Microstructure modelling for aerospace forging

- problems in investigating material data -

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Besides the simulation of metal forming processes showing material flow, stress- , strain distribution, temperature distribution etc. the microstructure modelling was developed intensively during the last ten years. These developments were very much influenced by the requirements of the aerospace industry.

This paper describes such a model for INCONEL 718 and shows typical results of an application. In addition the paper shows the state of the art of material data investigation for stress-strain curves and explains the influence of the stress-strain curves on the quality of the results of a microstructure analysis.

The paper wants to show that microstructure modelling is available, but that the quality of results is very much depending on input data (stress-strain-curves) which is not available in a sufficient quality. R&D in "old" fields like stress-strain curve investigation is still to be done.

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Introduction

Simulation is useful and necessary in the layout and analysis of forging processes. Especially in the aerospace industry there is an increasing demand to add micro structural analysis to such simulations. The clients want to check the hole technical data related to a product including not only the process parameters, the geometry, flow lines etc. but also the microstructure. This demand let to an intensive R&D activity in the last ten years.

Basic modelling

The figures in the appendix A show the principle structure of a microstructure model. Such a model consists of three sub models describing dynamic re-crystallisation, static re-crystallisation and a sub model to describe grain growth.

Typically a micro structural analysis starts from an initial situation with strain rate = zero and a given grain size.

During the metal forming operation (strain rate > 0) the grain distribution changes due to the dynamic re-crystallisation.

During periods of interruption of the forming operation or at the end of a forming sequence (strain rate = 0) the grain distribution will change due to static re-crystallisation and grain growth.

In a rolling process this procedure is well defined. For each forming operation it can be simply decided where the material is plastic or rigid.

In a forging operation the situation is much more complex due to the fact that the status (rigid material movement or plastic deformation) can change several times during the process. The local material status has to be considered continuously and this requires special considerations in coding a micro structural model for forging.

Application example

Appendix B shows an example of an application of a micro structural model for INCOLNEL 718.

The first figures show the geometry during the process in different tool positions.

Further figures show a sequence of temperature distributions and strain distributions and flow lines at the end of the operation.

The next figures show a comparison between the strain distribution and the re-crystallised fraction in different tool positions.

In the following figures detailed microstructure information is given.
The first figure shows the grain size distribution (D) deriving from dynamic and static re-crystallisation. For the material generates a dual phase (duplex) structure during dynamic re-crystallisation the average re-crystallised diameter (D d) is given as well as the diameter of the fine grain (D min) and the diameter of the coarse grain (D max) and the percentage of the fine grain fraction (F min).

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For static re-crystallisation the time of re-crystallisation (t) is given.

These figures show the typical information that can be gained from a micro structural model.

The results besides others are very much influenced by the used stress-strain curves. Depending on these curves all values of strain, strain rate, temperature etc. influencing the microstructure will have a good or poor quality.

Therefore the quality of the used stress-strain curves is decisive for the quality of microstructure analysis.

State of the art of stress-strain curve investigation

In the FORGE-NET project one of the topics is to analyse the existing situation in the area of material data investigation.

In Appendix C an extract of a report from the FORGE-NET is shown.
The used stress-strain curves derived form a report of NPL. This report describes the results of a comparison of stress-strain curve investigations undertaken at several institutions with sound reputation in the field.

The material data used in the report was NIMONIC 901.

For this material simulations of ring compression were performed using material data from the different sources.

The figures in the appendix show the very different results. Even the geometry develops different.

Conclusion

Micro structural modelling in principle can be done with success. There exist models that can be used. But the material data sources are not that reliable that a simulation of microstructure can be done successfully without careful consideration of the material data input.

The stress-strain curves are a weak point in this content.
There is still a lot of R&D work to be done to get at least a commonly agreed standard in measuring these values. Without doing this step forward any simulation of microstructure will remain imprecise.

Acknowledgements

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CPM express their acknowledgements to all partners involved in these developments.

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Appendix A

General Microstructure Model for a metallic Material

A) Typical microstructure sub-models:

1. Model for dynamic re-crystallization

$D_{dyn.rec.} = f(D_0, \epsilon, \dot{\epsilon}, T, \text{etc.})$
└ dyn. re-cryst. grain size

$F_{dyn.rec.} = f(\text{different process-param.})$
└ dyn. re-cryst. fraction

Occurrence: during (respectively directly after) the forming
Specialities: eventually formation of a Duplex Microstructure

2. Model for static re-crystallization

$D_{stat.rec.} = f(D_0, \epsilon, T, t, \text{etc.})$
└ stat. re-cryst. grain size

$F_{stat.rec.} = f(\text{different process-param.})$
└ stat. re-cryst. fraction

Occurrence: during holding time after a previous forming
Specialities: eventually premature stop of re-crystallization

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General Microstructure Model for a metallic Material (cont.)

