Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 81 (2014) 939 – 944

Procedia Engineering

www.elsevier.com/locate/procedia

11th International Conference on Technology of Plasticity, ICTP 2014, 19-24 October 2014, Nagoya Congress Center, Nagoya, Japan

Properties and application of high-manganese TWIP-steels in sheet metal forming

Christian Busch[a,*], Ansgar Hatscher[a], Manuel Otto[b], Stefan Huinink[c], Milan Vucetic[d], Christian Bonk[d], Anas Bouguecha[d], Bernd-Arno Behrens[d]

[a]*Volkswagen AG, Stellfelderstraße 46, 38442 Wolfsburg, Germany*
[b]*Salzgitter AG, Eisenhüttenstraße 99, 38239 Salzgitter, Germany*
[c]*Sitech Sitztechnik GmbH, Stellfelderstraße 46, 38442 Wolfsburg, Germany*
[d]*Institute for Forming technology and Forming machines, University of Hanover, An der Universität 2, 30823 Garbsen, Germany*

Abstract

Within this work uniaxial tensile tests have been performed with high-manganese TWIP-steel and different dual-phase steels to determine mechanical properties. The transfer of the results form uniaxial tensile tests to multi-axial stresses has been made with deep drawing experiments to describe and assess deep and stretch formability of the analysed materials. Forming limits of materials are demonstrated by forming limit diagrams. FE-simulation systems have been applied to predict deep drawing and spring-back behaviour of high-manganese TWIP in comparison to dual-phase steels. The simulation results are discussed between the different materials.

Selection and peer-review under responsibility of the Department of Materials Science and Engineering, Nagoya University

Keywords: TWIP-Steel; Sheet metal forming; FEM-Simulation; Formability

1. Introduction

The development of steels for a variety of automotive applications is characterized by an increase of strength combined with the preservation or improvement of its formability. The increase of strength enables car

* Corresponding author. Tel.: +49-5361-9-993561; fax: +49-5361-957-80232.
E-mail address: christian.busch@volkswagen.de

Selection and peer-review under responsibility of the Department of Materials Science and Engineering, Nagoya University
doi:10.1016/j.proeng.2014.10.121

manufacturers to reduce the weight of the car. Higher ductility makes a more complex structure design feasible. Austenitic TWIP-steels combine these properties, making them very attractive for automotive industry (Fig. 1). The high work-hardening rate plays a dominant role during deformation and results in excellent mechanical properties. The aim of this research is to obtain a better understanding of TWIP and TWIP/TRIP-alloys in sheet metal forming and prediction in forming simulation. [1][2]

The excellent properties of austenitic Fe-Mn-C steels were originally discovered by Robert Hadfield in the late nineteeth century. For thin sheet applications the high (>1wt%) carbon levels in Hadfield steels mean that they are difficult to process and have very limited weldability. Moreover the relatively low Mn content (~15%) facilitates the martensitic transformation γ→α' under plastic deformation. Reducing the carbon concentration and compensating with an increase in the manganese level conserves austenitic structure, suppresses the formation of α' martensite and lead to excellent mechanical properties. Several steelmakers have attempted to exploit this possibility either in conjunction with aluminum additions or aluminum and silicon additions. This compositions have the advantage that a significant reduction in density can be achieved. One TWIP/TRIP-steel TWIP/TRIP 1and two dual-phase steels DP 800 (HCT780X) and DP 1000 (HCT980X) were investigated. The chemical composition is given in Table 1[2, 3].

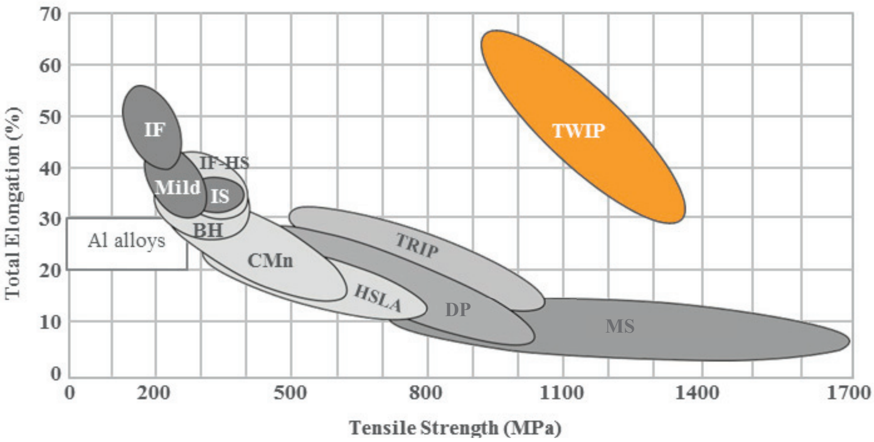


Fig. 1. Mechanical Properties.

