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Using Contact-less Optical Systems to Characterize and Measure Deformation of TWIP Materials

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Abstract

There is evident huge progress in the contact-less systems for measuring deformation by means of the photogrammetry especially during last ten years. From the forming point of view is very important that in many cases photogrammetry can improve knowledge about material deformation behavior under plastic deformation. This paper deals with characterization and description quite special deformation behavior of so-called TWIP (TWInning Induced Plasticity) materials by these contact-less optical systems (in this paper is used system ARAMIS). Beside the revealing deformation behavior there is also effort to find out development of anisotropy during whole static tension test and comparison of results from those measured at deformation values specified by the commonly used standard ČSN ISO 12 275. Other important results can be found during measurement of FLD for TWIP materials according standard ISO 12004-2. There is also possibility to compare values of true strain measured by optical system and results from numeric simulation program – in this case it was widely used simulation program for sheet forming from ESI company (France) PAM-STAMP 2G - comparing of real values of true strain and results from simulation, their mapping and final graphical display of differences between these values.

Keywords: Photogrammetry; TWIP Materials; Twinning Induced Plasticity; Tension Test; FLD; Simulation; Mapping

1. Introduction

Sheets producers are still under quite large pressure namely from automotive industry. Because there is requirement for safety of passengers on the one hand and on the other hand quite large requirement for light weight materials. There are wide reductions in weight, in fuel consumption and in the emission of exhaust gases. And that is why during last years was developed wide spectrum of materials suitable for

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automotive industry (IF, BH, DP, CP, MS, TRIP and TWIP steels, etc). Their stress-strain curves are shown in Fig. 1. In this paper are compared mainly two ultra high-strength steels – DOCOL 1200M and TWIP 1200 from the deformation behavior point of view (static tension test and FLD). The anisotropy measurement (for deep drawing material DX56) will be subject for next paper. Because of comparison (for anisotropy) reason there is also shown stress-strain curve for deep-drawing material (DX56). As it is commonly known ultra high-strength steels (UHSS) exhibit very high mechanical properties (offset yield strength $R_{p0.2}$ and ultimate tensile strength $R_m$) and low ductility – as for material DOCOL 1200M. But for TWIP 1200 (Twinning Induced Plasticity) there are excellent both mechanical properties and ductility.

![Stress-strain curves for UHSS materials (CP, DP, MS, TRIP and TWIP) and deep-drawing material (DX56)](image)

Fig. 1. Stress-strain curves for UHSS materials (CP, DP, MS, TRIP and TWIP) and deep-drawing material (DX56)

### Nomenclature

| Abbreviation | Description                     |
|--------------|----------------------------------|
| BH           | bake hardening                   |
| CP           | complex phase steels             |
| DP           | dual phase steels                |
| IF           | interstitials free steels        |
| MS           | martensite steels                |
| TRIP         | transformation induced plasticity|
| TWIP         | twinning induced plasticity      |
| UHHS         | ultra high-strength steels       |

### Greek letters

$\phi_{1,2}$ major and minor true strain, respectively
2. TWIP material deformation behavior – static tension test

TWIP materials (TWinning Induced Plasticity) are group of materials where the extraordinary elongation (thus ductility) together with high mechanical properties (offset yield strenght $R_{p0.2}$ and ultimate strength $R_m$) is attributed to strain-induced twinning (the TWIP effect). Such kind of materials contains austenite stabilising elements, e.g. Mn or Ni. Due to that stacking fault energy (thus also plastic deformation by slip) is decreased and there is extensive mechanical twinning under plastic deformation.

For evaluation TWIP sheets deformation behavior was used contact-less optical system ARAMIS from German company GOM. System ARAMIS is using for deformation measurement scanning of specimen by means of two cameras. Whole workplace lay-out is shown in Fig. 2a. Before measuring itself, the system has to be calibrated thus enabling to get relevant deformation measurement in given calibration volume. On the measured sample is then necessary to apply stochastic pattern. System ARAMIS with the help of this pattern allocates to each point characteristic number (grey shade) and apply own mesh. Measurement itself is further carried out by scanning these points displacement and thus deformation too. Image corresponding to initial measurement stage is shown in Fig. 2b. For more information see e.g. [1].

![Initial position](image1.png)

**Fig. 2.** Initial position – stage 0 (a) workplace lay-out; (b) graphical major strain $\varphi_1$ distribution

With the help of the following images it is quite easily possible to characterize deformation behavior of material TWIP 1200 under uniaxial tension loading. Images always contain graphical major strain $\varphi_1$ distribution (Fig. 3a) on the measured area and along specimen axis – Section 0 (Fig. 3b). First image couple is for stage when $\varphi_1 \approx 0,25$. It’s evident that till this stage is distribution of $\varphi_1$ almost uniform.

