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EXPERIMENTAL MODELING OF WELD THERMAL CYCLE OF THE HEAT AFFECTED ZONE (HAZ)

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Preliminary Note – Prethodno priopćenje

Contribution deals with experimental modeling of quick thermal cycles of metal specimens. In the introduction of contribution will be presented measured graphs of thermal cycle of heat affected zone (HAZ) of weld. Next will be presented experimental simulation of measured thermal cycle on the standard specimens, useable for material testing. This approach makes possible to create material structures of heat affected zone of weld, big enough for standard material testing.

Keywords: weld, P92, thermal cycle modeling, HAZ

INTRODUCTION

This paper is focused on the experimental temperature cycle simulation of steels. Described process is mainly aimed at very quick and precise simulation of temperature cycles, which occurs during welding of metal materials. During such temperature cycles are created different material structures, with very small volumes. For such small volumes of heterogeneous material structures it is very complicated to perform standard material testing (hardness, strength).

Proposed process can create material structure for given temperature cycle in volume sufficient for standard material tests (with use of metal samples of standard size of 10 mm x 10 mm x 100 mm). During temperature cycle can be created temperature affected zone of volume about 10 mm x 10 mm x 20 mm (size of affected zone depends on the speed of cooling).

Several experimental simulation of temperature cycles were done previously in [13] with use of temperature cycles simulator (Smitweld TCS 1406 etc.). Here is presented unique experimental machine, which is able to achieve better values of heating and cooling gradients, and which is more important, it is possible to use vacuum chamber for experiments.

EXPERIMENTAL PROCEDURE

For identifying the temperature cycles and sizes of heat affected areas, we have to use precise and quick temperature measurement.

Temperature measurement was done on the metal specimen made from the steel P92 [4] (see chemical composition in Table 1) with connected thermocouples.

Table 1 **Chemical composition of the P92 steel / wt.%**

C	0,0930	Mn	0,5000	Si	0,3200
P	0,0200	S	0,0030	Cu	0,1000
Ni	0,2060	Cr	8,6200	Mo	0,5170
V	0,1960	Ti	<0,004	W	1,5600
Al-c	0,0120	Nb	0,0640	Co	0,0230
B	0,0021	As	0,0090	Sn	0,0070
Pb	0,0030	Sb	0,0180	N	0,0330
O_2	0,0040	H /ppm	0,7000	Bi	<0,003

Thermocouples were welded into holes in testing plate, isolated by ceramic (see Figure 1).

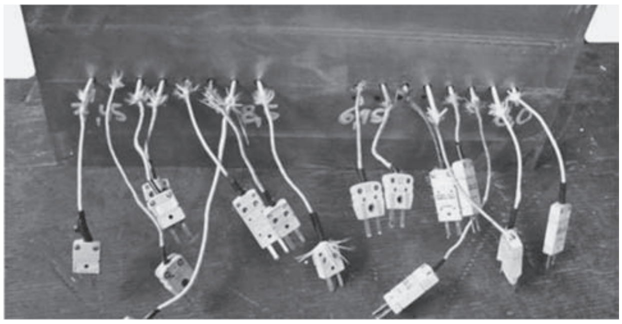

Figure 1 Testing plate with welded thermocouples

The distance between thermocouple sensors was 16 mm in line of weld and distance (depth) of the thermocouple sensors from the weld varies from 2 - 3 mm (see Figure 2).

On the Figure 3 are measured temperature cycles for thermocouples T1 to T8. From these measured temperature peaks can be identified type of heat affected zone (HAZ).

For mechanical and material testing of these measured temperature cycles and their zones, is necessary to have standard and homogenous specimens, which can be evaluated by standard tests. For such purposes, was developed unique testing machine, the Temperature cycle simulator with vacuum chamber (TCSV).

