Testing for Susceptibility to Hot Cracking on Gleeble™ 3500 Physical Simulator

Alsalamah Bassel1 László Kuzsell2,a Zsolt Lukács2,b
1PhD Student, 2Associate Professor
University of Miskolc, Hungary, Institute of Materials Science & Technology
3515, Miskolc-Egyetemváros
Phone: +36 46 565 091 - E-mail: makdekani@uni-miskolc.hu

ABSTRACT

Hot cracks appear when thermal shrinkage together with deformation caused by restraint cannot be accommodated by plastic deformation. This happens during welding to such alloys, which segregate on heating and cooling at near-solidus temperatures, in particular when low-melting and mechanically weak phases form and occur over a wide range of temperatures. To check for susceptibility to the liquation cracking caused by the low-melting, weak phases, hot tensile testing can be used in combination with a thermal cycle resembling that of real welding. This procedure, which can be executed on a Gleeble Thermal-Mechanical Simulator, comprises tensile testing of a number of cylindrical samples at the temperatures below solidus and determining their hot strength and ductility. An alternative to the hot tensile test during the simulated welding cycle is the Strain-Induced Crack Opening (SICO) test.

INTRODUCTION

During this study, I perform experimental series by GLEEBLE 3500 multifunction thermo-mechanical system with a modern physical simulator. GLEEBLE is capable of real-time simulation of various processes.

My test material is ZF50 unalloyed structural steel from which I perform a test of a deformation cracking test using a chemically tested cylindrical test piece. The specimen is heated by the GLEEBLE system and then bulked. As a result of the sealing, the cross-section of the volume fraction exposed to deformation increases considerably. The test is modeled and analyzed using DEFORM finite element software.

To validate physical and mathematical simulations, you must select a parameter that can be measured on the model and on the real piece. The parameters chosen by me will be the orientation of temperature and grain. The temperature is measured in the physical simulation by thermocouples welded to the test specimen. The orientation of the particle of the specimen after the physical simulation has been doubled along the length of the specimen, and then the embedding is visualized by sanding and polishing and milling. Finally, hardness measurements

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were performed in accordance with the matrix given on the metallographically prepared surfaces of the sample.

**PRESENTATION OF GLEEBLE 3500 AND DESCRIPTION OF SICO TESTS**

Physical simulation of material processing processes means modeling in laboratory conditions that accurately replicates the thermal and mechanical processes that reach the material during actual processing. By creating the conditions of final use, the behavior of the material or structure can be investigated, the effects can be analyzed.

At the University of Miskolc, Faculty of Mechanical Engineering and Informatics, Department of Materials and Materials Technology, GLEEBLE 3500 is a fully integrated, digitally controlled thermo-mechanical testing system with Windows-based software computer support that allows extensive thermo-mechanical testing and simulation. The unit can be divided into three main units: thermal, mechanical unit and digital control system.

When a scan or simulation has taken place, the results are automatically loaded into the Origin software, which is part of a powerful and flexible data analysis package that comes with GLEEBLE 3500. Origin offers many built-in math functions for data analysis and includes the LabTalk programming language that can be used to evaluate and process comprehensive, comparative simulation and test data. Origin can be configured to load data for each scan and instantly display any volumes of graphs that allow a quick and easy overview of the measurements. As a further positive note, Origin produces color and graphs of good quality graphics and tables.

![Fig. 1. The GLEEBLE 3500 thermo-mechanical simulator](image)

**SICO TEST**

The cracking caused by the deformation called SICO test is used to test materials that are prone to crack or crack during hot forming. The test can be split
into two phases, heat resistance to the desired temperature of the material, and compression of the material to the fracture appearance.

In the test, the heated sample is discharged using the GLEEBLE system. As a consequence, the diameter of the cylinder increases in the center of the specimen and in the middle, in the part of the deformation, a so-called dud is formed on which the cracks appear.

![Diagram](image)

**Fig. 2.** The outline of the SICO test shows crack formation on the tip of the sample.

The experiment is done on the GLEEBLE system at the Faculty of Mechanical Engineering and Informatics of the University of Miskolc. The GLEEBLE physical simulation is called the SICO test, during the experiment, the specimen is heated up and then stuffed with GLEEBLE. The specimen is made of ZF50, the exact dimensions of which are as follows:

- 85 (+ 0.2) mm long
- 10 (+ 0.2) mm in diameter.

![Image](image)

**Fig. 3.** A specimen for performing a SICO test, with thermocouples welded to appropriate positions.

![Image](image)

**Fig. 4.** After applying the SICO test in the GLEEBLE 3500 system.
The specimen is heated to 1150 °C by resistance heating, then cooled to 950 °C and 23-25 kN compression at 13 mm / s deformation speed. The size of the seal is 13 mm, so the test piece is clamped from 85 mm to 72 mm.