3. Model for grain growth

$\Delta D_{xx.} = f(D_{xx.rec.}, T, t, etc.)$ with: $_{xx.} = _{stat.}$ or $_{dyn.}$
└ growth of the xx. re-cryst. grain

Occurrence: for $\Delta D_{dyn.}$: after termination of dynamic re-crystallization
for $\Delta D_{stat.}$: after a complete static re-crystallization of the remaining microstructure

Specialities: ???

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General Microstructure Model for a metallic Material (cont.)

B) Typical sequence of change of microstructure

initial condition $\longrightarrow$ **forming (forging, rolling)** $\longrightarrow$ **holding time**

$\dot{\epsilon} = 0$ $\dot{\epsilon} \neq 0$ $\dot{\epsilon} = 0$

microstucture: D_0 **microstucture: D_0** **microstucture: D_0**

$D_{dyn.rec.}$

$D_{dyn.rec.} + \Delta D_{dyn.}$

$D_{stat.rec.}$

$(D_{stat.rec.} + \Delta D_{stat.})$

C) Special considerations for numerical modelling

1. rolling: **clear, process depending sequence given**

2. forging: **no clear, process depending sequence given**

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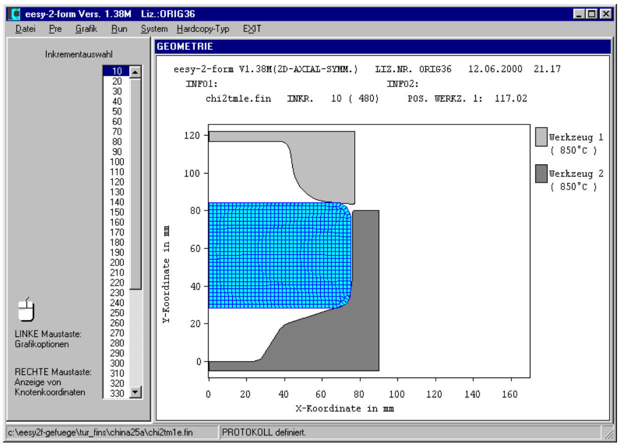
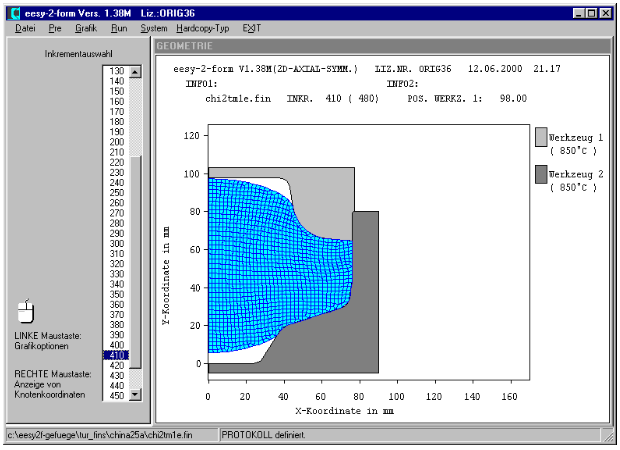
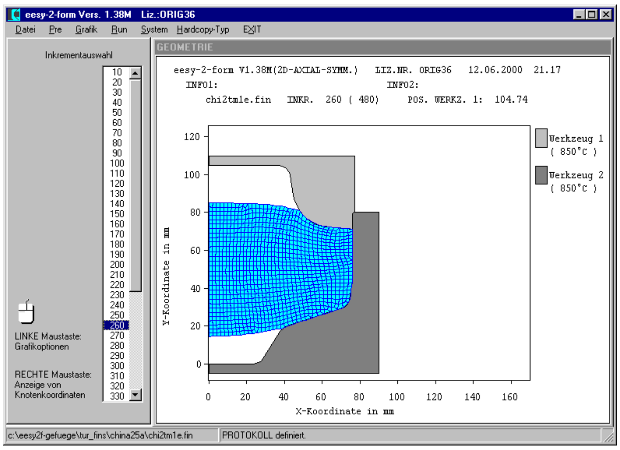
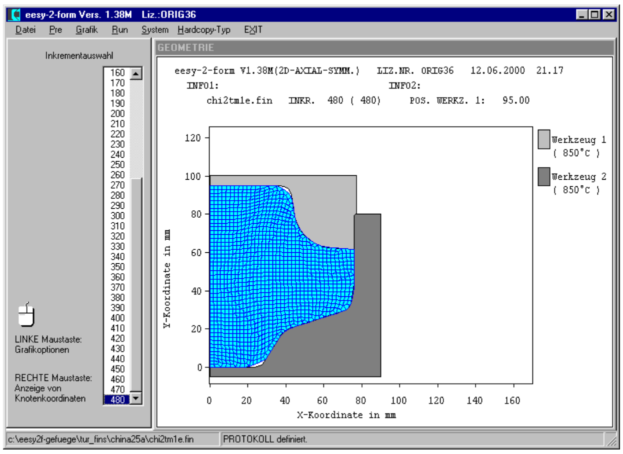
Appendix B