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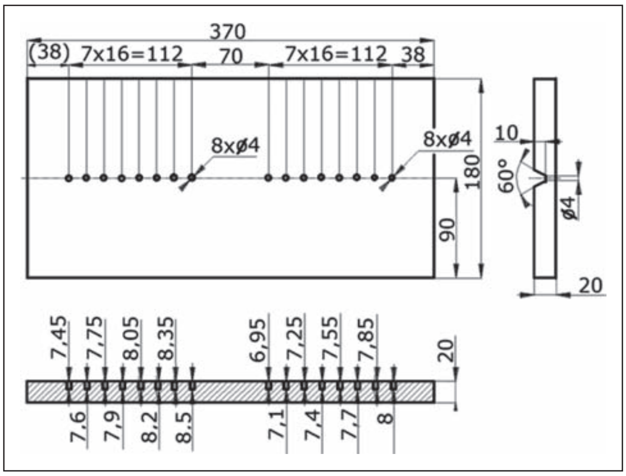

Figure 2 Thermocouples position on testing plate

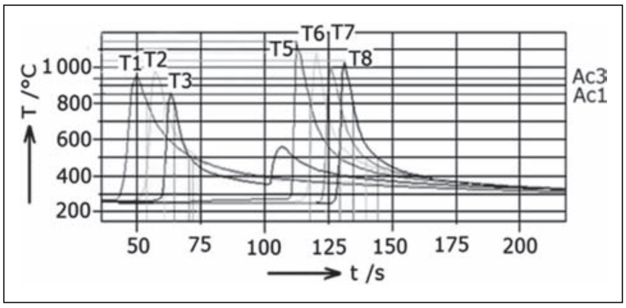

Figure 3 Measured temperature cycles

For temperature simulation was developed unique testing machine, with excellent power and quick control system with large number of measurement channels. (see Figure 4).

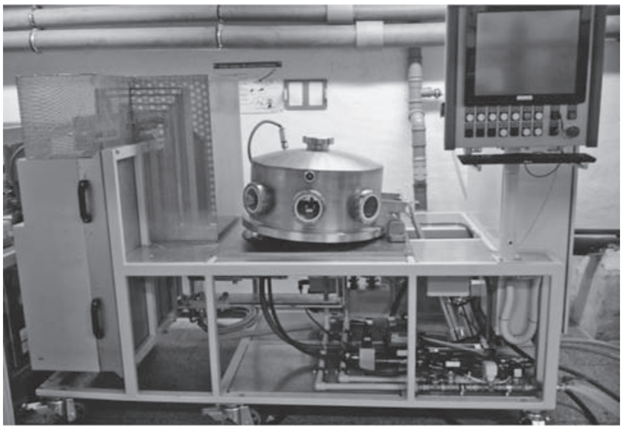

Figure 4 Temperature cycle simulator with vacuum chamber (TCSV)

The main parameters of the temperature simulator are in Table 2.

For heating of specimen was used the DC current. The advantage of the DC current for heating is more homogenous temperature distribution in the specimen plane, next advantage are smaller EMC interferences. The disadvantage of using DC current for heating is the persistent voltage gradient on the surface of specimen. This voltage gradient in millivolts / mm can affect welded thermocouples and create false temperature values. This problem is important, because measured temperature is the main goal of the temperature cycle simulator and should be very precise. The problem of false temperatures can be solved by different approaches:

- Change the temperature measurement method to infrared method. Disadvantage of this method is the necessary emissivity calibration and sensitivity to coolant gas.
- Solve the false temperature by subtracting the parasitic voltage from the measurement, for such process we have to calibrate each connected thermocouple sensor before simulation by automated process.

For quick and precise temperature measurement on the specimen have to be used thin thermocouple wires (0,5 mm and thinner). The thermocouple wires have to be welded to the surface of the specimen, and the joint should be very small. Good joint with specimen is necessary due to good heat transport. Also very important property of sensor joint with specimen is low resistance, because of risk of parasitic temperature.

