TriboForm® software evaluation for ArcelorMittal Steel Products

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Abstract. In numerical simulations, input data should be correctly defined to enable reliable numerical predictions, close to experimental observations. The purpose of this study is to better take into account the tribological behaviour of ArcelorMittal steel products during the stamping process. TriboForm® is an important additional software solution for the simulation of tribology, friction, and lubrication in sheet metal forming process and enables the generation of multiple friction models. A comparison between experimental observations and numerical predictions was investigated for three ArcelorMittal steel grades (CR4-GI, CR180BH-GI+NIT and CR440Y780T-DH-GI) on several stamping parts. This study illustrates the interest of TriboForm® friction law compared to a standard and constant predefined friction coefficient.

1. Introduction
In stamping numerical simulations, the blank rheological behavior and the sliding properties of its surface should be described. These properties are respectively defined by a constitutive hardening law of the steel, a yield surface and a friction coefficient generally considered as a constant. The ArcelorMittal identification for hardening models is only based on stress-strain curves determined in uniaxial tension. The “combined Swift and Voce (S-V)” law is recommended and was used for this study. It offers good prediction beyond uniform elongation (UE) for different experimental tests [1].

It is already well known that the friction coefficient is highly dependent on several parameters like the contact pressure, material in contact, oil type, quantity, tool roughness, ... [2]. However, the friction properties are generally still not considered in detail in stamping numerical simulations. A constant Coulomb friction coefficient is often used and may limit the overall simulation accuracy. For example, a friction coefficient value equal to $\mu=0.15$ is recommended by AutoForm® software.

TriboForm® software allows to simulate the effects of tool coatings, lubricants, material surface characteristics and new sheet materials. The objective of this study is to evaluate the effectiveness of TriboForm® software on ArcelorMittal steel grades during stamping process by comparing experimental observations to numerical predictions with AutoForm® using the standard and constant friction coefficient ($\mu=0.15$) recommended by AutoForm® and the friction model proposed by TriboForm®.

2. TriboForm® friction model
The TriboForm® friction law is obtained from physical measurements performed on the surfaces in contact (Fig 1). These measured parameters are the following:
- The sheet and tool roughness,
- The lubrication type and amount,
- Stamping process such as pressure, velocity and temperature.

By generating these measured parameters, the TriboForm® friction law can be illustrated as a function of the contact pressure, strain and other parameters (Fig 2).

The friction model proposed by TriboForm® can be imported in several stamping software such as AutoForm®, PamStamp® and LS-Dyna® using a TriboForm® FEM plug-in. In this study, all numerical simulations were conducted with AutoForm®, where an effective friction coefficient is calculated at each position of the blank and tools (upper and lower sheet sides, die, punch) for each calculation step (Fig 3).

The evolution of the friction coefficient depends on the current values of plastic strain, pressure, velocity and temperature [4] during the stamping process simulation.

Figure 1: Influencing parameters on the tribological behaviour during stamping process [3]

Figure 2: TriboForm® friction law [3]

Figure 3: Display of friction coefficient cartography for a rectangular part simulated by AutoForm® (a) at the die side (b) at punch side
3. Experimental and numerical approaches

3.1. Selected Materials
This study was conducted with three ArcelorMittal steel grades: CR4, CR180BH and CR440Y780T-DH, two surfaces types: Galvanized and Galvanized + New Inorganic Treatment (NIT) and three different tool shapes (Rectangular, Cross, and L-shape), Fig. 4.

![Shapes of the different parts](image)

**Figure 4**: Shapes of the different parts (a) rectangular, (b) cross and (c) L shape

The metal sheet used for the rectangular part is a CR4-GI and a Quaker 6130 lubricant is applied to the sheet material with a constant amount of 1g/m². The metal sheet used for the cross-part made of CR180BH-GI treated with NIT and a Fuchs 3802-39S lubricant with 0.95g/m² is applied to the sheet material. And finally, for the L-part, a CR440Y780T-DH-GI is applied oiled with Quaker 6130 lubricant with a constant amount of 1.24g/m².

