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ACCELERATED WELDABILITY INVESTIGATION OF TStE 420 STEEL BY WELD THERMAL CYCLE SIMULATION

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This paper presents accelerated weldability investigation after weld thermal cycle simulation of TStE 420 steel. The method enables single cycle or multiple cycle thermal simulation of base material specimens and obtaining any point in the heat-affected zone (HAZ) of a welded joint. After weld thermal simulation, an investigation of mechanical properties on treated specimens (hardness, toughness…) is foreseen, based on which it is possible to determine weak points in HAZ of a welded joint and inference regarding to base metal weldability.

Key words: weldability, TStE 420 steel, mechanical properties, weld thermal cycle simulation, Smitweld TCS 1405

INTRODUCTION

Investigations of weldability are usually very slow and expensive. However, they are necessary before constructing Welding Procedure Approval Records (WPAR) / Procedure Qualification Records (PQR), especially during the usage of contemporary materials. Weld thermal cycle simulation is a very suitable laboratory method used for weldability investigations. It is an accelerated investigation method that offers very fast single cycle or multiple cycle simulation of any point in HAZ of a welded joint. After that mechanical properties (hardness, toughness at various temperatures, tensile test…) and the microstructure of individual points in HAZ are investigated. [1] This method can significantly accelerate the process of obtaining WPAR/PQR and reduce costs of welding procedure qualification. There are several laboratory devices for weld thermal cycle simulation (Smitweld, Gleeble, Thermorestor, ...). In this paper authors used the Smitweld 1405 weld thermal cycle simulator which was applied for weldability investigation of TStE 420 steel.

HEAT INPUT AS THE MOST IMPORTANT INPUT FOR WELD THERMAL CYCLE

The most influential variables on weld thermal cycle are heat input, material dimensions and physical properties. Heat input as the most important variable determines very important values of weld thermal cycle: cooling time and cooling rate. In the process of welding steels sensitive to cold cracks (i.e. high-strength steels) it is necessary to keep cooling time between 800 to 500 ºC ($t_{8/5}$) in a strict limited range in order to avoid cold cracks and achieve good welding microstructure and mechanical properties of a welded joint. Figure 1 shows temperature cycle for a selected point in a welded joint during welding process (dependence of temperature T and time t during welding and cooling) as a result of heat input (E).

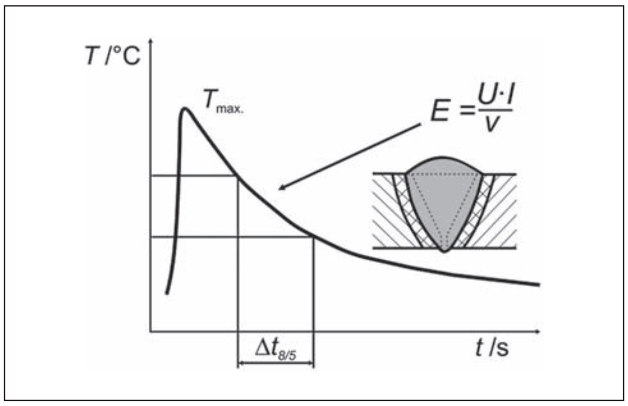

Figure 1 Simplified weld thermal cycle of a selected point in a weld joint

Heat input depends on welding current I (A) and voltage U (V) and welding rate v (mm/s). For welding parameters determination 2-dimensional and 3-dimensional models were derived, which are based on the Fourier heat flow equation that engineers use for main welding parameters determination.

In the case of 2-dimensional heat flow (high-speed moving line source on a thin plate), the heat input and consequently the main welding parameters can be determined by using equations 1 and 2. [2]

$$E_{ef} = \frac{q}{v} = \frac{U \cdot I \cdot \eta_1}{v} = \sqrt{\frac{4 \cdot \pi \cdot \lambda \cdot \rho \cdot c \cdot t_{8/5} \cdot \delta^2}{\left(\frac{1}{500 - T_o}\right)^2 - \left(\frac{1}{800 - T_o}\right)^2}} \quad (1)$$

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TTT diagrams are very often combined with equation for cooling time between 800 and 500 ºC (equation 2) and equation for cooling rate at individual temperature (equation 3). [2]

$$t_{8/5} = \frac{E_{ef}^2}{4 \cdot \pi \cdot \lambda \cdot \rho \cdot c \cdot \delta^2} \left[\left(\frac{1}{500 - T_o} \right)^2 - \left(\frac{1}{800 - T_o} \right)^2 \right] \quad (2)$$

$$w = \left(\frac{dT}{dt} \right)_T = -2 \cdot \pi \cdot \lambda \cdot c \cdot \rho \cdot \frac{(T - T_o)^3 \cdot \delta^2}{E_{ef}^2} \quad (3)$$

