent Young's modulus

Table 1 Plastic strain-dependent Young's modulus

$E0$ (GPa)	Ea (GPa)	ξ
203.5	160.8	109.45

Table 2 YU material model parameters of DP1180

Y (yield stress) (MPa)	$a0$ (initial value of $a = B–Y$) (MPa)	$C1$	$C2$	$b$sat (MPa)	m	Rsat (MPa)	h
800	429.0	420	180	95.0	15.0	50.0	0.2

Material parameters of plastic strain-dependent Young's modulus.

Material parameters identification was conducted by the fitting tools MATPARA which is able to easily fit YU material model parameters for DP1180 as shown in Table 2.

Simulation in JSTAMP/NV Using YU Material Model

Material Model

Yoshida and Uemori proposed a model of large strain cyclic plasticity that well describes the stress–strain responses in reverse deformation [2, 3, 4], as well as cyclic hardening characteristics. The key capability of YU model is the transient Bauschinger deformation characterized by early re-yielding and smooth elastic–plastic transition with a rapid change of work hardening rate. The permanent softening is characterized by stress offset observed in a region after the transient period. In addition, plastic strain-dependent Young's modulus and work hardening stagnation appear at a certain range of reverse deformation. Strain-range and mean-strain dependency of cyclic hardening, e.g., the larger the cyclic strain range the larger the saturated stress amplitudes.

It is noted that YU material model has been integrated into JSTAMP/NV. For JSTAMP users, a standard solution is recommended for AHSS springback simulation in sheet metal manufacturing field.

Simulation Result

A typical frame part using DP1180 was studied in this paper as shown in Fig. 7. Two material models are compared in sheet metal simulation. One is one of the common material models Hill'48. The other is YU model. Both of them use Hill's function as yield function and work hardening model is isotropic hardening in Hill'48

Fig. 7 Frame part of DP1180 by cold forming

and nonlinear kinematic hardening in YU model, respectively. Simulation model information is listed in Table 3.

Three stages to make the part are Bending, Flanging, and Cut/Restrike sequentially. To compare sheet simulation with scanned panel, geometry evaluation contour is used which shows the geometry coincidence percentage. Figs. 8, 9 and 10 show the geometry evaluation contour results between Hill'48 model and prototype panels as well as YU material model with scanned prototype panels. As a common springback evaluation method in industry, the area percentage of the part under ± 1.0 mm comes up to 79.6% in Bending stage, 73.7% in Flanging stage, and 83.2% in Cut/Restrike stage. However, in Hill' 48, the same value under ± 1.0 mm remains at 69.6% in Bending, 38.7% in Flanging, and 44.7% in Cut/Restrike stages, respectively.

The Hill'48 model overestimated that springback and YU model result is closer to prototype panel. Using the experimental data and fitting the material database, YU material model is able to realize bending and reverse-bending behavior during the Bending, Flanging, and Cut/Restrike stage processing. This is the main reason that YU model simulation result is closer to the prototype panel.

From this study, the geometry evaluation result shows 10 ~ 30% springback accuracy up during Bending, Flanging, and Cut/Restrike stages just by changing the

Table 3 Simulation model information

FEM code	JSTAMP/NV2.17 (Solver: LS-DYNA R10)
Basic formulations	Forming: Dynamic Explicit (LS-DYNA); Springback: Static implicit (LS-DYNA)
Element/Mesh technology	Full integrated Sheet Element
Contact property model	Penalty Method: Node to Surface
Friction formulation	Coulomb's friction law, friction coefficient 0.13

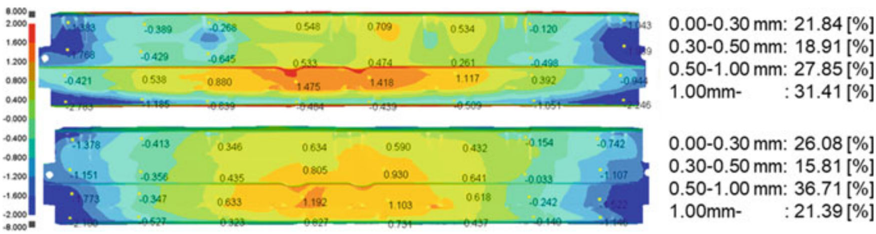

Fig. 8 Geometry evaluation contour of Bending stage by Hill'48 (upper) and YU model (lower)

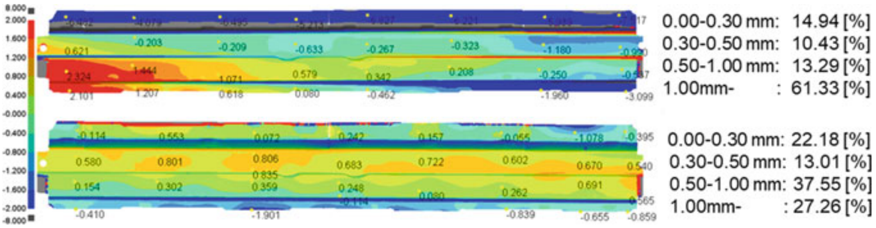

Fig. 9 Geometry evaluation contour of Flanging stage by Hill'48 (upper) and YU model (lower)

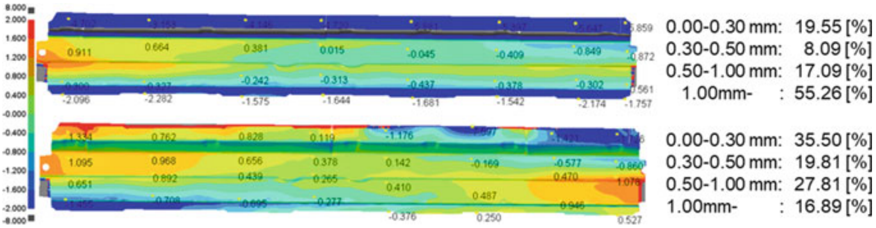

Fig. 10 Geometry evaluation contour of Cut/Restrike stage by Hill'48 and YU model (lower)

material model and material database. It is a practical way to improve sheet metal simulation accuracy for AHSS material. Considering the cost of uniaxial and CT experiments may not be acceptable for most of the industrial users, stimulating more AHSS material databases of mass production material in software will be one option.

Conclusions and Next Step

To perform calibration of sheet metal simulation for DP1180 steel, uniaxial tension, CT, and LUL experiments were performed. After fitting a YU database, it was used in JSTAMP/NV. The simulation result of springback shows that YU model and YU database are helpful to improve sheet metal simulation accuracy even for the current ultra-high-strength material DP1180. On the other hand, there is still left about 20–30% deviation between simulation and prototype. Tool deflection coupling effect is supposed to take much influence. That is going to be studied on the same model next.

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