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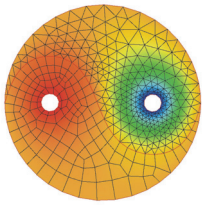
AKAPIT

COMPUTER METHODS IN MATERIALS SCIENCE

Informatyka w Technologii Materiałów

Vol. 7, 2007, No. 1



MODELLING THE MECHANICAL PROPERTIES OF MULTIPHASE STEELS

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Abstract

Due to economic, environmental and safety reasons the use of high strength steels for the automotive industry is increasing rapidly. For an optimal combination of strength and formability of multiphase steels an accurate material model is required for forming simulations. Currently, the microstructure of multiphase steels is not taken into account in FE simulations of forming processes which is the most important factor influencing the strain hardening behaviour of multiphase steels.

Within this work, an approach is presented which describes the microstructure evolution during intercritical annealing by thermodynamic calculations and predicts the strain hardening behaviour of dual phase steels by means of FE simulation of Representative Volume Elements based on microstructural characterisations. The calculated strain hardening behaviour will be used for the FE simulation of real forming operations.

Key words: dual phase steel, mechanical properties, FE simulation, representative volume element, modelling, intercritical annealing, microstructure, multiphase steels

1. INTRODUCTION

The application of high strength steels in the automotive industry is increasing rapidly due to economic, environmental and safety reasons. For an optimal combination of strength and formability of multiphase steels, an accurate material model is required for forming simulations. In FE simulations of real forming operations, the microstructure of multiphase steels is not considered at the moment, which is the most important factor influencing the strain hardening behaviour of multiphase steels.

In international projects like the ULSAB project, especially dual phase steels play an important role for the automotive industry (figure 1). Their strain hardening behaviour is strongly influenced by the microstructure as well known from several experimental investigations. Dual phase steels are composed of a soft ferritic matrix with hard inclusions of martensite, which causes a good formability and a high strength level.

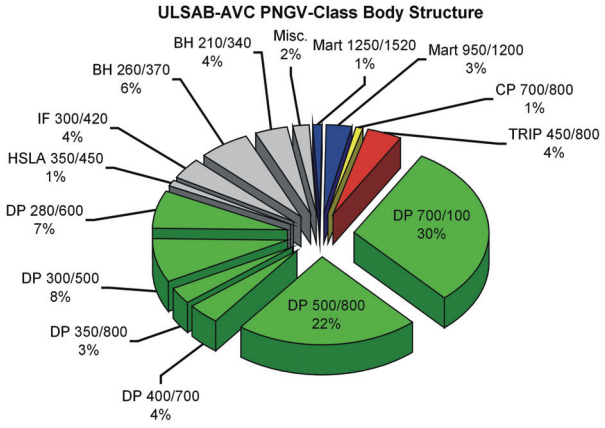


Fig. 1. *Future steel application in car bodies, according to international projects.*

ISSN 1641-8581

The description of the microstructure, the determination of the strain hardening behaviour and the formability will help to optimise the properties of multiphase steels by a precise microstructure design. Within our investigations, an approach is presented which describes the microstructure evolution during intercritical annealing by thermodynamic calculations and predicts the strain hardening behaviour of dual phase steels by doing FE simulation. For FE simulation a Representative Volume Element (RVE) is used based on microstructural characterisations.

2. EXPERIMENTAL WORK

The chemical composition of the investigated dual phase steel is presented in Table 1. The material has a ferritic/pearlitic structure after cold rolling.

Table 1. *Chemical composition of the investigated dual phase steel (mass%).*

Material	C	Si	Mn	P	S	Cr	Ni	Al	Cu	V
DP600 (thickness 1mm)	0,079	0,246	1,580	0,015	0,001	0,553	0,024	0,031	0,010	0,011

The samples were immersed in salt bath (holding time 5min) at temperatures of 740°C - 820°C and afterwards quenched in water. Three parallel tensile tests were carried out with one sheet and additionally, a metallographic characterisation of the sample was performed. The results of the experiments are presented in section 4.

3. THERMODYNAMIC CALCULATIONS

The amount and the carbon content of austenite and ferrite depend on the annealing temperature and on the holding time. Higher annealing temperatures causes higher austenite contents with a lower carbon level, the carbon content in ferrite is also slightly decreasing with increasing annealing temperatures. After a fast quenching, the austenite transforms to martensite, which yields a material of a soft ferrite matrix with strong martensite islands.

For the determination of the phase amounts and the carbon partitioning between the two phases, a DICTRA calculation was carried out, which considers thermodynamic and kinetic effects during intercritical annealing. This is favourable due to the fact, that the thermodynamical equilibrium can not be reached with a holding time of 5min in the intercritical area. The results of DICTRA simulation are shown in figure 2.

