



Doctoral Thesis

Virtuelle Bestimmung des Verfestigungsverhaltens von Bändern und Blechen durch verformungsinduzierte Martensitbildung bei metastabilen rostfreien austenitischen Stählen

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**Virtuelle Bestimmung des
Verfestigungsverhaltens von Bändern
und Blechen durch
verformungsinduzierte Martensitbildung
bei metastabilen rostfreien
austenitischen Stählen**

ABHANDLUNG

zur Erlangung des Titels

DOKTOR DER TECHNISCHEN WISSENSCHAFTEN

der

EIDGENÖSSISCHEN TECHNISCHEN HOCHSCHULE ZÜRICH

vorgelegt von

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Dipl.-Ing. der TU-Berlin

geboren am 24. März 1970

von

Richterswil ZH

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Virtual Determination of Forming Limits of Metastable Austenitic Stainless Steels Applied to Sheet Forming Processes

Summary

The real potential of metastable stainless austenitic steels – the low cost variants of the CrNi - SAH grades – can be utilized for the production of deep drawn parts in a restricted manner only without having the possibility to simulate the strain hardening and deformation behaviour including the structural change due to formation of deformation induced martensite. The given spread of the standards for chemical analysis and process parameters during production of strip and sheet material from these grades in connection with the generally accepted material data do not allow a satisfactory statement with regard to martensite formation and transformation during forming. This lack of relevant process oriented material models limits definitively the use of these materials for series production with necessary stable results.

The target set for this thesis was therefore – starting from a critical review of the existing attempts and models describing the formation of martensite during forming – to define a concept for relevant data acquisition, develop the respective experimental set-up and finally test in a sufficiently wide programme with sheet samples from different metastable austenitic steel grades in various dimensions in order to be able to formulate a production oriented, usable material model for the prediction of material behaviour – especially the forming limits – when exposed to a deep drawing process. Additionally a testing method had to be conceived for on-line testing of samples/data acquisition of those values necessary for running the developed model which could be integrated into the standard test procedure of strip and/or sheet material.

Critical review of the various attempts to describe or model the martensite formation and transformation for metastable austenitic SAH grades as well as analysis of the specific conditions during the deep drawing process revealed, that neither the isothermal nor the quasi – isothermal approaches published to date could fulfil the requirements set by productional needs; non-isothermal models could in fact describe the martensite related strain hardening for specific cases but were not applicable to

cope with the given target for a production related solution with the up to now used set of data.

Based on the analysis of the deep drawing process, respective testing methods as the extended tensile test (including continuous on-line martensite and temperature measurement), the bulge test as well as the Nakazima test for establishing the Forming Limit Curve (FLC) have been selected; these mechanical destructing test procedures have been backed by respective phase analyses through X-ray diffraction pattern and metallographic structure analyses. With these testing procedures, samples from supplies of different producers in different grades and thicknesses were tested or processed within operationally applied forming ranges and deformation speeds. The test results were continuously picked-up and processed via respective data handling programmes. Beside the dependency on the martensite formation ratio and the resulting martensite volume from chemical analysis of the prevailing material and the temperature for different deformation rates, the influence of the sample thickness was considered as well as the respective forming limit curves were produced.

Input of these results from the integral experimental set-up for evaluating the meshed forming/strengthening process of metastable austenitic stainless steels after processing via a specifically developed evaluation programme into the up to now most developed non-isothermal model of Hänsel revealed following results and conclusions:

1. Based on the data safety and accuracy as given by the selected testing procedures and the number of tests, a strongly simplified model can be formulated with an extensive reduction from six to two of the necessary input parameters for the simulation of material behaviour.
2. Supported by the specially developed evaluation programme these data can be gained for any strip or sheet under production conditions/environment directly via the extended tensile test (including continuous on-line martensite and temperature measurement).
3. The parameters obtained as explained, supply in connection with the correlated

strengthening law a multiply verified and thus secured data input set for the simulation of the forming and strengthening behaviour of metastable austenitic stainless steels.

With these results the given target – the development of a simply usable, production oriented material model for simulation of forming processes including the necessary data acquisition on basis of standard in-line testing methods – is clearly reached.

However, to further simplify the testing procedure an additional attempt was made to possibly eliminate the on-line continuous measurement of martensite and temperature during the tensile tests by applying neuronal net technology. With a learning curve based on approximately fifty test data sets, this approach has been successfully proven to be valid so that finally, for a given material, the new material model can be fed directly from respectively processed standard tensile test data and thus the advantages of metastable austenitic stainless steels for the stable/robust production of deep drawn parts can be fully gained.

The future processing in large scale production of such parts from metastable austenitic stainless steels will thus go along the chain of process steps as shown below.

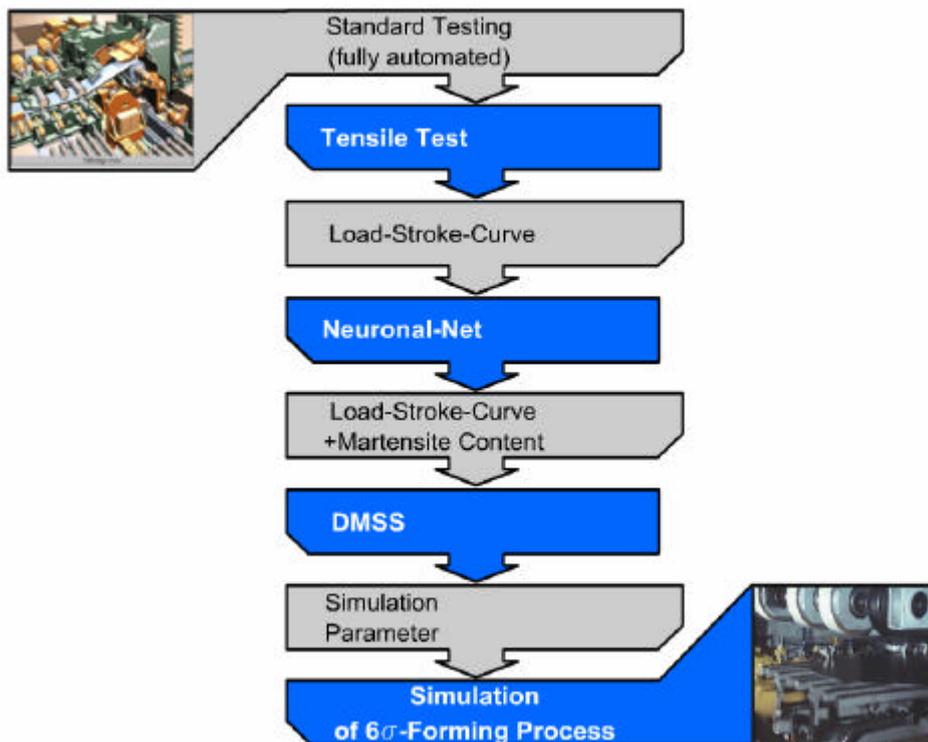


Abbildung 1: Virtual Determination of Forming Limits of Metastable Austenitic Stainless Steels

Based on the experience as gained during this work it is felt, that the principles set forth can successfully also be applied to modelling of low alloyed metastable steels (e.g. TRIP steels).