Control of the servo-press in stamping considering the variation of the incoming material properties

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Abstract. The variation of incoming material properties and the quality of emerging advanced high-strength steels significantly increases the costs for product design and production. It is not economical to tightly control material chemistry to eliminate the variation of material properties at steel mills. This paper introduces a methodology on how to implement a non-destructive evaluation (NDE) tool to measure the variation of the incoming material properties. The servo-controlled forming process was successfully optimized to adapt to variations in the incoming material properties in a lab-scale stamping cell with a 300-Ton mechanical servo press. Final stamping quality was obtained with three different batch materials by altering servo press parameters, such as the slide motion and blank holder force, to adjust for the variation of the material properties from one batch to another. Both a mid-strength (340-MPa tensile strength) steel and a high-strength steel (980-MPa tensile strength) were evaluated in this study. The study shows the effectiveness of an NDE tool to non-destructively measure the sheet material properties and the servo-press control to adjust the press parameters for the variation of the material properties.

1. Introduction

The variation of incoming material properties of emerging advanced high-strength steels as well as often conventional steels significantly increases the costs for product design and production. This variation can significantly change the part quality associated with necking and springback, and consequently, scrap rate. Therefore, the automotive industry is interested in measuring the incoming material properties and adjusting forming processes with the measurements. With this rationale, a novel concept of the intelligent servo control forming process was introduced to adapt the stamping process considering the variation of incoming material properties and process parameters [1]. The proposed approach is based on the Machine Learning algorithm which is different from the closed-loop or alternatively called feedback control of product properties or strain distribution in deep drawn parts [2, 3]. Both feedforward and feedback controls were introduced to control four different die cushion forces by artificially assuming the variation of material properties, blank position, blank thickness, die friction, and tool temperature in FE simulations of deep drawing of the kitchen sink part [4, 5]. The eddy-current system was used to measure the sheet thickness for the use of feedback control in deep drawing [6]. This study introduces a methodology to non-destructively measure the variation of the incoming sheet material properties and determine the most effective forming parameters using the servo press that can help the manufacturer adjust the variation of the material properties.
2. Objectives
The main objectives of this study are to:

- Measure the sheet material properties using an NDE tool
- Determine the effective servo press parameters such as slide motion and blank holder force
- Prove the effect of the incoming material properties on stamping quality and effectiveness of the servo press parameters that was recommended from FEA

3. NDE measurements of the sheet materials

The steel manufacturing process in the steel mills produces a unique microstructure of the steel. This resulting microstructure also determines both magnetic properties and material properties. Commercial NDE equipment, 3MA, was used to measure the material properties of the Bake Harden (BH) 340 and 980GEN3 sheet materials. 3MA system is capable to measure magnetic properties. Figure 1 shows the procedure of the one-time calibration and validation for 3MA. After completing the initial calibration of the selected sheet material, 3MA can predict various material properties considering in different orientations with respect to the rolling direction as shown in Table 1.

![Figure 1. Calibration and validation procedure of the 3MA](image)

Table 1. 3MA measuring conditions and target tensile properties

| Materials | Variations | Target Parameters | Repetitions |
|-----------|------------|-------------------|-------------|
| BH340     | Three variations from three different coils | • Yield strength, • Ultimate tensile strength, • Total elongation, • R-value | • 3 orientations (RD, TD, 45) • 3 repetitions each orientation • 40 activations of 3MA measurement |
| 980GEN3   |            |                   |             |

In this study, three different batch materials of the same grade and thickness steel, BH340 (0.75mm) and 980GEN3 (1.2mm) were obtained from three different coils of the same steel mill to consider a variation of the incoming sheet material properties. Table 2 shows the uniaxial tensile properties of these materials. BH340-A shows the lowest value of the yield strength while BH340-C shows the highest yield strength that is 20 MPa larger than BH340-A. Similarly, 980GEN3-A showed the lowest value of the yield strength while 980GEN3-C shows the highest yield strength that is 43 MPa larger than 980GEN3-A.

Table 2. Tensile material properties of three variation BH340 sheet materials

| Material | Thickness (mm) | Variation | Yield Strength (MPa) | Tensile Strength (MPa) | Total Elongation (%) |
|----------|----------------|-----------|----------------------|------------------------|----------------------|
| BH340    | 0.75           | A         | 240                  | 345                    | 43                   |
|          |                | B         | 250                  | 355                    | 41                   |
|          |                | C         | 260                  | 360                    | 40                   |
Figure 2 shows good correlations between the 3MA-measured tensile properties and destructive tensile testing data. The 3MA measured data and tensile data showed good correlations of 96% for the yield strength and about 92% for the tensile strength as shown in Figure 2.

![Figure 2. Correlation of yield strength (left) and tensile strength(right) between tensile test data and 3MA measured data for BH340 A/B/C materials](image)

4. **Stamping validations for the effect of the incoming material properties**

Three selected BH340 and 980GEN3 materials were tested with the universal formability test tooling that was developed by EWI Forming Center. As shown in Table 3, five different testing conditions of press slide motion and blank holder force (BHF) were selected from preliminary FE simulations. These selected testing conditions were implemented with a 300-Ton AIDA servo press that is available at EWI Forming Center. The final drawing depth was set to be 68.8mm for the most testing conditions. Fuchs Anticorit PL 39 LV 12 was uniformly applied on the blank surfaces before the test using the motorized roller application equipment, UNIST. Figure 3 illustrates the Attach-Detach (AD) slide motion from 5mm and 15mm offsets from the bottom dead center (BDC). The press ram changes its moving directions during drawing the blank under a constant BHF. The intermediately-drawn part does not release from the die and binder during the slide detach while the drawn top surface is separated with the stationary bottom punch that allows local springback and creates new contact points with the punch at the second-stroke drawing.