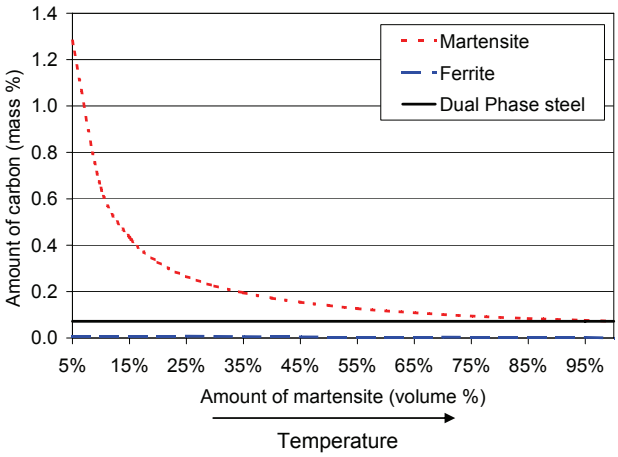


Fig. 2. *Results of the DICTRA simulation for an intercritically annealed dual phase steel.*

4. FINITE ELEMENT SIMULATION

Numerical calculations of the flow behaviour of dual phase steels were performed by using the finite element code ABAQUS/Standard. A finite element mesh was generated as a Representative Volume Element of the material using 10-node-tetrahedron elements. In order to get a two phase structure, elements around a randomly chosen corner node were defined as the second phase. Thereby the second phase was defined as a cluster of 32 elements with the shape of a tetrakaidekahedron (figure 3). A detailed description of the RVE can found in the thesis of Kaluza (2004).

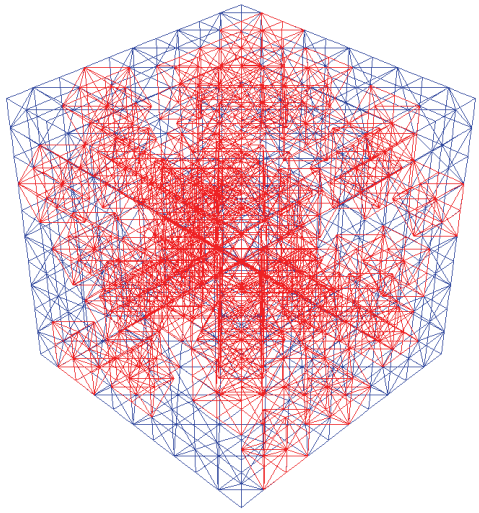


Fig. 3. *RVE with 30% martensite.*

For the calculation of the ferritic and martensitic input flow curves, a model based on dislocation theory (Bergström, 1969; Estrin & Mecking, 1984; Gil-Sevillano, 1993) with the original constants of Rodriguez & Gutierrez (2003/2004) was used as

shown in (1) and table 2. The dislocation mean free path was estimated to be 15 µm.

$$\sigma = \sigma_0 + \Delta\sigma + \alpha * M * \mu * \sqrt{b} * \sqrt{\frac{1-\exp(-Mk\varepsilon)}{k * L}} \quad (1)$$

M: Taylor factor (M=3); µ: shear modulus (µ=80 000MPa)

b: Burger's vector (b=2,5*10^{-10}m)

σ_0: Peierls stress and effects of elements in solid solution

σ_0 = 77+80*(%Mn)+750(%P)+60*(%Si)+80*(%Cu) +45*(%Ni)+60*(%Cr)+11*(%Mo)+ 5000*N_{ss}

α: constant

$\Delta\sigma$ strengthening by precipitation and carbon in solution

L: dislocation mean free path

k: recovery rate

C_{ss}: carbon in solution

[C]: carbon in martensite

d_α (m): ferrite mean linear intercept

Table 1. *Model for the calculation of flow curves of the single phases (Bergström, 1969; Estrin & Mecking, 1984; Gil-Sevillano, 1993; Rodriguez & Gutierrez 2003/2004).*

Phase	$\Delta\sigma$	$L(m)$	k
Ferrite	5000*C_{ss}	d_α	$10^{-5}/d_\alpha$
Martensite	3065[C]-161	3,8*10^{-8}	41

The input flow curves for the dual phase steel are calculated for each annealing temperature separately, based on the thermodynamical approach presented in section 3. Except of carbon partitioning all other elements are assumed to be uniformly distributed in the ferritic and martensitic phase. In figure 4, the input flow curves of ferrite and martensite for a volume content of 30% martensite are shown (annealing temperature approximately 775°C).