Table 1. Chemical composition [%].

Material	C	Mn	Si	Al	Cr+Mo	V	B
HCT780X	0.17	1.98	0.29	0.07	0.88	0.12	0.004
HCT980X	0.21	2.45	0.57	0.16	0.89	0.14	0.003
TWIP/TRIP 1	0.71	15.24	2.29	2.43	0.11	-	0.002

Nomenclature

E	Young's modulus
σ_{ij}	stress
ε_{ij}	strain
ν	Poisson's number
t	thickness
ρ	radius

2. Material's description

2.1. Static tensile tests

Simple tension tests were carried out based on ISO 6892 and ISO 10113 with specimens (Fig. 2) prepared by water-jet cutting and laser cutting to evaluate surface condition effects. Tensile speed was 0.1 mm/s, which corresponds to approximately 0.002 1/s in the engineering strain rate considering a 50 mm gauge length. Specimens were prepared along and orthogonal to the rolling direction. Test results were compared with that of the DP 800 and DP 1000 specimen as shown in Fig. 2. As for the TWIP/TRIP 1 steel, the maximum elongation was larger than 55% and the tensile strength was close to 1000MPa, while the initial yielding strength was almost as low as that of the DP800 steel. The TWIP/TRIP 1 steel had a larger area under the hardening curve compared to that of the DP 800 and DP 1000 steel, implying larger toughness and energy absorption capability of the TWIP/TRIP 1 steel. The earlier failure of the TWIP/TRIP 1 specimens prepared by water-jet cutting confirmed the ductility sensitivity to the surface condition of the TWIP/TRIP 1 steel sheet, requiring its test specimens need to be prepared with care for tests. The large hardening rate (associated with twinning) observed in the stress strain curve (along the rolling direction) shown in Fig. 3 corresponds to an n-value of 0.42 when fitted with the Swift hardening law.

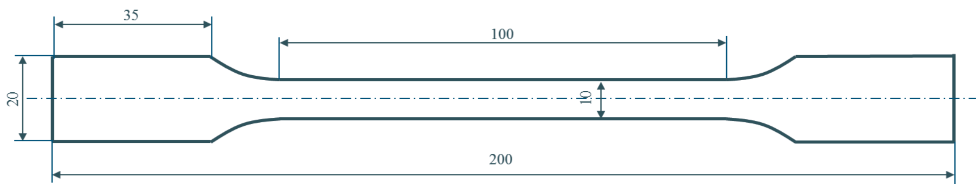


Fig. 2. Tensile test specimen.

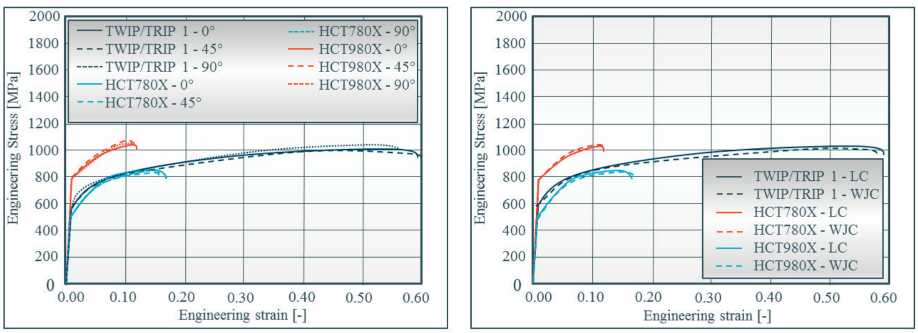


Fig. 3. (a) Stress-strain curve; (b) Influence of surface conditions.

