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To cite this article: C imir *et al* 2017 *J. Phys.: Conf. Ser.* **896** 012059

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# A Material Perspective on Consequence of Deformation Heating During Stamping of DP Steels

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**Abstract.** Recent studies showed that, during stamping of high strength steels at industrially relevant production rates, local temperature in the blank may rise up to 200°C – 300°C due to deformation heating. Moreover, die temperature may also rise up to 100°C – 150°C for progressive stamping dies. Based on the common assumption that the blank softens as the temperature increases, thermal softening creates a margin in Forming Limit Diagram (FLD) and therefore the FLD determined at room temperature can safely be used for those cases. In this article, the validity of this assumption on DP590 steel is questioned by high temperature tensile tests (RT - 300°C) at various strain rates ( $10^{-3} \text{ s}^{-1} - 1 \text{ s}^{-1}$ ). The results indicated a decrease both in uniform and total elongation in 200°C – 300°C range together with several other symptoms of Dynamic Strain Aging (DSA) at all strain rates. Concurrent with the DSA, the simulated FLD confirms the lower formability at high temperature and strain rates. Thus, it is concluded FLD determined at RT may not be valid for the investigated steels.

## 1. Introduction

Dual phase (DP) steels have been continuously used in automotive industry for decades. Due to the necessity of light-weighting, DP steels have been serving as a good solution for the automotive industry and more specifically for the body design engineering. DP steels typically have high ultimate tensile strength (590-1400 MPa) due to the presence of martensite; combined with low initial yield strength (enabled by ferritic matrix), high early-stage strain hardening, and macroscopically homogeneous plastic flow (due to the absence of Luder's effects). These features make DP steels ideal alloy systems for automotive-related sheet forming operations [1,2].

Forming limit curve (FLC) is the major tool in determination of formability of sheet blanks. Although FLC is drawn under the assumption of straight strain paths and there are complex damage models available to predict the failure of the blank, it has been widely employed in industrial solutions due to its simplicity and open-source data in the literature [3,4]. In addition to the FLC, flow curve and yield surface are the other major inputs for the simulation sheet metal forming processes.

During a forming process, strain generally increases towards the forming limit curve (FLC). When the strain reaches the FLC, necking or fracture occurs. By comparing the strains measured in the



formed part to the FLC, the severity and nature of the deformation can be assessed and process parameters such as lubricants and draw beads can be re-designed accordingly in order to assist the forming operation [5].

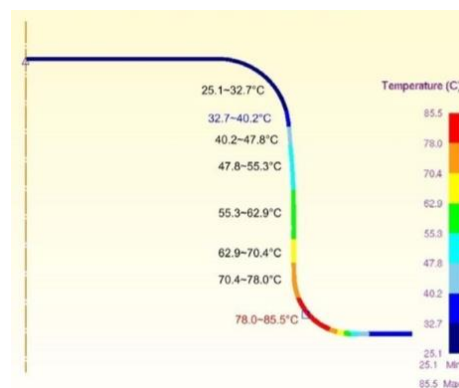
## 2. Deformation Heating Phenomena

Plastic work during deformation causes a temperature increase in the part by conversion of plastic work to the heat. The plastic work could be determined by computing the area under the flow curve:

$$W_p = \int_0^{\bar{\epsilon}_p} \bar{\sigma} \cdot d\bar{\epsilon}_p \quad (1)$$

Despite the fact that there are some studies in the literature focusing on the dependence of  $\beta$  (the ratio of plastic work which is converted to heat energy) to strain state or strain rate, as a general assumption  $\beta$  could be assumed as 0.90 for most of the sheet metal forming applications [6]. Mac Dougall also proposed that approximately 90% of the plastic work within the specimen is converted to heat energy during deformation, while rest is converted to the other types of energy, such as sound, microstructural change, and etc. [7].

As a subgroup of 1<sup>st</sup> generation Advanced High Strength Steels (AHSS), DP 590 steel has a relatively high yield strength compared to the conventional mild steels and its ductility is also sufficient for many metal forming processes. In other words, they could stand for high amount of plastic work and therefore they are likely to be faced with high temperature rise during the forming operations. A sample thermo-structural simulation of DP590 in deep drawing operation is illustrated in Figure 1.

