The Influences of Tensile Test Directions and Yield Stress Selections on the FE Results of TBF1180 U-Channel

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Abstract

There is no standard on how to decide the yield stresses of Advanced High Strength Steel (AHSS) sheet materials. Is it necessary to decide the accurate yield stresses of AHSS materials in stamping FE simulations? A U-Channel part and TBF1180 material were selected to study this question.TBF1180 is a new third generation AHSS sheet metal. Three uniaxial tensile tests on 0^o (L), 45^o (D) and 90^o (T) directions with respect to the rolling direction are available for this material. All the three uniaxial tensile test stress-strain curves and three yield stresses for each tensile curve were used in FE simulations. The simulation results show that the different tensile curves and different yield stresses have the same Draw-Ins. The three tensile curves have limited differences in forming force (2% difference) and springbacks (about 5% difference). The three given yield stresses have very little forming force differences (less than 0.6%), but have big springback differences (up to 46%). Therefore yield stress has big influence on springbacks. What is the relationship between the yield stress and the springbacks and how to decide a yield stress for better formability and springbacks prediction need more study.

Introduction

Uniaxial tensile test is an ISO standard and the simplest material test method. It is the first choice in sheet metal stamping industry to get a few useful material parameters for stamping FE simulations. Because the tensile test data have been successfully used for many sheet metal FE simulations, the current stamping simulation software, LS-DYNA®, AutoForm® and PAMSTAMP®, all developed material models to directly use uniaxial tensile test data. To transfer the tensile test data into the material models used in the software, two things are need to do: (1) Extend the tensile true stress-strain curve to higher strain level; (2) Transfer the tensile true stress-strain curve into true stress-plastic strain curve (SPSC).

Because of necking and fracture in uniaxial tensile test, it is impossible to get the stress-strain curve in higher strain zone. In the real stamping industry, the true strain levels are often above the tensile test strain ranges. Therefore, to reflect the real situations, it is necessary to extend the tensile true stress-strain curve to higher strain ranges. How to extend the stress-strain curve more realistically, many people have done a lot of works. A. Nasser [4], etc. used Viscous Pressure Budge to extend the stress-strain curve.

One easy and widely used method to extend the tensile stress-strain curve is to extrapolate the curve by power law, and it was used in this paper.

To transfer the tensile true stress-strain curve into true SPSC curve, the elastic strain is removed from the tensile stress- total strain curve. Here the elastic strain is the strain corresponding to the yield stress. For low carbon and low stress sheet metals, it is easy to find the yield stresses and the elastic strains. For AHSS sheet metals, however the transitions between the elastics and the plastics are very smooth. Therefore it is very difficult to find the yield stresses. In addition, there is not much information about how to decide the yield stress on an AHSS tensile stress-strain curve. Is it very important to find the accurate yield stress for a FE material model? What are the influences of the yield stress differences on the simulation results?

In addition, because sheet metals usually have planar anisotropy properties, sheet metal uniaxial tensile tests are often taken at 0^o, 45^o and 90^o with respect to the rolling direction. There are no information on how to use the three tensile test stress-strain curves in LS-DYNA, AutoForm and PAMSTAMP.

TBF1180 is a new AHSS sheet metal. Based on the tensile tests on 0^o, 45^o and 90^o directions, the influences of tensile test directions and yield stresses on the FE results are studied in this paper.

Tensile Test Data Analyses

Table 1 is the material property parameters of TBF1180 tensile tests. Three samples were taken in three directions with respect to the rolling direction, 0^o or longitudinal direction – noted L; 45^o or diagonal direction – noted D; 90^o or transverse direction – noted T. The tensile tests were done by GM material laboratory.

Table 1. TBF1180 tensile test material parameters on three directions

Specimen ID	Thickness (mm)	UTS (MPa)	0.2% YO (MPa)	% UE	% E_f	K Value	N Value	r-Value
TBF1180-L1	1.4	1229.2	994.6	9.3	16.1	1685	0.09	0.85
TBF1180-T1	1.4	1247.7	1017.1	5.9	11.6	1589	0.06	0.66
TBF1180-D1	1.4	1227.1	1015.4	7.3	13.5	1588	0.07	0.79

Here YO is the yield stress of 0.2% plastic strain.

The three uniaxial tensile true stress-strain curves of TBF1180 are shown in Figure 1. The tensile curve L1 is at the lowest position, and T1 is at the highest position. D1 is slightly higher than L1. All the three curves are running fairly parallel during uniform elongation, and this shows the n-values on three directions are fairly close – 0.09 on L direction, 0.06 on T direction and 0.07 on D direction.

To understand how much difference between the tensile curves, the true stress of tensile curve L1 was added 4%, and the curve with 4% off (red color curve) was plotted in Figure 1. The tensile curves – T1 and D1, are between L1 and L1 with 4% off. Therefore, the maximum difference among L1, T1 and D1 is about 4% of L1.