2.2. Hydraulic bulge tests

Hydraulic equibiaxial bulge tests were performed, characterizing the flow behavior at strain levels beyond the uniform elongation of the uniaxial tensile test. The test was realized in a modular tool system consisting of a die, blank holder and a fluid chamber installed in a hydraulic press Dunkes HD250 with a maximum force of 2500kN.
Initially, a circular blank is clamped between the die and blank holder with the lock restricting material flow between the tools (Fig. 4). A bulge is then formed by pressing a fluid slowly into the chamber until fracture occurs. The deformation of the blank is continuously recorded with a GOM Aramis system, which estimates the strain field in the sheet plane as well as the blank curvature radius and correlates them to the measured values of the fluid pressure. The true stress-strain curves from the uniaxial tensile test can only be determined up to the plastic strain

at the instability point. Since much higher plastic strain are usually attained in forming processes, the curve needs to be extrapolated. To minimize the deviation from the actual flow behavior at high plastic strains hydraulic bulge test were performed. First result is a significant influence a significant higher plastic strain in stretch forming for TWIP/TRIP 1 steel compared to DP 800 and DP 1000 (Fig. 5). The combination of uniaxial tensile test up to the uniform elongation and the converted curve from the hydraulic bulge test beyond it was used.

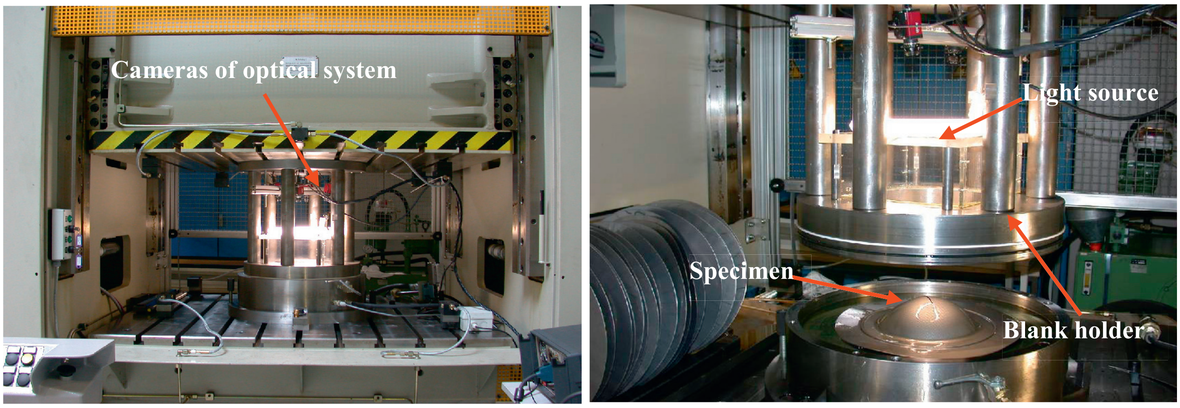
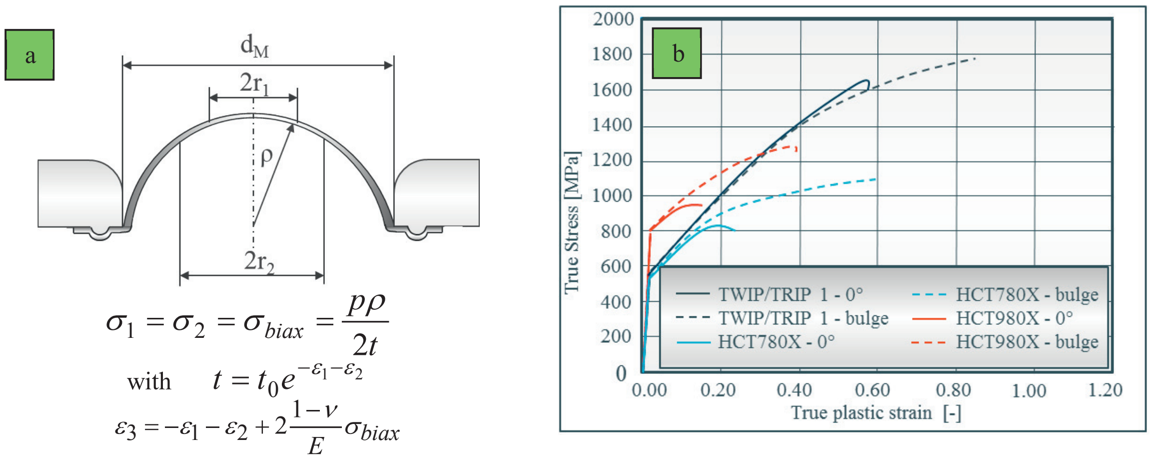


Fig. 4. Setup hydraulic bulge test.



$$\sigma_1 = \sigma_2 = \sigma_{biax} = \frac{p\rho}{2t}$$

with $t = t_0 e^{-\varepsilon_1 - \varepsilon_2}$

$$\varepsilon_3 = -\varepsilon_1 - \varepsilon_2 + 2\frac{1-\nu}{E}\sigma_{biax}$$

Fig. 5. (a) Circular areas for averaging sheet thickness t; (b) Hydraulic bulge test results.