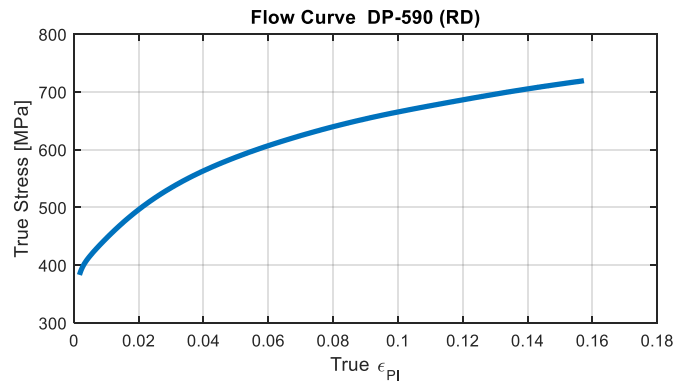


**Figure 1.** Temperature prediction of DP590 in deep drawing by Deform 2D [8].

In general for sheet metal forming operations the deformations take place under low strain rates which provides the necessary time for dissipation of the heat generated by the plastic work. However, for industrial cases, especially in mass production with progressive stamping dies, the temperature of tool surfaces may rise to 100 °C. For these specific cases, the heat dissipation through the blank is not possible, which results in adiabatic heating condition. If the temperature of tool surfaces is sufficiently high, the blank may be heated by the tool just before the forming operation. When heat generation due to the friction also contributes to this situation, the temperature of the blank may locally rise to 300 °C [9]. This temperature rise should be accounted in the simulation of forming processes, as it may cause severe changes in the deformation behavior of the blank material. Therefore, the effect of the temperature on FLC's should also be determined and taken into account for sheet metal forming simulations.

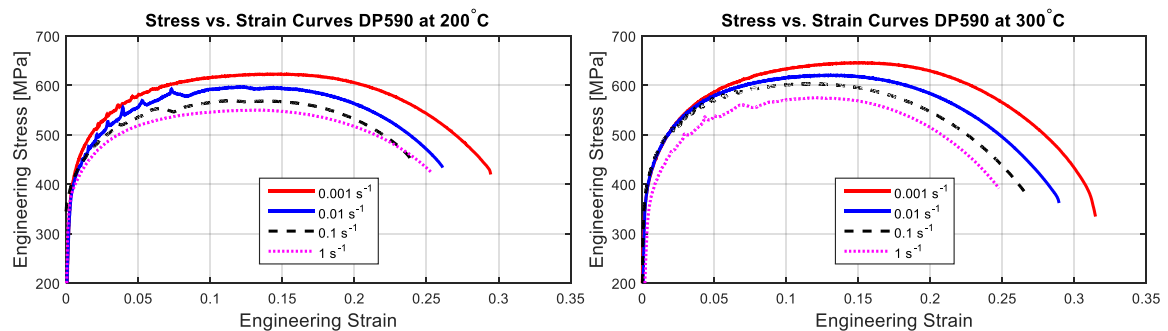
### 3. Tensile Testing of DP590

Room temperature tensile tests of DP590 were performed on Zwick/Roell Z300 Machine (300 kN capacity) with standard tensile test specimens. The elongations were recorded by an extensometer of class 0.5 that was embedded to the Zwick machine.

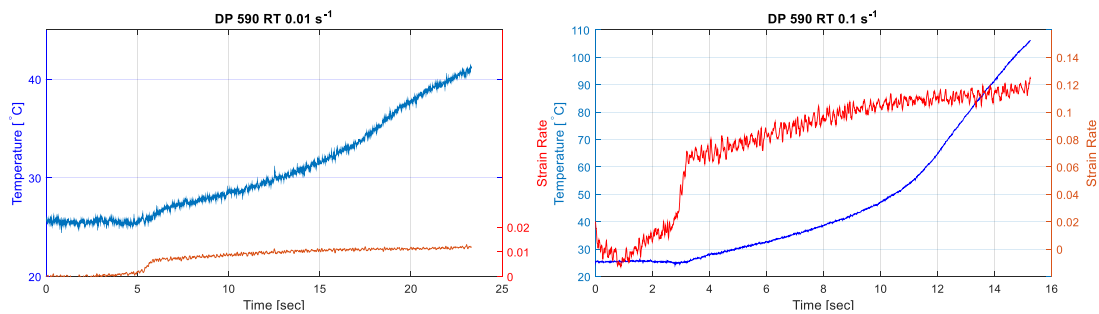


**Figure 2.** Flow Curve of DP590 in rolling direction.

The high temperature and high strain rate tests were conducted within a multi-function dilatometer (DIL 805A/D, TA-Baehr). The dilatometer employs inductive heating in order to provide the desired temperature during the tensile test. During the tensile test at high temperature, the strain rate was also controlled by the dilatometer [10]. The strain values were recorded by the high precision LVDT system which was embedded to the dilatometer. The results of the tensile tests at 200 °C and 300 °C with different strain rates are shown in Figure 3. The variation of temperature and strain rate during the experiments is also shown in Figure 4.