Geometry

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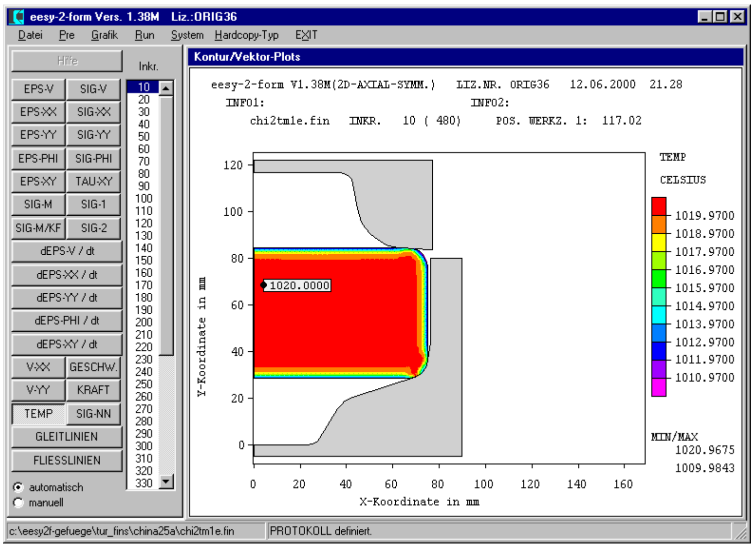