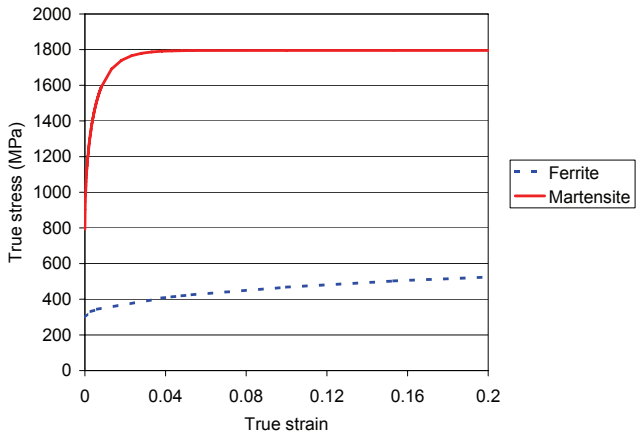


Fig. 4. *Example for the input data of the FE simulation for a dual phase steel with a martensite content of 30%.*

Performing uniform tensile tests in numerical simulation the faces of the mesh had to stay plane and opposite faces had to stay parallel to each other since the modelled finite element mesh was used as a Representative Volume Element of the material. During the simulation one face of the mesh was displaced in one direction.

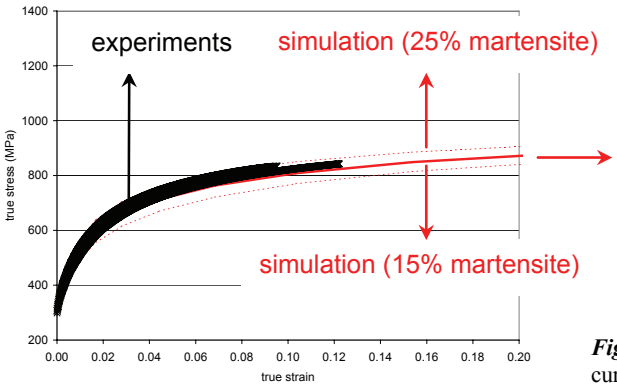
The results of FE simulation are presented in figures 5-9 and compared with experimental determined flow curves in tensile tests (section 2). The results of the FE simulation are in good agreement with the experiments of the tensile tests of salt bath annealed material within the uncertainties of metallographic measurements. The inaccuracy of metallographic measurements of martensite content is +/- 5% volume percent martensite. The yield point for dual phase steels with high martensite contents is underestimated in FE simulation. That is probably due to inaccuracy of input flow curves of the single phases.

5. CONCLUSIONS

Within this work, an approach is presented which describes the microstructure evolution during intercritical annealing by thermodynamic calculations and predicts the strain hardening behaviour of dual phase steels by performing an FE simulation with a Representative Volume Element (RVE), which is based on microstructural characterisations.

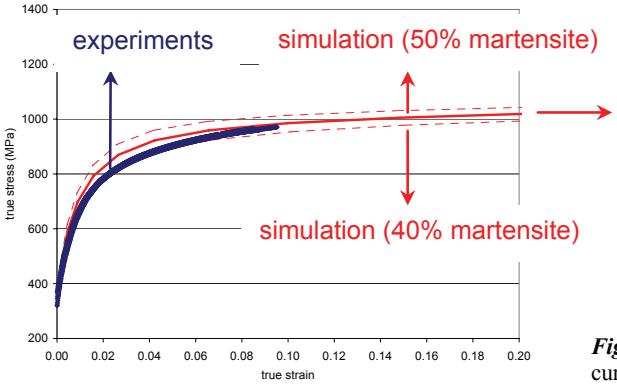
The resulting strain hardening behaviour in simulation shows a good matching with the experimental determined strain hardening behaviour in tensile tests within the error range of the metallographical characterisation except of yield point calculation for dual phase steels with high martensite contents.

Acknowledgement. This research has been funded by the Netherlands Institute for Metals Research (NIMR). The authors would like to thank the NIMR for the scientific and financial support.