**Figure 3.** Strain vs. Stress curves of DP590 at different temperature and strain rates.

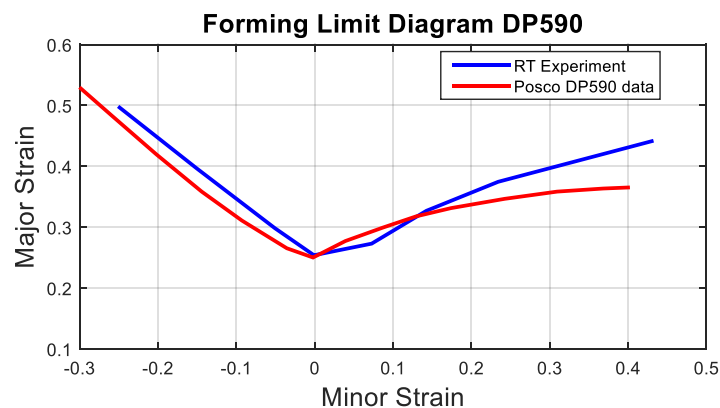


**Figure 4.** Process parameters of the tensile tests at 0.01 and 0.1 strain rates

### 3.1. FLC Prediction via Standard Tensile Testing

Conventionally FLC's are obtained by formability tests such as Nakazima or Marciniak and for both methods several experiments should be performed at various strain paths. Therefore, certain number of specimens should be prepared in advance according to the required strain path. These constraints result in an expensive and labour-intensive process. Alternative approaches for the determination of FLC via tensile testing have been proposed by some researches. Cayssials has proposed a new method which couples the plastic instability theory with a damage approach [11]. In this method, a precise construction of the FLC is possible with the tensile test data (yield strength, hardening exponent, Lankford parameter) and the specimen thickness. Abspoel et al. have proposed and demonstrated an improved method, which provides an accurate prediction of the FLC [12].

At present both of the techniques were implemented into the Autoform software. In this study, FLC's were computed according to the Cayssials (Arcelor) model and compared with the FLC data of Posco DP 590, which was obtained from the literature. The difference is found to be reasonable as shown in Figure 5.



**Figure 5.** A comparison of FLC for DP590.

For the high temperature FLC computations, the Lankford parameter of DP590 was assumed to be the constant. This assumption is decided to be reasonable since the high temperature experiments were still below the recrystallization temperature of DP590.

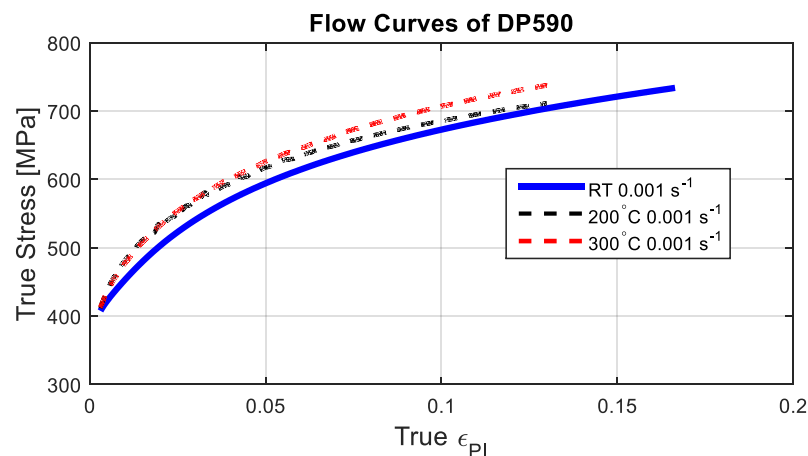
## 4. Results and Discussion

The tensile tests performed within the scope of this study clearly reveal that the formability of DP590 steels decreases as the temperature approaches to the 200 - 300 °C range, which can be accessed in the industrial practice. The formability decrease is evident from the flow curves of DP590, as the flow stress increases and the ductility decreases with the increasing temperature (Figure 6).