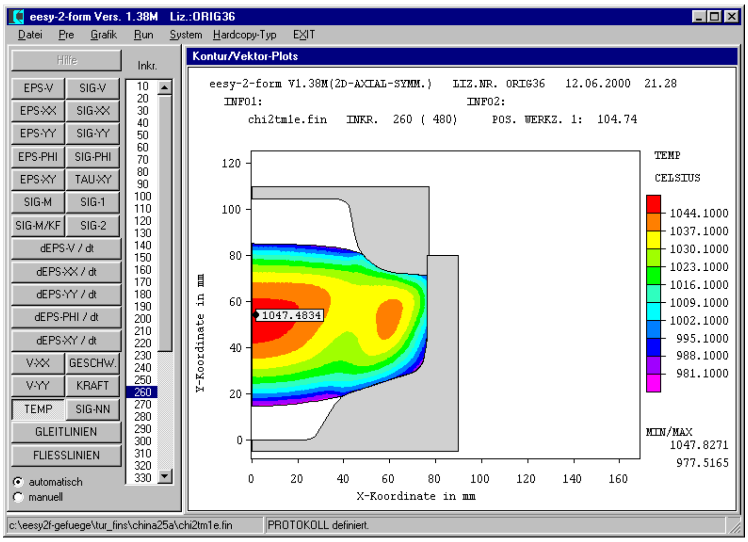

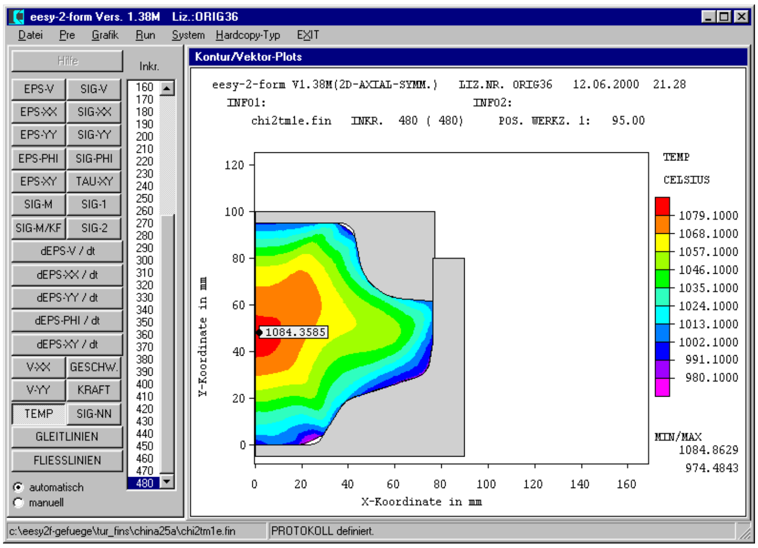

Temperature

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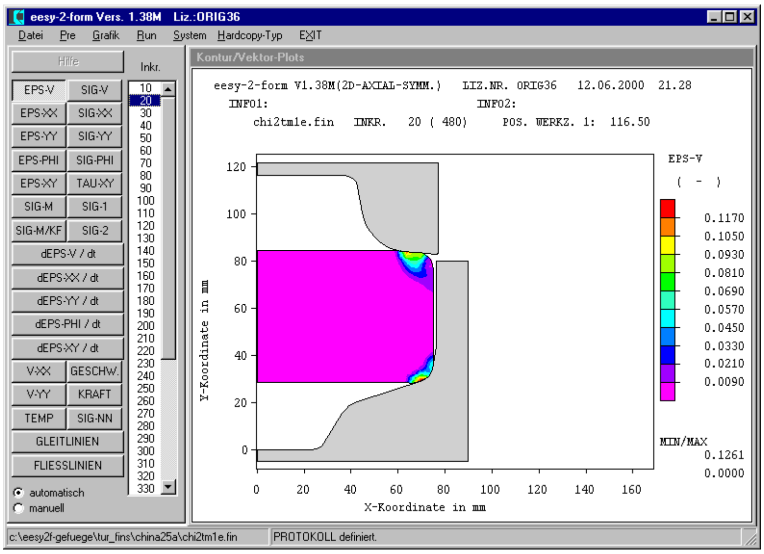

