Petr TOMČÍK*, Radka ŠVRČKOVÁ**, Radim TROJAN***, Adéla MACHÁČKOVÁ****
TEMPERATURE MEASUREMENT DURING THE TENSILE TEST OF 12013 STEEL
WITH ALTERNATING MAGNETIC FIELD APPLICATION
MĚŘENÍ TEPLITVY V PRŮBĚHU TAHOVÉHO TESTU GCELI 12013 S APLIKACÍ
STŘÍDAVÉHO MAGNETICKÉHO POLE

Anotace
Článek popisuje metodiku měření teploty v průběhu tahového testu. Teplota byla měřena
termočlánky s krátkou dobou odevzdy. Sběr dat z experimentů probíhal v reálném čase. Pro měření
teply byla užita měřicí ústředna, která se skládala z PC s operačním systémem Windows 98, měřicí
kartou ICP-DAS 1800H, zakončovacím panelem ICP-DAS DB 8225/2 a termočlánky typu
K s kompenzačním vedením. Při měření teploty v průběhu tahových testů s aplikací střídavého
magnetického pole docházelo k zkreslení dat šumem, který byl vyvolán právě tímto polem. Proto
bylo nutné navrhnout a odzkoušet metody filtrace dat.

Abstract
This paper describes manner and equipment for the temperature measurement during tensile
test. The temperature changes were measured with thermocouples. Experimental data has been
collected to PC during experiments (in real time). For high-speed temperature measuring, was chosen
the thermocouples with a quick time response. For the temperature measuring have been used a
measuring set, which consists of personal computer with Windows 98 operating system, data
acquisition card ICP-DAS 1800H, daughter board ICP-DAS DB 8225/2 and thermocouples type K
with extension grade. During the tensile test with alternating magnetic field application the
temperature measuring data were with noise. The data noises were caused with the alternating
magnetic field that is why there data were filtered. The situation has been described.

Introduction
During plastic deformation the flow stress is influenced with a strain rate, attained strain and
with the temperature. It is needed to determine an evolution of the temperature during tensile test.
About 95-98% from strain energy is changed into heat - adiabatic heating. This process is strain rate -
dependent. We wanted to use the measuring set for temperature measurement during tensile test in
magnetic field application [1]. Main aims were:

☐ measuring the temperature change, which is caused with the magnetic field
☐ average flow stress curves with magnetic field and without

* VŠB—Technical University of Ostrava, Faculty of Mechanical Engineering, Center of Advanced Innovation
Technologies, 17. listopadu 15, 708 33 Ostrava — Poruba, Czech Republic, petr.tomcik@vsb.cz
** VŠB—Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Mechanical
Engineering Technology, 17. listopadu 15, 708 33 Ostrava — Poruba, Czech Republic,
radka.svrckova.st@vsb.cz
*** VŠB—Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Mechanical
Engineering Technology, 17. listopadu 15, 708 33 Ostrava — Poruba, Czech Republic,
radim.trojan.st@vsb.cz
**** VŠB—Technical University of Ostrava, Faculty of Faculty of Metallurgy and Materials Engineering, Center
of Advanced Innovation Technologies, 17. listopadu 15, 708 33 Ostrava — Poruba, Czech Republic,
adela.machackova@vsb.cz

215
Experiment and results

Steel 12013
Steel 12013 is ferritic steel with small quantity of pearlite. The steel 12013 has guaranteed magnetic properties. Chemical composition of the studied steel 12013 is in Table. 1.

Table. 1 Chemical composition of steel 12013.

<table>
<thead>
<tr>
<th>element</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>Al</th>
<th>V</th>
<th>Nb</th>
<th>Zr</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>weight%</td>
<td>0.028</td>
<td>0.415</td>
<td>0.037</td>
<td>0.020</td>
<td>0.007</td>
<td>0.037</td>
<td>0.064</td>
<td>0.002</td>
<td>0.014</td>
<td>0.015</td>
<td>0.030</td>
<td>0.050</td>
<td></td>
</tr>
</tbody>
</table>

The microstructure is composed with ferrite and very small quantity of pearlite.

Temperature measuring
During tensile test the temperature was measured as function of time. These measurements were practised with five thermocouples. Thermocouples were welded on five segments of the sample (Fig. 1). Testing length L1 of the sample was divided into five segments, every segment were 10 mm long. On the right and left side from the centre of every segments, guidelines were plotted (Fig. 1). Their distances between guidelines were 2 mm (Fig. 1).