2.3. Forming limit diagram (FLD)

The forming limit diagram (FLD) was obtained by conducting the hemispherical dome test based on the ASTM E 2218-02 standard using a 50 ton double action hydraulic type press machine, by varying the width of blanks from 30 mm to 200 mm, while the longitudinal (aligned in the transverse direction) is fixed in length with 200 mm. Test were performed with lubrication. Test specimens were carefully prepared by laser cutting since test results were sensitive to surface conditions. With test specimens prepared with less care, failure occurred at the edge of specimen, resulting in inaccurate measurement. The measured forming limit curve is shown in Fig. 5, compared with that of the DP 800 and DP 1000 steel. The FLD (when the minor strain vanishes) of the TWIP/TRIP 1 is much larger than that of the DP 800 and DP 1000, suggesting superior formability of TWIP/TRIP 1compared to DP 800 and DP 1000 (Fig. 6)[4].

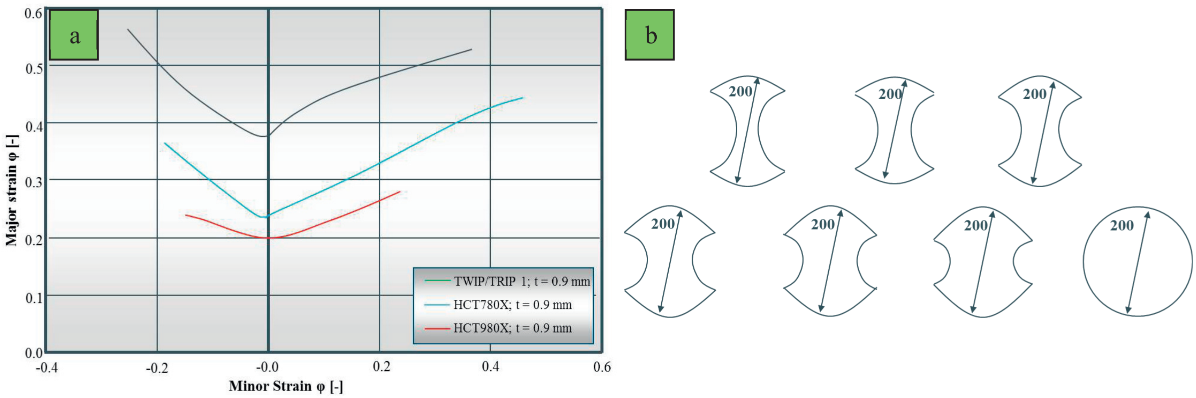


Fig. 6. (a) Forming limit curves; (b) Hasek specimens.

3. Forming simulation

3.1. Formulation of yield functions

Based on the measured material properties, three yield functions were formulated: Mises, Hill 48 and Barlat-3k. In addition to that MF-GenYld from MatFem was used for TWIP-materials. In order to evaluate the anisotropic behavior of TWIP/TRIP 1 a stress based material approach has to be considered (Fig. 7).

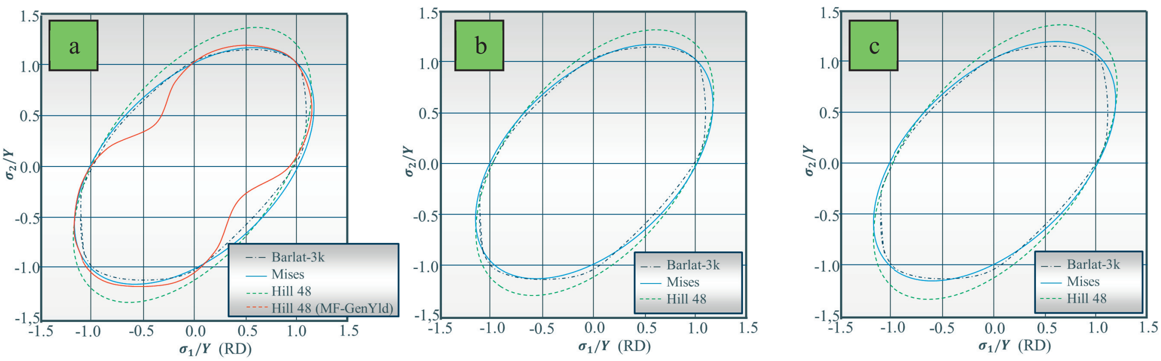


Fig. 7. Yield locus (a) TWIP/TRIP 1; (b) HCT780X; (C) HCT980X.