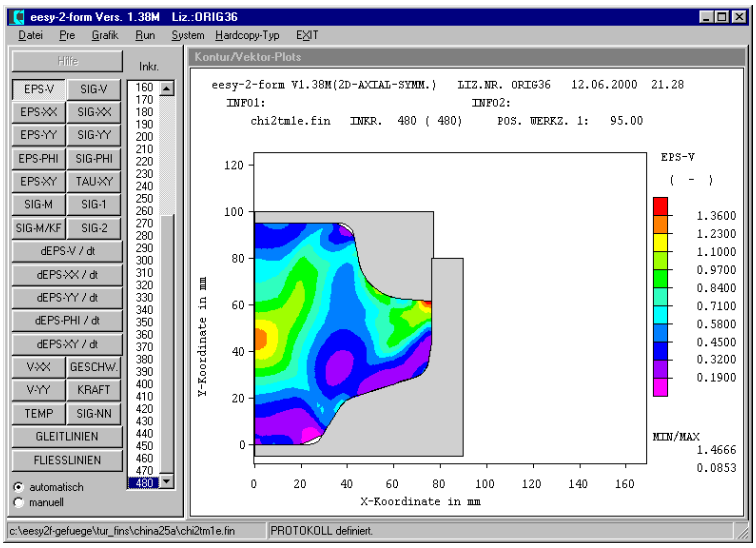

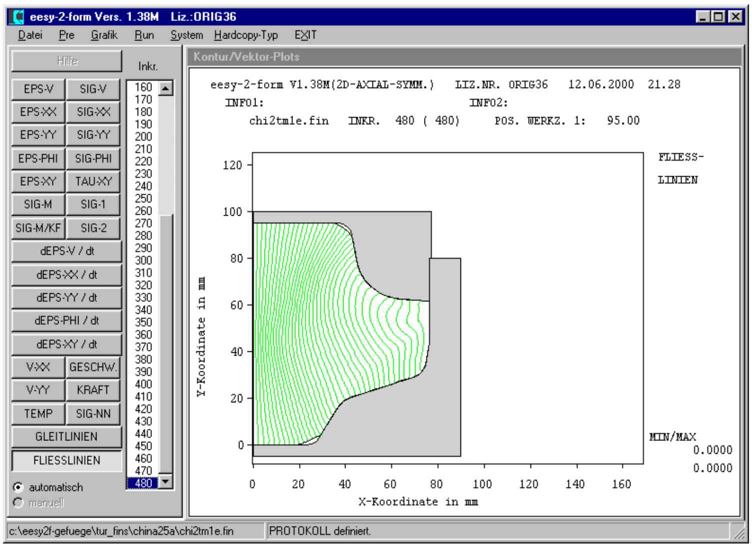

Strain and flow lines

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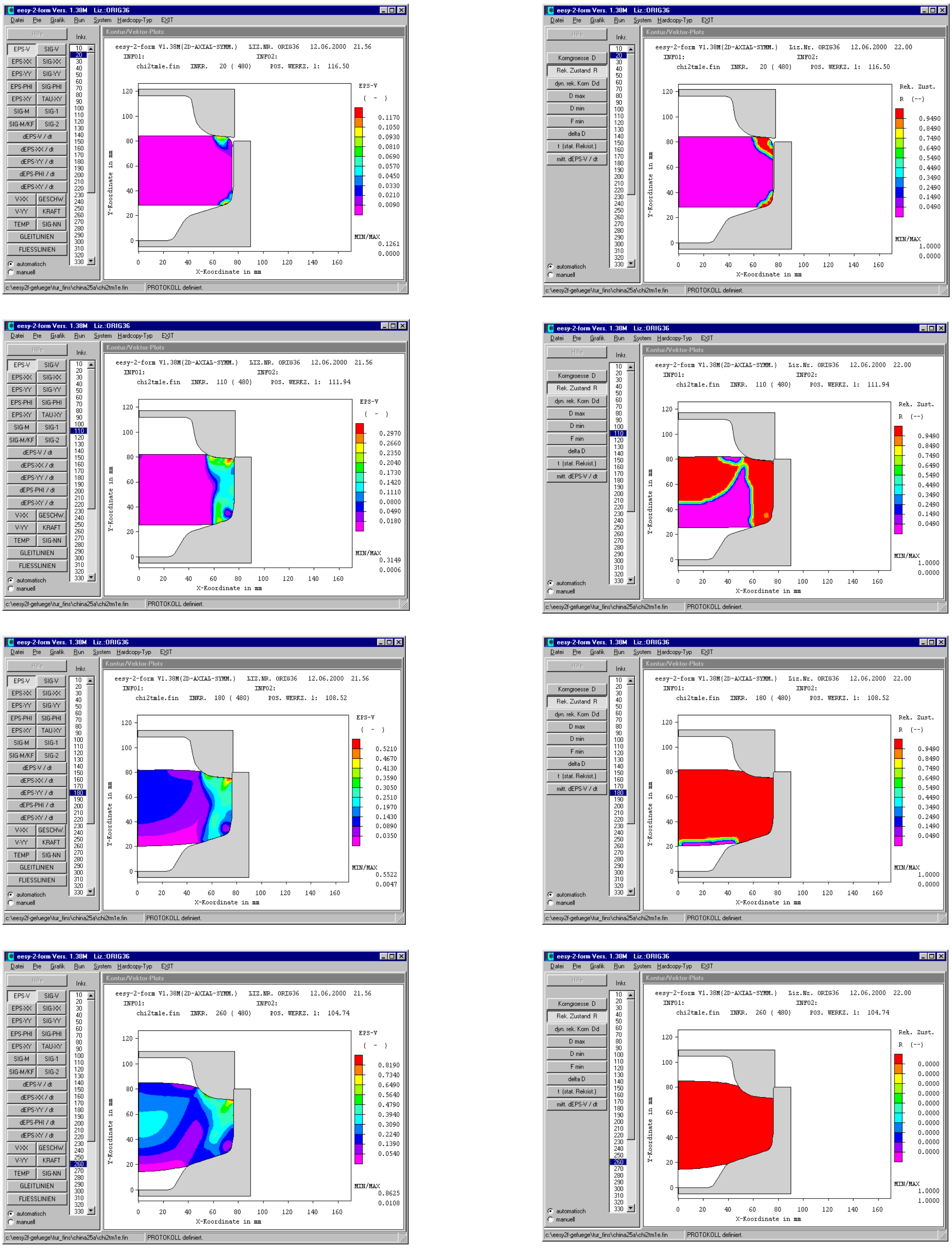