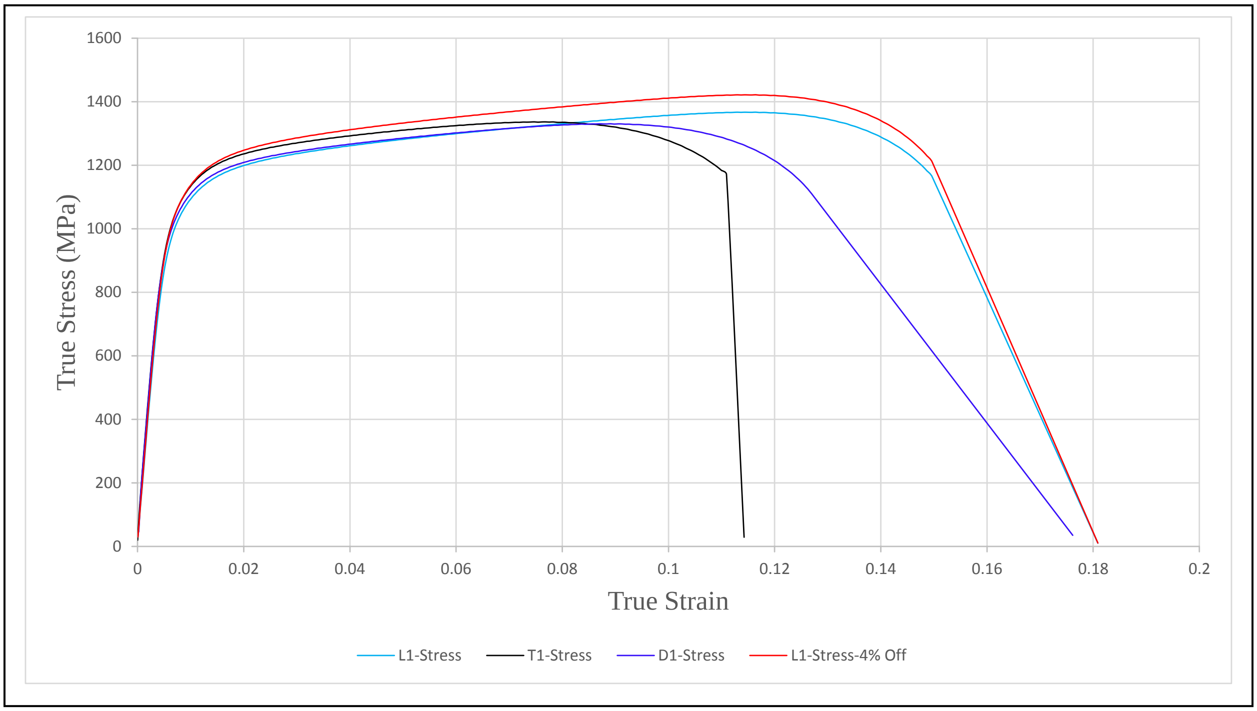

Figure 1. Tensile Test True Stress-Strain Curves

Tensile Test Data Application

To use the tensile test data directly, the first thing is to extrapolate the tensile curves to high strain level. The three tensile curves – L1, T1 and D1, were extrapolated to strain 0.5 by power law in this paper (Figure 2a – 2c). The uniform elongation portions of the three curves were kept, and the other portions were added by power law. The power law parameters are close to the values in Table 1.

The second thing is to transfer the tensile test true stress-total strain curves into true stress-plastic strain curves (SPSC). The true SPSC curves are derived from the true stress-total strain curves by removing the elastic strains. One of the purposes of this paper is to study the influences of yield stresses on simulation results. Therefore, three different yield stresses were selected for each tensile curve, and then the corresponding elastic strains could be find on the tensile curves (L1, T1 and D1). The stress with plastic strain equal to 0 on SPSC curve is the yield stress. In LS-DYNA MAT-37, the yield stress is decided by the true SPSC curve.

To study the influences of yield stresses, three yield stress levels were selected: YH – 90% of the 0.2% YO in Table 1; YM – 75%, and YL – 60%. In addition, to study the influences of material directions, the three tensile test curves: L1, T1 and D1, were used respectively. The yield stresses selected and the corresponding elastic strains for the three tensile curves are shown in Table 2.

From each tensile test curve, three true SPSC curves are derived, like L1-YH (L1-YH-SPSC), L1-YM (L1-YM-SPSC) and L1-YL (L1-YL-SPSC) derived from TBF1180-L1. To show the differences among YH-SPSC, YM-SPSC and YL-SPSC, the three SPSC curves for L1, T1 or D1 were overlaid in Figure 2a, Figure 2b and Figure 2c, respectively. From the Figure 2a-2c, there are slight differences among YH-SPSC, YM-SPSC and YL-SPSC in about 0.00 to 0.03 strain range. Above 0.03 strain level, they are almost the same for each of L1, T1 or D1.