![Fig. 1](image)

The logarithmic plastic strains around thermocouples were determined from changes measuring guidelines distance. We supposed that maximum measured temperatures for separate thermocouples relate to maximum obtained strains in surroundings these thermocouples. In this way was performed transfer from the measuring temperature as function of time to measuring temperature as function of logarithmic strain.

During the tensile test with alternating magnetic field application the temperature measurement data were distorted with noise (Fig. 2). Because generated voltage, which causes data noise is alternately and measuring thermoelectric voltage thermocouple is direct-current voltage and then could be connected to thermocouple parallel capacity with acceptable sizes [2]. This parallel capacity operates as filter for the data noises. The filtered measuring data with parallel capacity are on Fig. 3. For transparence in Fig. 2 and Fig. 3 are plotted measuring data only for one thermocouple.

216
Fig. 2 Distorted measuring data with noise

Fig. 3 The filtered measuring data with parallel capacity application

**Tensile test**

The strain rate was 0.005s⁻¹ for start the tensile test. The sample was loaded in alternating magnetic field – intensity of magnetic field for start of the tensile test was 470 kA/m. Magnetic intensity was measured with transverse Hall probe. The tensile tests were making also without magnetic field application for confrontation. Average flow stress curves as function logarithmic strain were determined for identical conditions of the experiment (with application magnetic field or without). Average total strains at fracture, the value of the homogenous plastic strains were determined for identical conditions of the experiment too. The partial measurement errors \( \chi \) were calculated too. Then we compared influences of magnetic fields with measurement errors which are determined by Gauss quadratic law accumulation errors.

217
Fig. 4 The sample with welded thermocouples placed in coils, ready for tensile test.

Results

![Graph showing flow stress curves with and without magnetic field]

- **Alternate mag. field**: 470 kA/m
- **Without mag. field**
- **Influence mag. field - softening in units percents flow stress curve without magnetic field**
- **Measurement error in units percents flow stress curve without mag. field**

Fig. 5 Comparison average flow stress curves with magnetic field vs. without magnetic field, influence magnetic field vs. measurement error.
**Fig. 6** Comparison of temperature change during tensile tests

Table 2 Comparison of average total strain at fracture $\varepsilon_f$ with magnetic field vs. without magnetic field, value of the homogenous plastic strains with magnetic field vs. without magnetic field, influence magnetic field vs. measurement error.

<table>
<thead>
<tr>
<th></th>
<th>alternate mag. field 470 kA/m</th>
<th>without mag. field</th>
<th>influence mag. field</th>
<th>measurement error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_f$</td>
<td>0.3630</td>
<td>0.3928</td>
<td>-0.0298</td>
<td>0.0223</td>
</tr>
<tr>
<td>$\varepsilon_{hom}$</td>
<td>0.1480</td>
<td>0.1620</td>
<td>-0.0139</td>
<td>0.0109</td>
</tr>
</tbody>
</table>

**Discussion and conclusions**

The alternate magnetic field with magnetic intensity 470 kA/m for strain rate 0.005 s$^{-1}$ evidently caused shift of the flow stress curve to less values of the mechanical stress. Influence of magnetic field is over measurement error (Fig. 5).

The temperature evolution during the tensile test, their comparison with application magnetic field and without is on Fig. 6.

In the case without magnetic field the temperature changes are caused with adiabatic heating. This is produced with the plastic strain process. With application the alternate magnetic field the temperature changes are caused with adiabatic heating and with induction heating. The induction heating is result of losses at alternate magnetization. The alternate magnetic field influenced the temperature rises about maximum 35°C.

If we make comparison average total strains at fracture with magnetic field vs. without magnetic field application, then we find that with application the magnetic field decrease average total strains at fracture (Table. 2). The explanation we can find in magnetostriction vibrations. The changes of the value of the homogenous plastic strains caused by magnetic field are on Table. 2. We considered that the decreasing of the total strains at fracture and of the homogenous plastic strains is connected with strain ageing. This strain ageing is caused with alternating magnetic field. The strain ageing process runs during tensile test [3, 4].

219
Acknowledgements
Project was realized with the financial support of the FRVŠ registration number: 346/2006/F1/a

Recenzent: Ing. Jiří Kulhánek, Ph.D.

References