Strain and re-crystallised fraction

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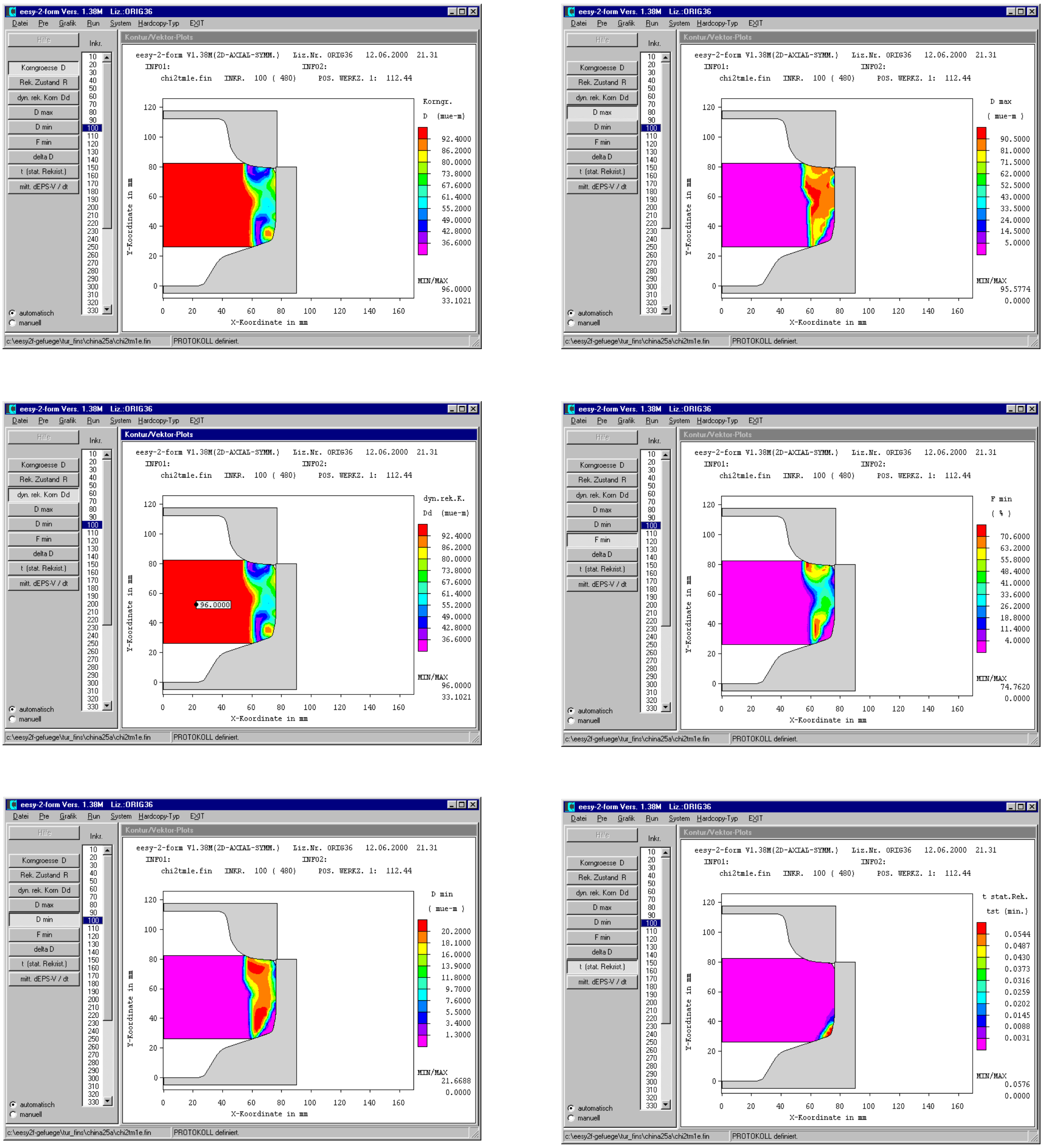