Table 2. Selected Yield Stresses and Elastic Strains

Tensile Test Name	YH (90% $YO_{0.2}$)		YM (75% $YO_{0.2}$)		YL (60% $YO_{0.2}$)	
	Yield Stress (Mpa)	Elastic Strain	Yield Stress (Mpa)	Elastic Strain	Yield Stress (Mpa)	Elastic Strain
TBF1180-L1	895.14	0.005314	745.95	0.003986	596.76	0.003029
TBF1180-T1	915.39	0.005043	762.825	0.003742	610.26	0.002796
TBF1180-D1	913.86	0.005101	761.55	0.003743	609.24	0.002799

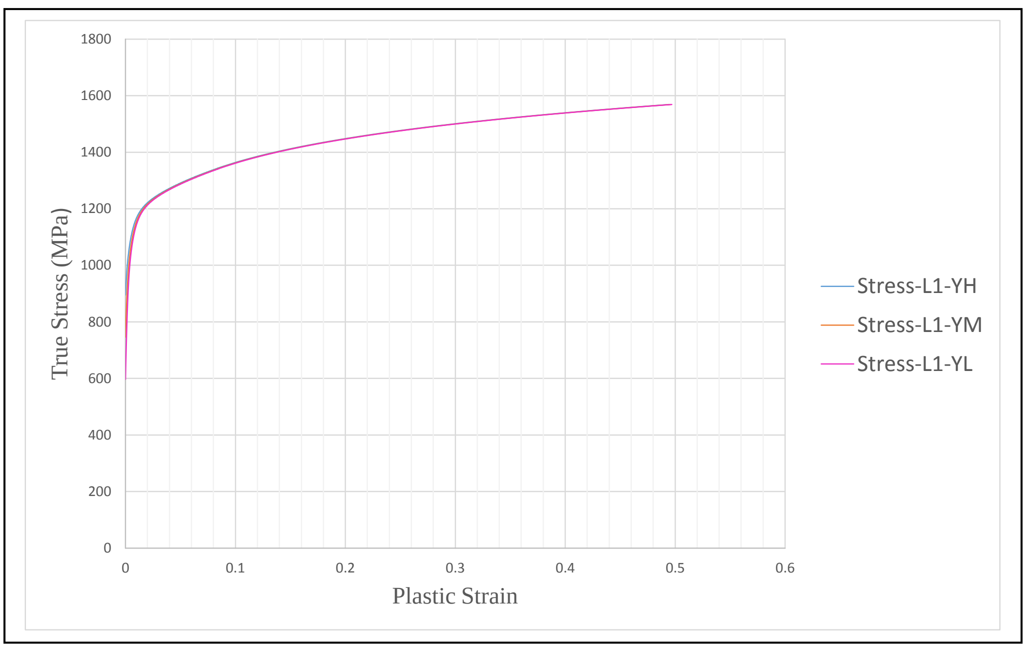

Figure 2a. L1-YH, L1-YM and L1-YL SPSC Curves

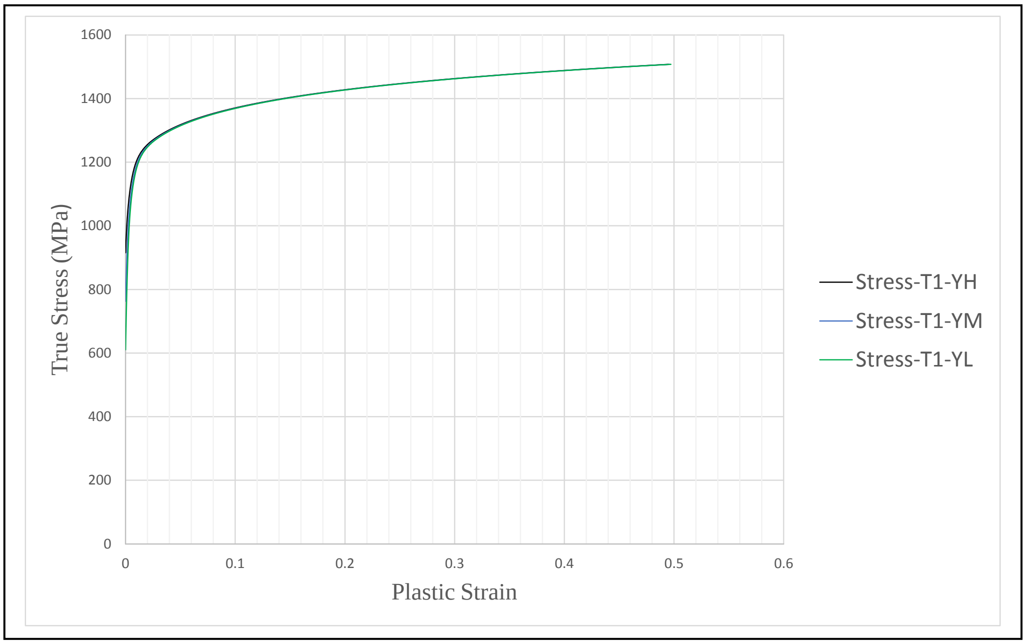

Figure 2b. T1-YH, T1-YM and T1-YL SPSC Curves

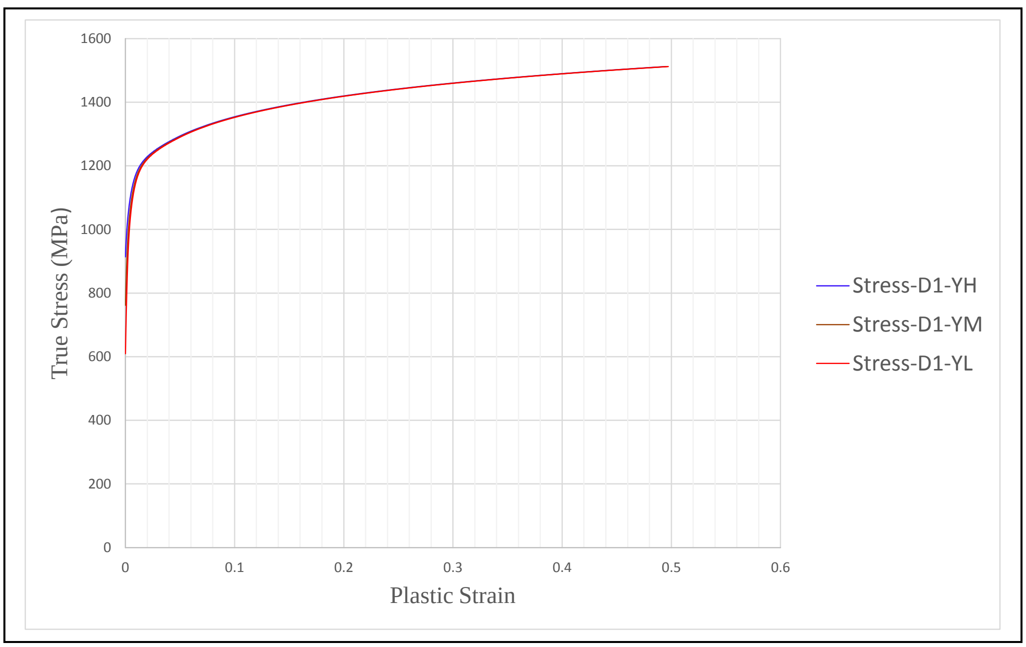

Figure 2c. D1-YH, D1-YM and D1-YL SPSC Curves

Because YH-SPSC, YM-SPSC and YL-SPSC for each of L1, T1 or D1 are very close, and the differences among them are very similar for the three tensile curves, only L1-YH-SPSC, T1-YH-SPSC and D1-YH-SPSC are overlaid to show the differences among them (Figure 2d). L1-YH-SPSC has the highest n-value (0.09), so the stresses on L1-YH-SPSC have the biggest changes.

Compared with T1-YH-SPSC, L1-YH-SPSC changed from -4% of L1-YL-SPSC at lower strain zone to +4% at high strain zone. See the two red curves in Figure 2d, the three SPSC curves (L1-YH-SPSC, T1-YH-SPSC and D1-YH-SPSC) are in the range of +/-4% of L1-YH-SPSC curve.

D1-YH-SPSC is close to L1-YH-SPSC at low strain, but it is lower than L1-YH-SPSC at higher strain zone because its n-value (0.07) is smaller. T1-YH-SPSC is higher than L1-YH-SPSC and D1-YH-SPSC at lower strain zone, but it is lower than L1-YH-SPSC and close to D1-YH-SPSC at higher strain zone because its n-value is 0.06 and is close to that (0.07) of D1-YH-SPSC.