An overview of the applied tribology system of the different stamping parts is summarized in Table 1.

**Table 1**: Tribology system for rectangular, cross and L-parts

| Sheet material   | Sheet roughness | Sheet thickness | Lubricant             | Tool material       | Tools roughness |
|------------------|-----------------|-----------------|------------------------|---------------------|----------------|
| CR4-GI           | 1.25 µm         | 0.7 mm          | Quaker 6130 (1 g/m²)   | DIN X160 CrMoV12   | 0.31 µm        |
|                  |                 |                 |                        | (rectangular tool) |                |
| CR180BH-GI+NIT   | 1.03 µm         | 0.65 mm         | Fuchs 3802-39S (0.95 g/m²) | DIN X160 CrMoV12   | 0.34 µm        |
|                  |                 |                 |                        | (cross tool)       |                |
| CR440Y780T-DH-GI | 0.87 µm         | 1.22 mm         | Quaker 6130 (1.24 g/m²) | DIN 45 CrMnMoS8    | 0.22 µm        |
|                  |                 |                 |                        | (L-tool)            |                |
3.2. Comparison between experimental observations and numerical predictions (AutoForm®)

In order to evaluate the interest of TriboForm®, numerical simulations were also conducted with a constant friction coefficient ($\mu=0.15$). All numerical predictions were confronted to experimental observations in terms of stamping force, final sheet thickness after forming and plastic strain on localized areas.

Thinning measurements were done using an ultrasonic device. Experimental thinning and numerical predictions are illustrated in Figure 5 for the rectangular box made of CR4-GI 0.7mm. The Blank holder force is equal to 494 kN. A constant friction coefficient of $\mu=0.15$ induces much higher thinning in the wall than those measured experimentally. The use of the TriboForm® friction model allows to predict more accurately experimental observations even if thinning is slightly underestimated.

To confirm the previous results, experimental thinning and numerical prediction for a rectangular box made of CR4-GI were done also with blank holder forces of 659 kN and 786 kN. The results show the same prediction accuracy than those obtained with a blank holder force equal to 494 kN.

Experimental thinning and numerical prediction were confronted for L-part and cross-part made of respectively CR440Y780T-DH-GI 1.22mm and CR180BH-GI+NIT 0.65mm. The comparison confirms that the use of TriboForm® friction law allows to predict more accurately the experimental observations than the standard Coulomb friction coefficient ($\mu=0.15$).

![Figure 5: Experimentally measured and simulated thinning results for the Rectangular box made of CR4-GI 0.7mm](image)

The stamping force evolution during the cross-shape forming of a CR180BH-GI and pretreated with NIT is illustrated in Figure 6. It can be clearly seen that the stamping force evolution including the TriboForm® friction model predict well the observations in try-out. However, the stamping force determined with a constant friction coefficient ($\mu=0.15$) overestimates the experiments.
An element of the L-Shape part made of CR440Y780T-DH-GI 1.22mm has been selected to compare the plastic strain predictions to an experimental measurement using Digital Image Correlation (Fig 7). The predicted couple major-minor plastic strains are again better estimated when TriboForm® friction model is used compared to a standard friction coefficient ($\mu=0.15$) where plastic strains are overestimated.

**Figure 6:** Experimentally measured and simulated stamping force results for the cross-shape made of CR180BH-GI+NIT 0.65mm

**Figure 7:** Experimentally measured and simulated plastic strain results for a localized area of L-shape part made of CR440Y780T-DH-GI 1.22mm
4. Conclusion

This study reveals the interest of the TriboForm® friction law compared to a standard and constant predefined friction coefficient ($\mu=0.15$). A strong influence of the tribology, friction and lubricants conditions on the stamping process is observed. Numerical predictions are improved for three stamping parts, in terms of sheet thickness reparation after forming, stamping force evolution and plastic strain field, when TriboForm® friction model is used. The effects of type and amount of lubricant can also be taken into account in TriboFrom. This functionality allows to determine the optimal stamping process parameters (like drawing velocity and blank holder force) to enhance the part formability [5].

References

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