Dyn. re-cryst. grain, D min , F min, D max, D, t

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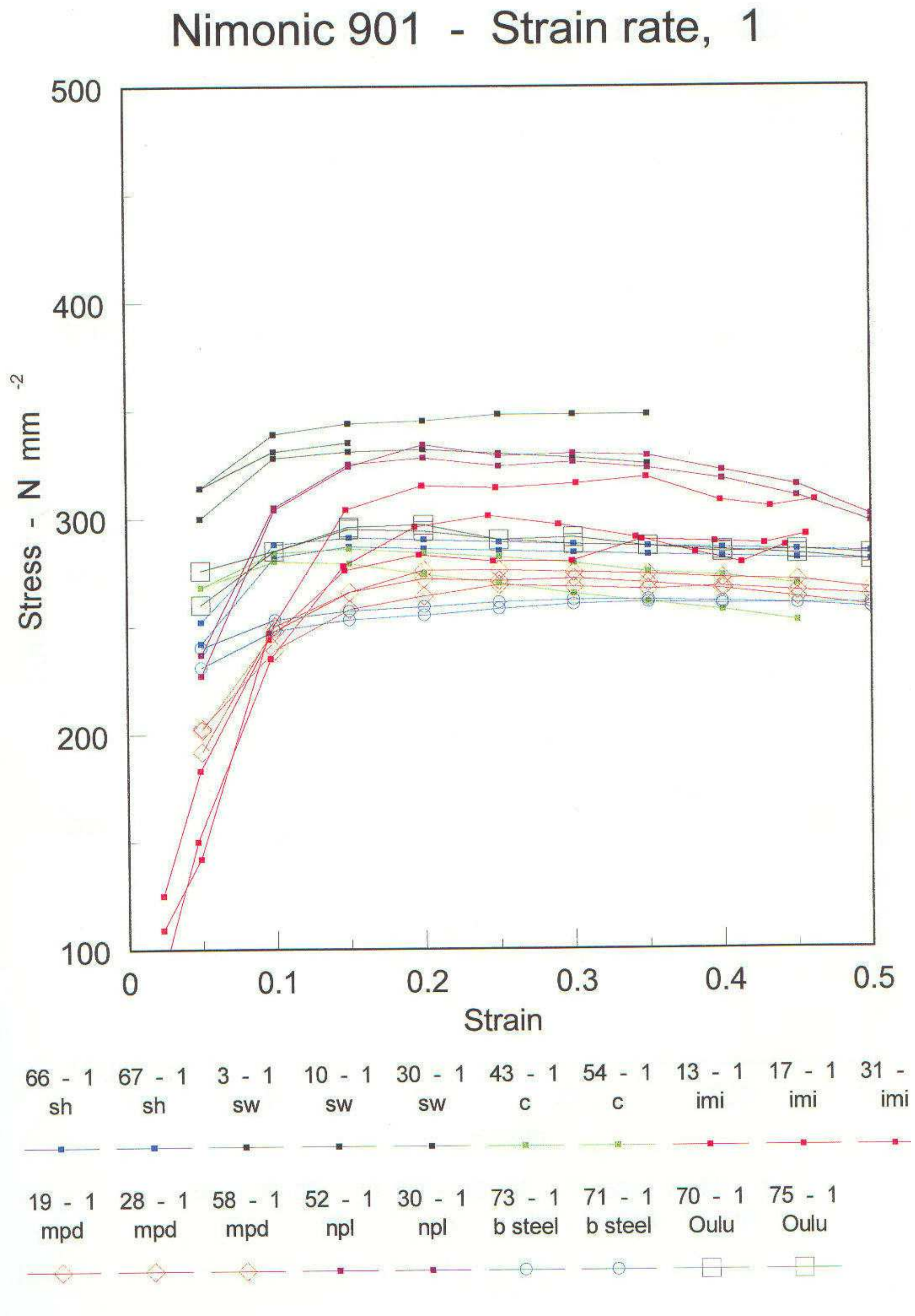

Stress-strain curves from different sources for Nimonic 901

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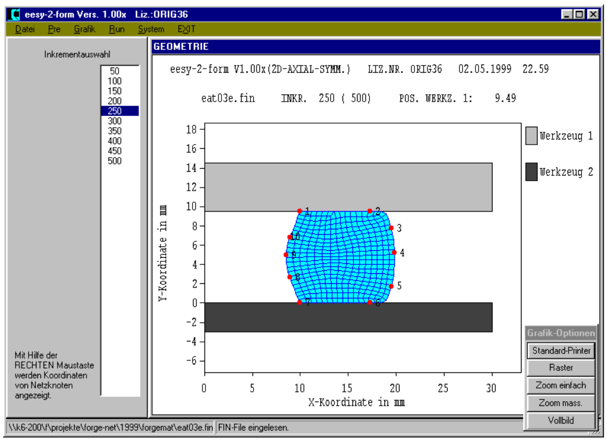
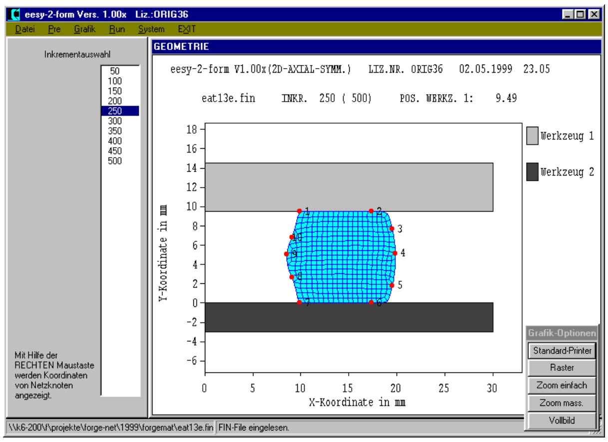