Table 2 **Main parameters of TCSV**

Maximal heating current	6 000 /A
Maximum voltage on specimen	7 /V
Maximum temperature heating gradient[1]	200 /°K/s
Maximum temperature cooling gradient[1]	50 /°K/s
Maximal temperature of specimen	1 250 /°C
Minimal temperature of specimen	15 /°C
Size of specimen plane	10 x 10 /mm
Length of specimen	70 – 200 /mm
Minimal vacuum pressure	0,15 /mBar
Number of thermocouple inputs	8 pcs

[1]Depends on material of specimen

COMPENSATION OF TEMPERATURE MEASUREMENT

Principle of temperature measurement with thermocouple is based on measurement of voltage in millivolts. During resistive heating is on specimen surface gradient of voltage in millivolts also, which can create false, parasitic temperatures on thermocouples.

For automatic detection of parasitic temperature is used short current pulse of 3000 A. During this pulse, the specimen is heated by electric work, visible on the Figure 5 from time 15 s to 18 s (linear progression). At the end of current pulse, the temperature rises slowly for several seconds due to the inertia of system (to the time 26 s). On the Figure 5 thermocouple responds to the current (the dashed curve). This sensitivity makes it impossible to control temperature.

For compensation of temperature jump was created compensation formula:

$$T_{comp.} = T \cdot (1 + U_{clamps} \cdot k) \ /°C$$

$T_{comp.}$ ... compensated temperature /°C
T … measured temperature /°C

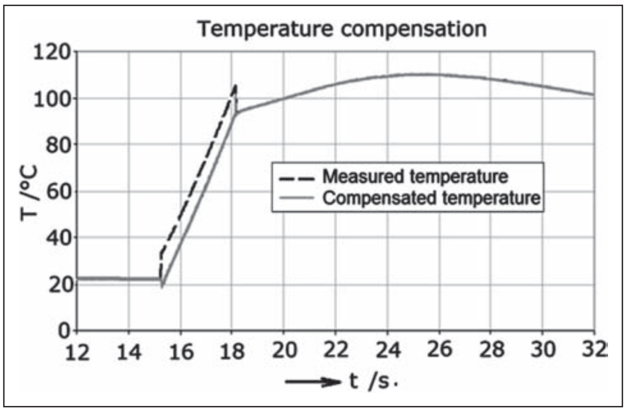

Figure 5 Temperature compensation

U_{clamps} ... measured voltage on clamps /V
k ... *compensation constant* /V^{-1}

From the current pulse and measured voltage on clamps (Figure 5) is computed compensation constant *k*. For higher values of *k* is better to create new thermocouple sensor.

COOLING OF SPECIMEN

The temperature simulator (TCSV) has excellent parameters for heating of specimen, for precise simulation of temperature cycle of welding it is also necessary to have good cooling gradient.

The cooling gradient is dependent on [5]:

- Heat transfer to water cooled clamps
- Heat radiation
- Heat transfer to air (gas)

In vacuum chamber is the most important factor the heat transfer to the water cooled clamps (see Figure 6).

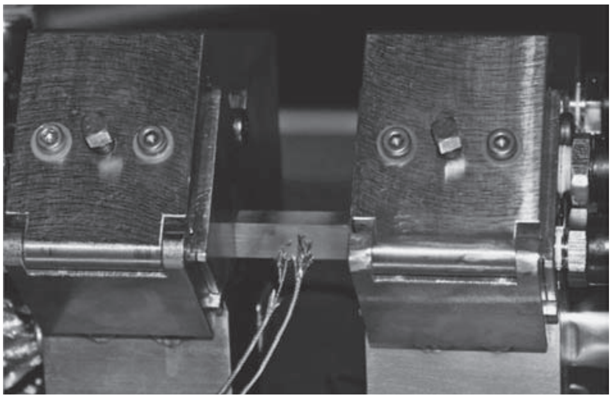

Figure 6 Heating and cooling of specimen in the clamps

For higher cooling gradient it is necessary to move clamps closer to each other. For even higher cooling rate can be used also cooling with inert gas nozzle.