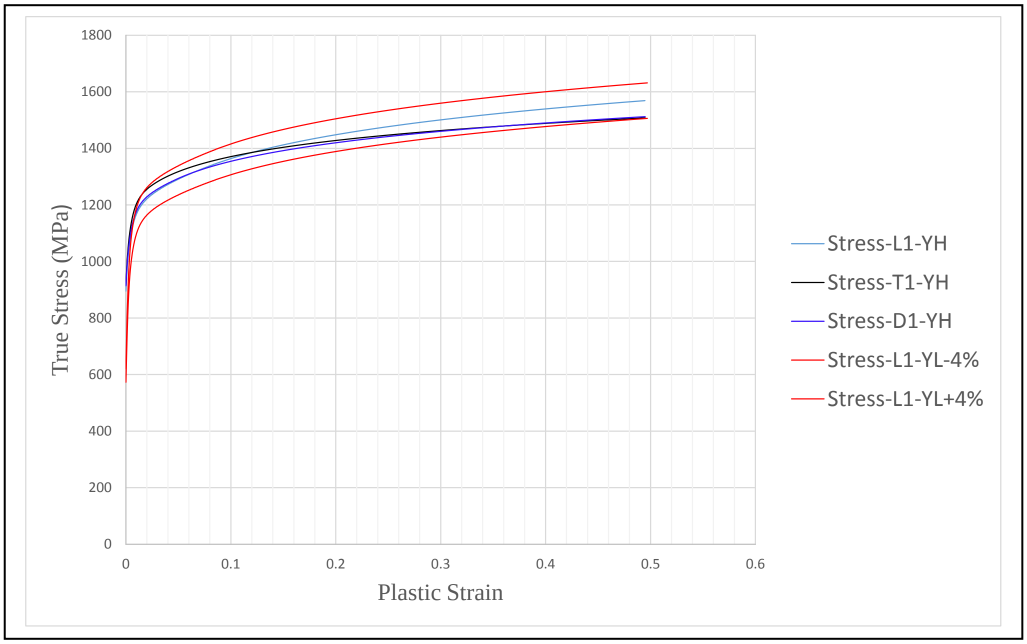

Figure 2d. L1-YH, T1-YH and D1-YH SPSC Curves

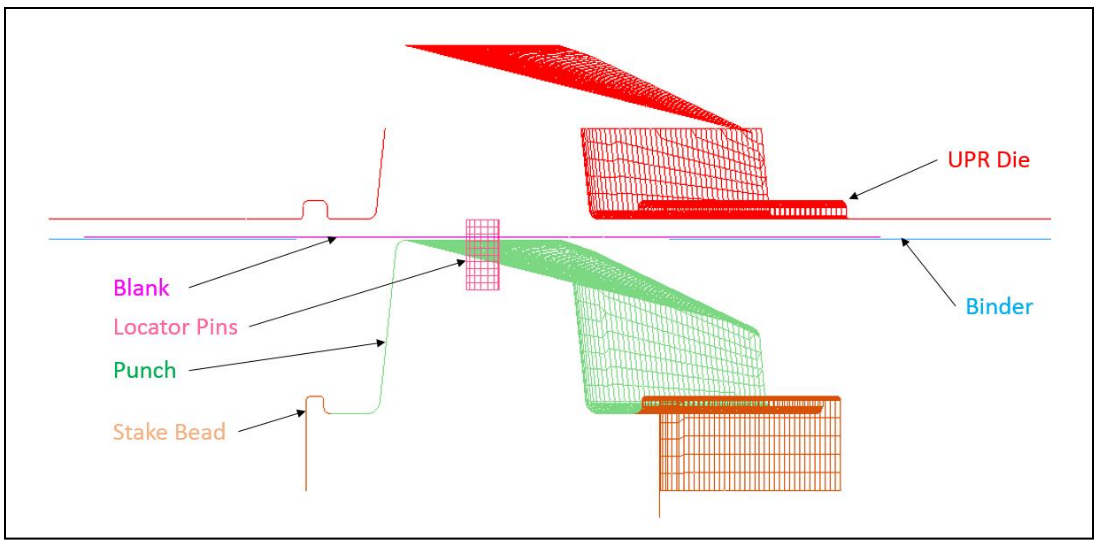

Figure 3. U-Channel Die Set Up

Simulation Set-Up Information

The simulation solver used is LS-DYNA R7.12 and Pre/Post Processor used is DynaForm®. Material is TBF1180, thickness 1.4mm. Blank sizes is 150mm X 420mm. Blank orientations were not studied with respect to L, T and D. Material models are MAT-37 with the tensile true SPSC curves defined as above. The r-value used was the average r_m (0.77) defined by the r-values on L, T and D directions. Nine TBF1180 U-channel parts that have very big wall opening and wall curling springbacks were simulated.

Draw-Ins Compare

The simulation results were analyzed in three aspects: Draw-In, forming force and springbacks. Draw-In is a very important simulation result. In stamping industry, Draw-In decides the blank sizes. In fact, Draw-In is a compound parameter, and it is the results of sheet metal flow. So, it can be said that if the Draw-Ins of two simulations with the same set-ups are matched, the sheet metal flows in the two simulations will be the same, and their strain distributions will be the same as well.

To compare the Draw-Ins of the simulations with the SPSC curves (YH-SPSC, YM-SPSC and YL-SPSC from each of TBF1180-L1, TBF1180-T1 or TBF1180-D1), the boundaries of the nine simulated parts were overlaid (Figure 4). It can be seen that the nine Draw-Ins are matched very well. The different yield stresses and the different tensile stress-strain curves on L, T and D directions have the very similar influences on TBF1180 sheet metal Draw-Ins.

Forming Force Analyses

Forming force is an important simulation result and can be used to select the stamping press. The forming forces of the nine simulations were in Table 3. For the same tensile curve like TBF1180-L1, the maximum forming force difference among YH-SPSC, YM-SPSC and YL-SPSC is about 0.57%. In stamping industry, this difference can be neglected. Therefore, it can be said that different yield stresses have little influences on the forming forces.