EAT 03: Strain Rate 1.0 , Temperature 1000 °C



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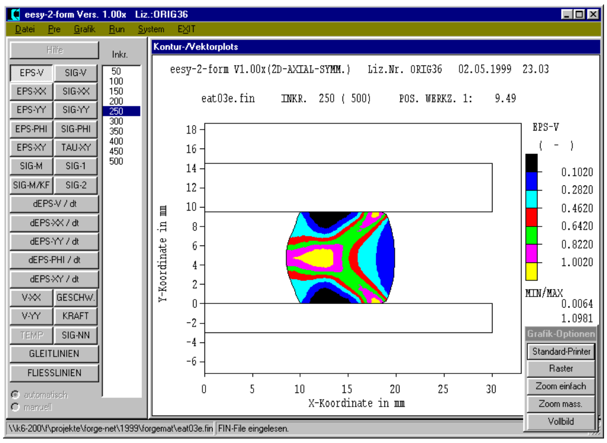

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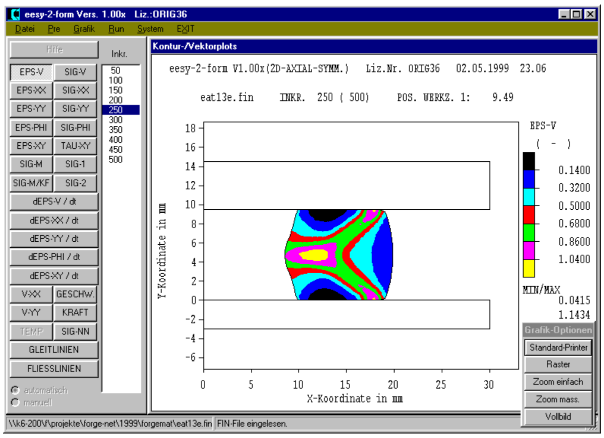

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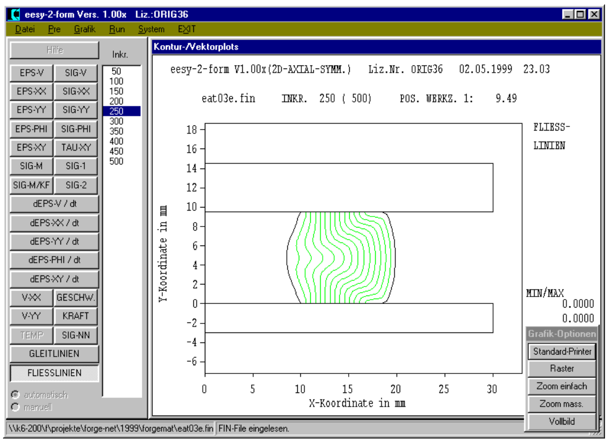

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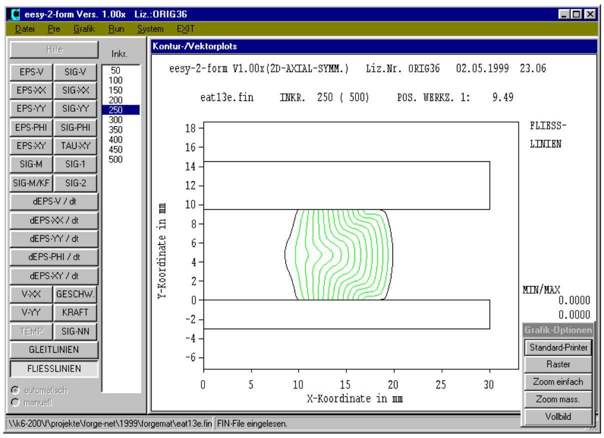

EAT 13: Strain Rate 1.0 , Temperature 1000 °C

Ring test for two different sources of stress-strain curves

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