![Stage 160](image2.png)

**Fig. 3.** Stage 160 at $\varphi_1 \approx 0,25$ (a) graphical major strain distribution; (b) major strain distribution along section 0
The next image couple shows the stage right before fracture of tested material (TWIP 1200). There is again shown graphical major strain $\dot{\varepsilon}_{ij}$ distribution (Fig. 4a) and the distribution along specimen axis (longitudinal one – Fig. 4b). In the moment right before material fracture there is possible to find an area with certain strain localization (major strain $\dot{\varepsilon}_{ij} > 0.55$) – necking area. However such strain localization is already at the end of measurement and major strain $\dot{\varepsilon}_{ij}$ distribution in the rest of specimen ($\dot{\varepsilon}_{ij} = 0.3 \div 0.5$) reveals stairs-like character. Thus there is the greatest interest given to the deformation behavior within the interval from $\dot{\varepsilon}_{ij} \approx 0.25$ up to material fracture. From the stress-strain curve of material TWIP 1200 (Fig. 1) is evident that uniform ductility $A_g$ almost equals to total ductility $A_{50mm}$ thus ultimate stress $\sigma_m$ is close to the moment of material fracture and necking process is strictly limited.

As was already mentioned before, the deformation behavior within the interval $\dot{\varepsilon}_{ij} \in <0.25; \sigma_m>$ reveals a unique character. It seems that there exist a quasi “strain waves” passing through material and always increase the strain to higher and higher values (stairs-like character). Detail (due to scale) of such “strain wave” passing material is shown in Fig. 5a. Every measured stage (depends on frame rate) from the interval $\dot{\varepsilon}_{ij} \in <0.25; \sigma_m>$ is subsequently shown in Fig. 5b where red curve corresponds to stage 250. There is evident that after “strain wave” passing value of major strain $\dot{\varepsilon}_{ij}$ is always increased following this stairs-like character and that such increment is higher and higher. This unique deformation behavior arises from massive twinning during plastic deformation where it is possible to observe twinning process by means of these “strain waves” and their movement through material. From Fig. 5b is also evident that necking process takes place not early than right before material fracture.
3. TWIP material deformation behavior – FLD

For measurement FLDs is in our department using method of stretching shaped (with different widths) specimens by a semi-spherical punch. From tested materials (TWIP 1200 and DOCOL 1200M) were cut specimens with different shapes. Were chosen 5 different widths (30, 75, 105, 120 and 210 mm) where 210 mm means “full” blanks. With the help of system ARAMIS were scanned all stages of tested materials during test. Limit stage of material represents stage right before crack opening. For each width were measured 5 samples. Because of space are in Fig. 6 shown graphical \( \varepsilon_{ij}^1 \) distributions for stage just before specimen fracture only for width 30 mm.

![Fig. 6. Major strain \( \varepsilon_{ij}^1 \) distribution (a) TWIP 1200; (b) DOCOL 1200M](image)

From all used specimens were chosen stages just before crack opening and thus were found out coordinates of maximal major strain \( \varepsilon_{ij}^1 \) and minor strain \( \varepsilon_{ij}^2 \). A few years ago was proposed standard how to decrease these maximal values to avoid necking in the thickness direction of material [2]. This standard is using inverse parabola and its peaks (both for \( \varepsilon_{ij}^1 \) and \( \varepsilon_{ij}^2 \)) are new coordinates for FLDs. In the following figure (Fig. 7) are shown final FLDs calculated both from \( \varepsilon_{ij}^1 \) and \( \varepsilon_{ij}^2 \) maximal values and according standard ISO 12004-2 for both materials (TWIP 1200 and DOCOL 1200M).

![Fig. 7. Final FLDs measured according both maximal values and ISO 12004-2](image)
4. Comparison of results from ARAMIS system and numerical simulation

Comparison of results for material TWIP 1200 were carried out by means of the simulation program PAM-STAMP 2G (ESI company). Because of space there aren’t shown results from such simulation. Subsequently (to ensure the same orientation and position) was by means of program S-VIEW carried out positioning of these results with that ones measured by ARAMIS system. It was further followed by manual pre-registration, best fit registration and finally mapping. Mapping itself was carried out both for the distance [mm] (fig. 8a) and major strain $\varphi_1$ differences [-] (fig. 8b). In this case it was done just for the lowest width of specimens – 30 mm.

Fig. 8. Comparison of ARAMIS with PAM-STAMP 2G results (a) distance differences [mm]; (b) major strain $\varphi_1$ [-] differences

5. Conclusion

At first sight it is evident that TWIP steels represent a material group with extraordinary values which have led to a great interest in these steels [3]. The excellent mechanical properties (clear also from FLDs) are due to massive twinning in the austenitic matrix during deformation. The greatest advantage for strain behavior monitoring by optical systems rests in the possibility to reveal quite unique deformation behavior especially under tension test. There is clearly evident passing of a quasi “strain waves” through loaded material (in this case for $\varphi_1 \in <0,25; \sigma_{m}>$) - there is always increase for major strain $\varphi_1$ value and then keeping on such value until the next “strain wave”. In many papers there is also a discussion about the slip and twinning plastic deformation ratio for this material and it seems that already within the range $\varphi_1 \in <0,25; \sigma_{m}>$ there is massing twinning which reveals as these “strain waves”. From the FLDs comparison point of view are evident different limits for used UHSS namely at comparison according standard ISO 12004-2. Results from real measurement (ARAMIS) and simulation reveals a very good conformity. However there is need to carry out further research about TWIP deformation behavior.

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