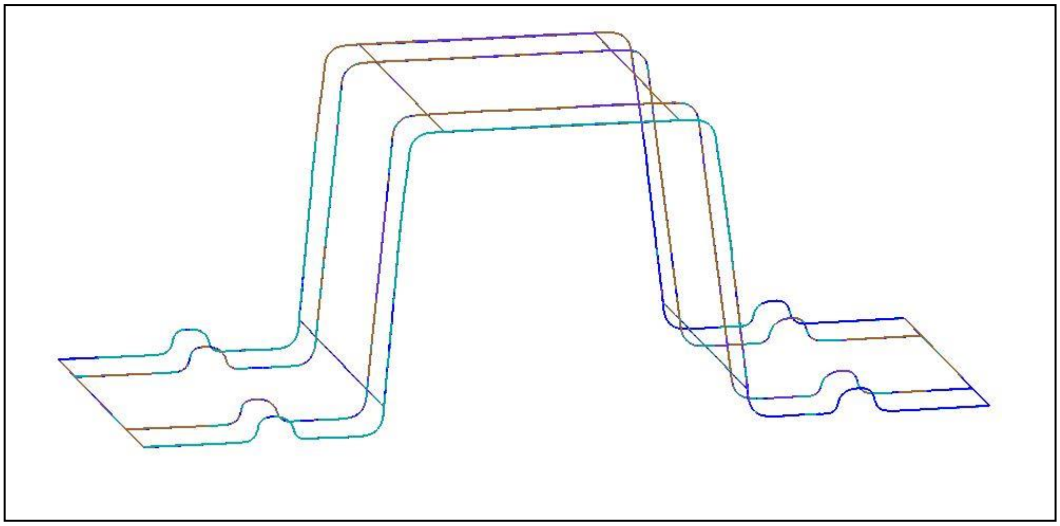

Figure 4. Draw-Ins Overlay

Table 3. Simulation Forces

Tensile Test Name	YH-Force (N)	YH-Force/ YL-Force (%)	YM-Force (N)	YM-Force/ YL-Force (%)	YL-Force (N)	YL-Force/ YL-Force (%)
TBF1180-L1	952228.0	100.57%	948925.0	100.22%	946824.0	100.00%
TBF1180-T1	962048.0	100.35%	957654.0	99.89%	958728.0	100.00%
TBF1180-D1	948950.0	100.38%	946930.0	100.16%	945380.0	100.00%

To find the influences of the three tensile curves (TBF1180-L1, TBF1180-T1 and TBF1180-D1) on the forming forces, the forming forces and yield stresses were compare in Table 4. The yield stresses for TBF1180-T1 and TBF1180-D1 at each yield level (YH, YM and YL) are about 2% bigger than that of TBF1180-L1, but the forming forces of TBF1180-T1 are about 1% higher than that of TBF1180-L1, and the forming forces of TBF1180-D1 are slight less than that of TBF1180-L1.

The reasons of the influences of the yield stresses and the tensile curves on the forming forces can be explained by Table 2 and Figure 2a-2d. From Table 2, because the elastic strains of the selected yield stresses are so small, the YH-SPSC, YM-SPSC and YL-SPSC curves for each tensile curve are very close. In addition, because the elastic strains are so small, the total strains will be approximately equal to the plastic strains at higher strain zone. Therefore, the flow stresses from the different SPSC curves will be very close at high strain zone (Figure 2a-2c), and the forming forces from them are very close.

For the three tensile curves, the SPSC curves will have influences on the forming forces. But the differences of the influences of the three tensile curves on the forming forces are very limited. For strain range 0.0 – 0.5, the flow stresses change about +/- 4% of TBF180-L1 (Figure 2d), the forming forces changes should be about the same range. For the cases in this paper, the forming force differences among the three tensile curves are less than 2.3% (Table 4.)

Table 4. The Compare of The Forming Forces of L1, T1 and D1 Stress-Strain Curves

Tensile Test Name	% L1-YH Yield	% L1-YH Force	% L1-YM Yield	% L1-YM Force	% L1-YL Yield	% L1-YL Force
TBF1180-L1	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
TBF1180-T1	102.26%	101.03%	102.26%	100.92%	102.26%	101.26%
TBF1180-D1	102.09%	99.66%	102.09%	99.79%	102.09%	99.85%

Springback Analyses

TBF1180 material is one of the third generation AHSS sheet materials. Springback control will be a critical factor for this material to be successfully used in production. As we all know, springback is directly related to the stresses. Are there any relationships between yield stresses and springbacks?

Springback is a compound value which comes from angle opening and wall curling, etc. Usually, different locations will have different springback values. To analyze the springbacks quantitatively, two points on the section were selected as the springback measurement points (Figure 5). The locations of the measurement points on the sheet metal are the same before and after springback. The measurements are shown in Figure 6. To compare the simulation springback results, the scanned sprung part was added in the overlay (Figure 5, 6). The springback results of the nine simulations were shown in Table 5.