![Table 3. Fiver different testing conditions for stamping tests with BH340](image)
Figure 3. AD slide motion with 5mm offset from BDC (left), and with 15mm offset from BDC (right)

Experimental results for BH340 are summarized in Table 4. BH340A with the lowest yield strength gave good parts for most testing conditions except the crank slide motion. While BH340B and BH340C gave successfully formed parts with only AD slide motions.

Experimental results for 980GEN3 are summarized in Table 5. 980GEN3-A with the lowest yield strength gave bad parts for most testing conditions except the AD slide motions. While 980GEN3-B and -C gave successfully formed parts with most testing conditions except the low-high BHF.

These results indicate variation of the incoming material properties can influence on the part quality. Servo press is also capable to adjust to this variation by implementing the AD slide motions or conventional crank motion to obtain the consistent quality parts depending on the strength and formability of the sheet materials.

Table 4. Stamping test results of three variational BH340 materials with various testing conditions

| Material | Repetition | Crank | High-Low | Low-High | AD at 5 mm | AD at 15 mm |
|----------|------------|-------|----------|----------|------------|-------------|
| BH340 A  | 1          | Neck  | Good     | Good     | Good       | Good        |
|          | 2          | Neck  | Good     | Good     | Good       | Good        |
|          | 3          | Good  | Good     | Good     | Good       | Good        |
| BH340 B  | 1          | Crack | Good     | Crack    | Good       | Good        |
|          | 2          | Crack | Neck     | Crack    | Good       | Good        |
|          | 3          | Neck  | Neck     | Neck     | Good       | Good        |
| BH340 C  | 1          | Neck  | Neck     | Neck     | Good       | Good        |
|          | 2          | Crack | Neck     | Good     | Good       | Good        |
|          | 3          | Neck  | Neck     | Good     | Good       | Good        |
Table 5. Stamping test results of three variational 980GEN3 materials with various testing conditions

| Material  | Repetition | Crank | High-Low | Low-High | AD at 5 mm | AD at 15 mm |
|-----------|------------|-------|----------|----------|------------|-------------|
| 980GEN3 A | 1          | Crack | Crack    | Crack/Wrinkle | Good      | Good        |
|           | 2          | Crack | Crack    | Crack/Wrinkle | Good      | Good        |
|           | 3          | Crack | Crack    | Crack/Wrinkle | Neck      | Good        |
| 980GEN3 B | 1          | Good  | Good     | Good      | Good      | Good        |
|           | 2          | Good  | Good     | Wrinkle   | Good      | Good        |
|           | 3          | Good  | Good     | Good      | Good      | Good        |
| 980GEN3 C | 1          | Good  | Good     | Wrinkle   | Good      | Good        |
|           | 2          | Good  | Good     | Good      | Good      | Good        |
|           | 3          | Good  | Good     | Good      | Good      | Good        |

The BH340 parts were scanned with the ARGUS GOM system to compare the thinning distribution on the part. As shown in Figure 4, the necking part obtained from the crank slide motion showed 30.7% maximum thinning and the good part obtained from the AD slide motion showed 26.5% maximum thinning. Figure 5 compares the BH340’s FLD data of the necking part with the crank motion and the successfully formed part with the AD motion. The AD motion showed a safer zone in FLD compared to the crank motion.

Figure 4. ARGUS-measured thinning data of the necking part with the crank motion (left) and the successfully formed part with the AD motion (right) with BH340 materials
Figure 5. ARGUS-measured FLD data of the necking part with the crank motion (left) and the successfully formed part with the AD motion (right) with BH340 materials.

The 980GEN3 parts were scanned with the ARGUS GOM system to compare the thinning distribution on the part. As shown in Figure 6, the necking part obtained from the crank slide motion showed 40% maximum thinning and the good part obtained from the AD slide motion showed 35% maximum thinning. Figure 7 compares the 980GEN3’s FLD data of the necking part with the crank motion and the successfully formed part with the AD motion. The AD motion showed a safer zone in FLD compared to the crank motion.

Figure 6. ARGUS-measured thinning data of the necking part with the crank motion (left) and the successfully formed part with the AD motion (right) with 980GEN3 materials.
Figure 7. ARGUS-measured FLD data of the necking part with the crank motion (left) and the successfully formed part with the AD motion (right) with 980GEN3 materials

5. Conclusions

The following conclusions can be drawn from this study.

- 3MA can be used to non-destructively measure the material properties of the incoming sheet material from the coil to coil or batch to batch.
- Variation of the incoming material properties can impact the part quality significantly.
- Attach-detach motion improved part quality when crank motion produced failures.
- Servo-press can help manufacturers produce quality parts consistently with the advanced and flexible control of the slide motion and BHF.

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