MECHANICAL AND MATERIAL TESTS OF SPECIMEN

For validation of temperature simulation accuracy were done several tests of material structures and mechanical parameters. On the Figure 7 there is one of tested temperature cycle corresponding to the T3 temperature from Figure 3. The dashed curve is desired temperature cycle measured from welding, the solid curve is measured temperature from TCSV. The difference between desired and measured temperature is minimal and acceptable.

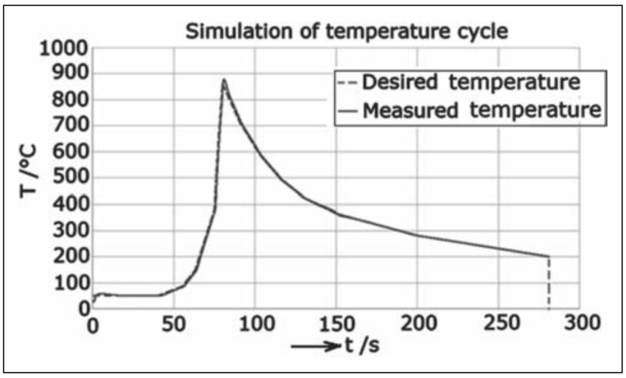

Figure 7 Simulation of temperature cycle

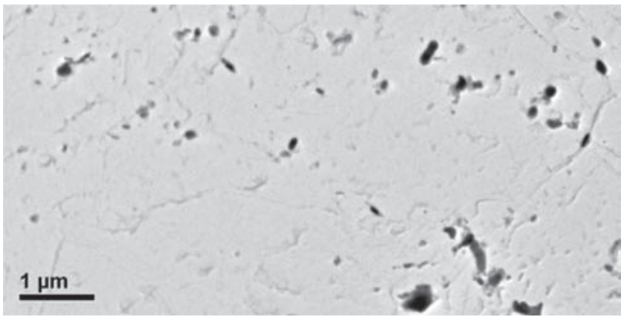

Figure 8 Microstructure of simulated specimen with precipitation

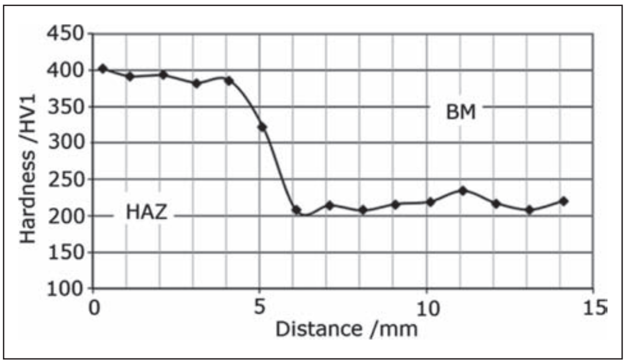

Figure 9 Hardness in longitudinal axis of specimen

In the microstructure of simulated specimen are visible dissolved particles of precipitate (see Figure 8) with full austenitization. It is identical with microstructure of real welded material.

On the Figure 9 there is measurement of the hardness in longitudinal axis, the distance is measured from the center of specimen. On the hardness curve is visible significant border between heat affected zone (HAZ) and basic material (BM) in the distance of 5 mm. It corresponds to with the size of heat affected volume 10 x 10 x 10 mm.

CONCLUSION

Main goal of this work is to verify ability of TCSV machine to accurate simulate temperature cycles of welding.

On the TCSV machine was simulated specimen with identical temperature cycle, and this specimen was compared with parameters of heat affected zone from testing plate.

Compared microstructures and hardness parameters were identical, it proved accuracy of temperature cycle simulation. This test was done for several different temperature cycles with good results.

Next it is necessary to test different materials and different types of heat treatment to create methodology for experimental simulation of temperature cycles. It is necessary to consider, that gradient of cooling rate is dependent on material and his microstructure [6].

Acknowledgement

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Note: The responsible for English language is J. Taussik (State Exam in English)