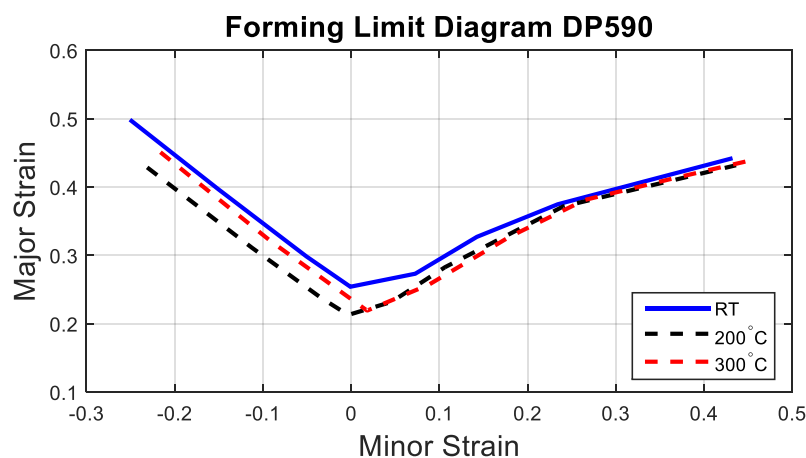
Unlike the general assumptions of thermal softening in the flow stress, DP590 hardens within the specific temperature range, while the flow behavior is normal at room temperature and 400 °C. Parallel to the abnormal flow behaviour, FLC decreases with increasing temperature up to 300 °C for DP590 steel as designated in Figure 7. The reduction in the limiting strains is most significant at 200 °C, approaching to a 20% decrease under certain strain paths. The plastic instabilities in the form of local necks may start early in the deformation due to the reduced formability and the strain will accumulate in these instabilities leading to the premature fracture of the blanks. Therefore, the DP steels should be either formed at room temperature or at 400 °C, avoiding the 200 °C - 300 °C range.

#### 4.1. DSA controlled deformation in DP590

The presented results show serrated flow (PLC effect), an increasing strength and work hardening rate with increasing temperature in the range of 200 °C - 300 °C, all of which are symptoms for dynamic strain aging [13] and also have been reported to be observed in other DP-steels [14]. Dynamic strain aging occurs when the rate of straining is such that the interstitials can diffuse and pin the mobile dislocations, and serrations occur because of rapid generation of new dislocations, which are needed to sustain flow [15]. Those symptoms also lower the FLC diagram, cause inhomogeneous flow; and hence lower the formability of DP-steels.



**Figure 6.** Comparison of flow curves.



**Figure 7.** FLC for RT, 200 and 300 °C.

## 5. Summary

Forming limit curves of the DP590 steel are generated from the tensile test data obtained between room temperature – 400 °C and  $10^{-3} \text{ s}^{-1}$  –  $1 \text{ s}^{-1}$ . Both the tensile test results and the FLCs indicate a loss in ductility and formability within a specific temperature range of 200 °C - 300 °C. Dynamic strain aging controls the deformation behaviour at these temperatures and it is responsible for the reduced formability. In real forming practice, the samples may reach these temperatures because of the deformation heating at high strain rates ( $10 - 100 \text{ s}^{-1}$ ) employed in industrial forming processes. As the strain rate gets higher ( $10 - 100 \text{ s}^{-1}$ ), the adiabatic heating may raise the local temperature of the deforming regions to the DSA range. The higher strain rates can also intensify the effects of DSA and result in a further reduction in the total ductility and the formability.

## References

- [1] Tasan CC, Diehl M, Yan D, Bechtold M, Roters F, Schemmann L, Zheng C, Peranio N, Ponge D, Koyama M, Tsuzaki K and Raabe D 2015 *Annu. Rev. Mater. Res.* **45** 19 1-41
- [2] Billur B, Cetin B, Gurleyik M 2016 *International Journal of Scientific and Technological Reserach* **2** 1 50-62
- [3] Tasan CC, Hoefnagels JPM, Diehl M, Yan D, Roters F and Raabe D 2014 *International Journal of Plasticity* **63** 198-210
- [4] Alharbi K, Ghadbeigi H, Efthymiadis P, Zanganeh M, Celotto S, Dashwood R and Pinna C 2015 *Modelling Simul. Mater. Sci.Eng.* **23** 8 1-17
- [5] Barata da Rocha, Santos AD, Teixeira P and Butuc MC 2009 *Journal of Material Processing Technology* **209** 5097-109
- [6] Rusinek A, Klepaczko JR 2009 *Material and Design* **30** 35-48
- [7] MacDougall D 2000 *Experimental Mechanics* **40** 3 298-306
- [8] Kim H 2008 Phd Thesis The Ohio State University USA
- [9] Ceron E 2013 Phd Thesis Technical University of Denmark Denmark
- [10] Mustak O, Evcil E, Simsir C 2016 *Mat.-wiss. u. Werkstofftech.* 1-11
- [11] Cayssials F 1998 *Proc. 20th IDDRG Congress (Brussel)* 443-454
- [12] Abspoel M, Schloting ME and Droog MM 2013 *Journal of Material Processing Technology* 2013 **213** 759-769
- [13] Van den Beukel A 1975 *Phys. Stat. Slo.* **30** 197-206
- [14] Queiroz RRU, Cunha FGG and Gonzalez BM 2012 *Mat.Sci.Eng. A* **543** 84-87
- [15] Sачev AK 1982 *Metall. Trans. A* **13A** 1793-1797