To find the influences of the different yield stresses on the springbacks, the springbacks of the simulated parts with different yield stresses (YH, YM and YL) for each tensile curve (L1, T1 or D1) were compared (Table 6.). The yield stresses for YM-SPSC curves are bigger than that of YL-SPSC curves, but the springbacks from YM-SPSC are smaller than that from YL-SPSC for L1 and T1 tensile curves. YH-SPSC curves have highest stresses, the springbacks from YH-SPSC curves are the highest. The maximum springback difference among YH-SPSC, YM-SPSC and YL-SPSC is about 45%. The yield stress differences have big influences on springbacks.

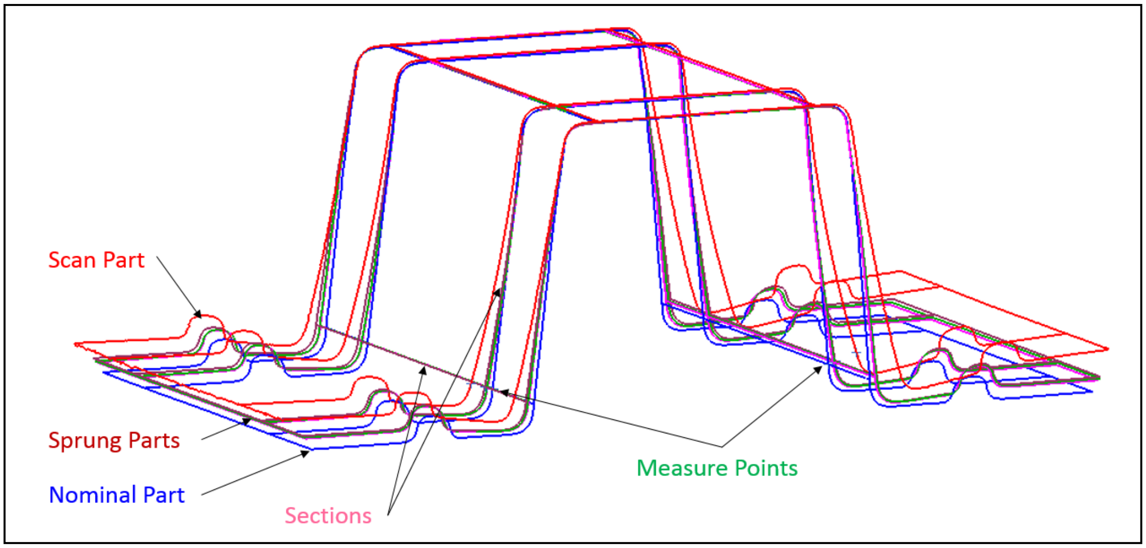

Figure 5. Springback Measurement points

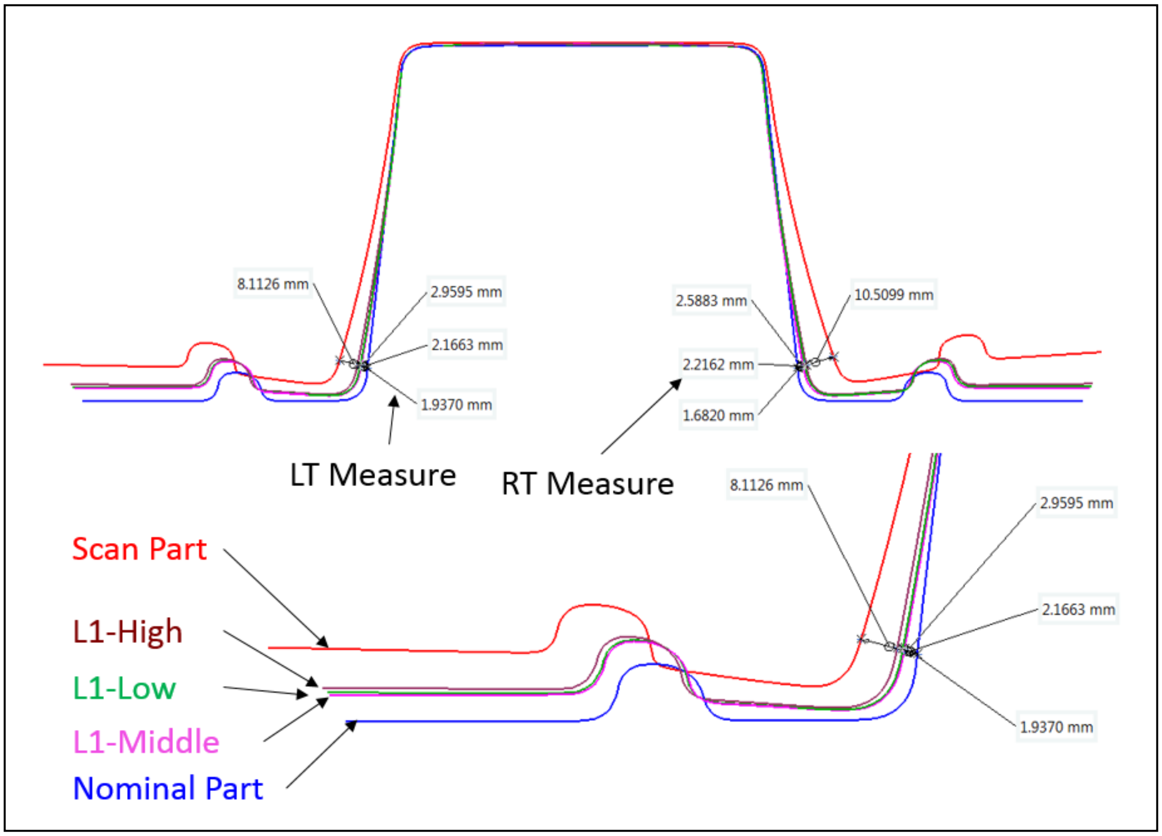

Figure 6. Springback measurements

Table 5. Springback Measements

Tensile Test Name	YL-SPSC Springback			YM-SPSC Springback			YH-SPSC Springback		
	LT (mm)	RT (mm)	Total (mm)	LT (mm)	RT (mm)	Total(mm)	LT (mm)	RT (mm)	Total (mm)
TBF1180-L1	2.166	2.216	4.382	1.937	1.682	3.619	2.960	2.588	5.548
TBF1180-T1	2.299	1.876	4.175	2.028	1.606	3.634	2.940	2.584	5.524
TBF1180-D1	2.224	1.923	4.147	2.310	1.850	4.160	2.846	2.463	5.309
Scan	7.413	9.81	17.223						

Table 6. The Springback Compare of Different Yield Stresses

Tensile Test Name	YL-SPBK/ YL-SPBK (%)	YM-SPBK/ YL-SPBK (%)	YH-SPBK/ YL-SPBK (%)	Max Difference (%)
TBF1180-L1	100.00%	82.59%	126.61%	44.02%
TBF1180-T1	100.00%	87.04%	132.31%	45.27%
TBF1180-D1	100.00%	100.31%	128.02%	28.02%

Table 7. The Springback Compare of Different Tensile Curves

Tensile Test Name	% L1-YH-SPBK	% L1-YM-SPBK	% L1-YL-SPBK
TBF1180-L1	100.00%	100.00%	100.00%
TBF1180-T1	95.28%	100.41%	99.57%
TBF1180-D1	94.64%	114.95%	95.69%
Max Difference	5.36%	14.95%	4.31%

The tensile curves in different directions have influences on the springbacks also (Table 7). But their influences are relatively small, except for YM-SPSC, the differences are about 5.5%.