3.2. U-Profile simulation results

Fig. 8 shows the results for simulation with different materials. Experimental results of u-profiles show a high backspring of TWIP/TRIP 1 and HCT980X steel compared to HCT780X. Simulations with MF-Gen Yld led to good prediction accuracy of TWIP/TRIP1 steel with a stress based approach. HCT780X and HCT980 show good results with Hill48 criterion (Fig. 8).

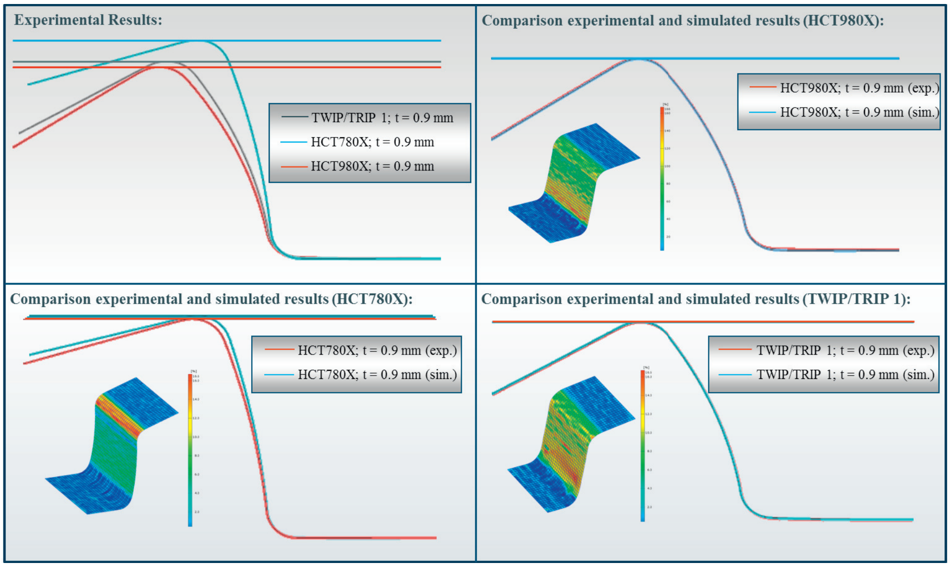


Fig. 8. Experimental and simulated results U-Profile.

4. Conclusions

Different material properties such as hardening curves, r-vlaues and FLD were characterized for TWIP/TRIP1, HCT780X and HCT980X. Compared to dual-phase steels TWIP/TRIP1 had large strain hardening rate, strength and total elongation with slightly negative average rate sensitivity and anisotropy in the elastic and plastic properties. TWIP/TRIP1 was sensitive to surface conditions as confirmed with the simple tension test utilizing water-jet and laser cutting. Anisotropic properties were obtained considering the directional difference in the yield stress and the plastic strain ratio measured from the uniaxial tension test as well as the hydraulic bulge test. A stress based approach has to be considered for TWIP-materials for high prediction accuracy in forming simulation.

Acknowledgements

The authors thank Salzgitter Mannesmann Forschung GmbH for fruitful collaboration and the provided material as well as Volkswagen Research and Development for valuable comments and specimen preparation. Also Sitech Sitztechnik GmbH is gratefully acknowledged.

References

[1] Chung,K; Ahn,K.; Yoo,D.-H.; Chung, K.-H.; Seo, M.-H.; Park,S.-H., 2009. Formability of TWIP automotive sheets, International Journal of Plasticity, elsevier, Seoul.
[2] Grässel,O., 2000. High strength Fe-Mn-(Al, Si) TRIP/TWIP steels development – properties – application; International Journal of Plasticity, Pergamon, Düsseldorf.
[3] Kuntz,M., Lampenauer,K., 2007. Verformungsmechanismen hochmanganlegierter austenitischer TWIP-Stähle, Stahl und Eisen, S. 83-89, Stuttgart.
[4] Peshekhodov, I., Vucetic, M., Bouguecha, A., Behrens, B.-A., 2012. Characterization of the quasi-static flow and fracture behavior of dual-phase steels in a wide range of plane stress states, Auto Met Form, S. 265-278, Wroclaw.