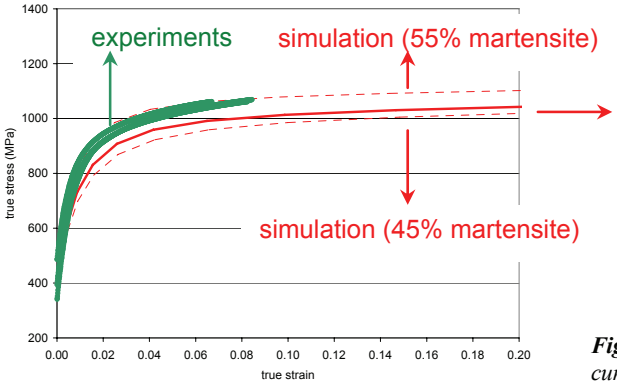
Annealing temperature: 740°C;
Amount of martensite: 20% +/-5
Experiments: 3 tensile tests in rolling direction

Fig. 5. Comparison between experimental determined flow curves and FE simulation



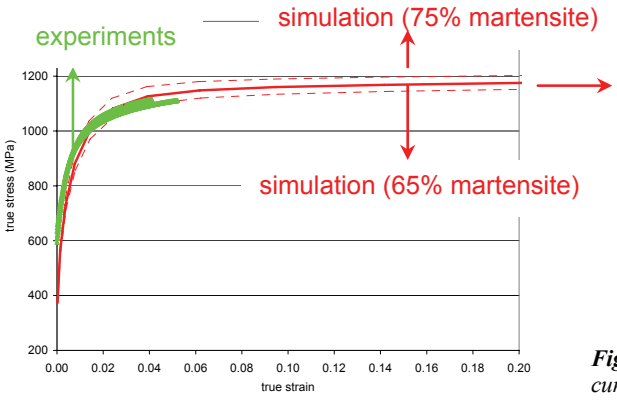
Annealing temperature: 760°C;
Amount of martensite: 45% +/-5
Experiments: 3 tensile tests in rolling direction

Fig. 6. Comparison between experimental determined flow curves and FE simulation



Annealing temperature: 780°C;
Amount of martensite: 50% +/-5
Experiments: 3 tensile tests in rolling direction

Fig. 7. *Comparison between experimental determined flow curves and FE simulation*



Annealing temperature: 800°C;
Amount of martensite: 70% +/-5
Experiments: 3 tensile tests in rolling direction

Fig. 8. *Comparison between experimental determined flow curves and FE simulation*

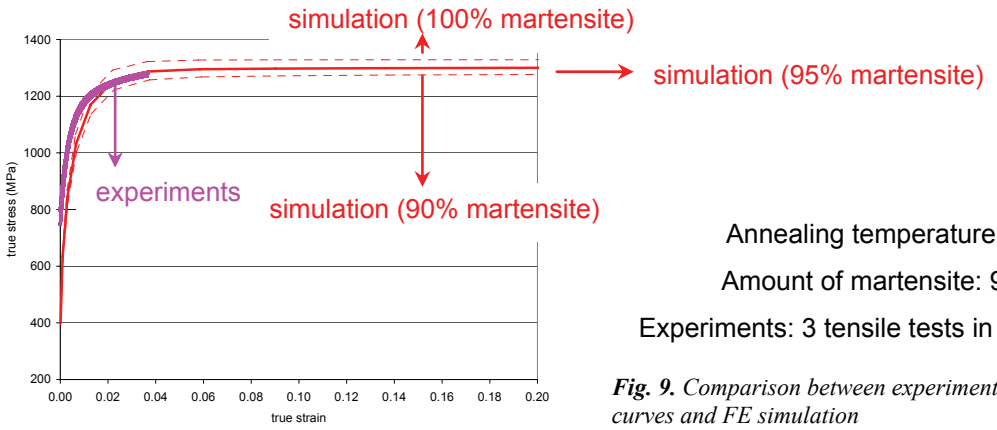


Fig. 9. *Comparison between experimental determined flow curves and FE simulation*

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MODELOWANIE WŁASNOŚCI MECHANICZNYCH STALI WIELOFAZOWYCH.

Streszczenie

Z powodów ekonomicznych, środowiskowych oraz bezpieczeństwa gwałtownie wzrasta zapotrzebowanie na wytrzymałą stal dla przemysłu samochodowego. W celu otrzymania optymalnej kombinacji wytrzymałości i plastyczności dla materiału wielofazowego, wymagany jest odpowiedni model materiału, który następnie zostanie wykorzystany w symulacji. Obecnie mikrostruktura materiału wielofazowego nie jest brana pod uwagę, a w symulacjach procesów przeróbki plastycznej metodą elementów skończonych jest ona jednym z najważniejszych czynników wpływających na umocnienie materiału. Niniejsza praca przedstawia podejście opisujące rozwój mikrostruktury podczas etapu wyżarzania poprzez zastosowanie obliczeń termodynamicznych oraz przewidujące efekt umacniania dwufazowej stali. Analizę prowadzono z zastosowaniem odpowiednich symulacji MES. Obliczone parametry wykorzystane zostaną w rzeczywistym procesie przeróbki.

Submitted: November 21, 2006
Submitted in a revised form: November 6, 2006
Accepted: December 6, 2006