Fig. 5. Test specimens after a SICO test

At the end of the experiment, the data obtained using thermocouples are evaluated.

RESULTS

For symmetrical reasons, on the longitudinal axis of the test piece, only four pairs of thermocouples were fixed at 3 mm apart from the 25 mm section between the jaws only on the 12.5 mm section. Thus, the positions of the thermocouples TC1, TC2, TC3, and TC4 were positioned at a distance of 0, 3, 6 and 9 mm from the center point as in 2.1. Also shown in Fig. The data collected by the device was subsequently evaluated using ORIGIN 8.5 software. In the four tests, the temperatures provided by the four thermocouples can be seen as a function of time.
The diagrams show that in all cases, the temperature of the thermostat TC1 thermocouple corresponds very closely to the temperature of the PTEMP control signal. The black curve can hardly be seen on the chart in all cases. In the SICO 3 test, the TC2 thermocouple signal is not predictable, which indicates a failure of the thermocouple, so exempted that experiment not to affect the other correct results.

The actual deformation is completely identical in all cases. You cannot distinguish between the curves. This proves that the GLEEBLE mechanical control system was working properly, and the hydraulic system worked perfectly. The diagram starts after 55 seconds, as during the test, after the end of the heat cycle, the deformation started at this time.

Test specimens are embedded after etching, prepared for structural testing.
To validate the simulation, you must select a parameter that can be measured on the model and on the real piece. The parameter I choose will be the temperature distribution and the grain orientation. Perform a hardness measurement on a prepared specimen. The hardness is tested with a MVK hardness tester with 1 kg load (HV1).

During the test, a 136 ° peak-angle diamond imprint was pressed into the test material in the same manner as in the Brinell assay. The square pyramid-shaped leaves a mark on the surface of the piece, this is measured off the diagonal, and determined by the Vickers hardness using this. During the hardness measurement, the distance between the lines is 2 mm; the distance between the columns is 1.5 mm. Depending on the location of the test, the individual hardness values are given.
Depending on the location of the test, the hardness values for the specimen 1

DEFORM

Deforms is a Finite Element Method (FEM) based process simulation system designed to analyze various forming and heat treatment processes used by metal forming and related industries. By simulating manufacturing processes on a computer, this advanced tool allows designers and engineers to:

1. Reduce the need for costly shop floor trials and redesign of tooling and processes.
2. Improve tool and die design to reduce production and material costs.
3. Shorten lead time in bringing a new product to market.

Fig. 10. The logical structure of DEFORM
NUMERICAL MODELING OF A SICO TEST IN DEFORM:

I specified the three processes identified by Roman numbers. First, heating process was modelled (I) at 1150 °C for 23 sec during the feedback thermocouple 1. My goal is to approach the inhomogeneous temperature field created by the GLEE BLE system in the work piece as much as possible during this modeling step.

![Temperature vs. Time Graph](image)

**Fig. 11.** The stages of modeling as a function of time

The next characteristic phase is the controlled cooling process (II) in modeling during 20 sec Finally, complete the sealing process at the shutter speed set in the physical test (III). When linking the modeling, I use the DEFORM system to proceed with the next sub-process from any step in the modeling process, thus combining the whole modeling problem.

In the figure 12 On the right side of it appears DEFORM system, prior to the sealing, a deflated flow netting is defined as a wind deflected density, then distorted by the local deformities after forming. This will identify the movements of the individual parts of the material. This provides an opportunity to compare physical modeling and numerical modeling from another aspect.
above we can see in Figure 12 that the right and the left material flow lines show a good match on the basis of a geometric comparison. Overall, it can be stated that if the measured and calculated results are compared in a number of respects, then many results variables in numerical modeling are likely to give good results to the process.

**CONCLUSIONS**

- In my dissertation, physical simulation and mathematical modelization of the SICO test (Strain-Induced Crack Opening) on ZF50 steel grade was performed and the results obtained were validated.

- On the GLEEABLE system, after the cylindrical specimens that made of ZF50 steel are prepared and four thermocouples are welded, I performed short heat treatment cycle, heating up with DC current till 1150 °C hold for 2 seconds then cool down to 950 °C which is the temperature of the experiment when the compression is applied.

- For the mathematical modelization of temperature distribution the DEFORM finite element program was used which has empirical models so the result we have is very close to the real phenomena that’s why it was used during the thesis work.

- For validation, I chose parameters that can be measured in both processes. These two parameters were temperature distribution along the samples and grain orientation after deformation.
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