The simulation springbacks are compared with scan data in Table 8. The yield stress differences can influence the simulation springback results. But compared with scan data, LS-DYNA MAT-37 with selected yield stresses SPSC curves can predict the springbacks up to 32% of the scan values. The springback prediction is inaccurate.

Table 8. Simulation and Scan Springback Compare

Tensile Test Name	YL-SPBK/ Scan SPBK (%)	YM-SPBK/Scan SPBK (%)	H-SPBK/Scan SPBK (%)
TBF1180-L1	25.44%	21.01%	32.21%
TBF1180-T1	24.24%	21.10%	32.07%
TBF1180-D1	24.08%	24.15%	30.83%

Conclusion

The three uniaxial tensile curves of TBF1180 sheet material on L, D and T directions were compared. Three yield stresses (YH, YM and YL) were selected for each tensile curve, and nine SPSC curves (YH-SPSC, YM-SPSC and YL-SPSC for each of the three tensile curve) were derived. The nine SPSC curves were analyzed, and nine simulations based on the nine SPSC curves were conducted. From the simulation results, the following conclusions can be drawn:

1. The yield stress differences of the same tensile curve do not have influences on Draw-Ins and forming forces.
2. The tensile curves on L, T and D directions have limited influence on the forming forces and the springbacks. But the tensile curves do not have obvious influences on Draw-Ins. In stamping industry, the tensile curve on L direction may be a better choice.
3. The different yield stresses of the same tensile curve have big influences on the springbacks. Because the yield stresses are not sensitive to Draw-In and forming force, it is possible to select a better yield stress for springback prediction. To do so, more studies need to be done to learn the relationship between the yield stresses and springbacks.
4. LS-DYNA material model MAT-37 in this paper has low springback prediction. New material model is needed to improve the springback prediction.

References

1. LS-DYNA manual R7.1.
2. AutoForm Manual.
3. PAMSTAMP Manual.
4. A. Nasser, A. Yadav, P. Pathak, T. Altan, 2010, Determination of the flow stress of five AHSS sheet materials (DP 600, DP 780, DP780-CR, DP 780-HY and TRIP 780) using the uniaxial tensile and the biaxial Viscous Pressure Bulge (VPB) tests, Journal of Materials Processing Technology 210, 429–436