In the case of 3-dimensional heat flow (high-speed moving point heat source on a semi-infinite or thick plate), the heat input can be determined by using equation 4. [2]

$$E_{ef} = \frac{q}{v} = \frac{U \cdot I \cdot \eta_1}{v} = \frac{2 \cdot \pi \cdot \lambda \cdot t_{8/5}}{\frac{1}{500 - T_o} - \frac{1}{800 - T_o}} \quad (4)$$

For 3-dimensional model the equation for cooling time between 800 and 500 ºC (equation 5) and the equation for cooling rate at individual temperature (equation 6) are also frequently used. [2]

$$t_{8/5} = \frac{E_{ef}}{2 \cdot \pi \cdot \lambda} \cdot \left(\frac{1}{500 - T_o} - \frac{1}{800 - T_o} \right) \quad (5)$$

$$w = \left(\frac{dT}{dt} \right)_T = -2 \cdot \pi \cdot \lambda \cdot \frac{(T - T_0)^2}{E_{ef}} \quad (6)$$

where:
T_o ... preheating temperature / °C
δ ... thickness / mm
λ ... thermal conductivity / W/(mm °C)
c ... specific thermal capacity / J/(kgK)
t ... time / s
v ... welding speed / mm/s
ρ ... density / kg/m^3
q ... heat flow ($q = U \cdot I \cdot \eta_1$) / W
η_1 ... arc weld efficiency / -

DESCRIPTION OF THE SMITWELD 1405 WELD THERMAL SIMULATOR

By using a single cycle or multi cycle weld thermal simulation it is possible to determine the proper cooling time that will allow for a satisfactory microstructure and mechanical properties as well as determine weak locations in the welded joint. [3] Figures 2 shows the main parts of the Smitweld 1405 weld thermal cycle simulator.

Figure 3 shows single weld thermal cycle simulation, whereas Figure 4 shows double weld thermal cycle simulation. Beside the temperature – time relation, the temperature – dilatation relation during weld thermal cycle is shown.

An example of diagrams recorded during simulation by the Smitweld 1405 simulator for the peak temperature amounting to 1 350 ºC and very fast cooling is given in Figures 5, 6 and 7.

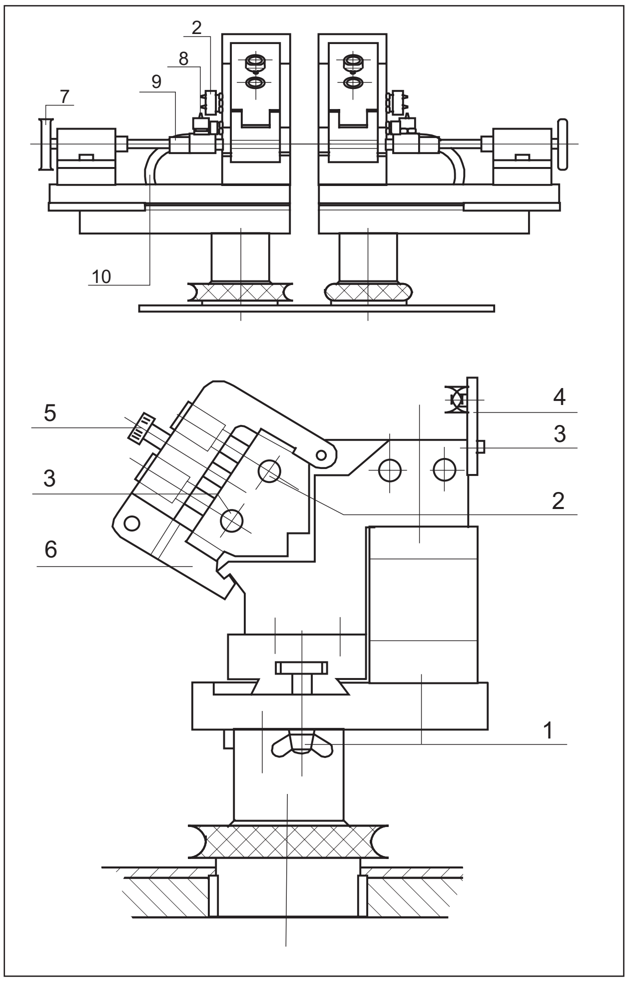

Figure 2 Execution unit of the Smitweld TCS 1405 weld thermal cycle simulator [4]
1 - Base screw with bolt, 2 - Pipe connectors for indirect cooling, 3 - Water flow canal for indirect cooling, 4 - Dilatometer and temperature sensor, 5 - Base screw for jaws, 6 - Jaw block for fixation, 7 - Contraction screw for direct cooling application, 8 - Pipe connectors for direct cooling, 9 - Direct cooling block, 10 - Current cable.

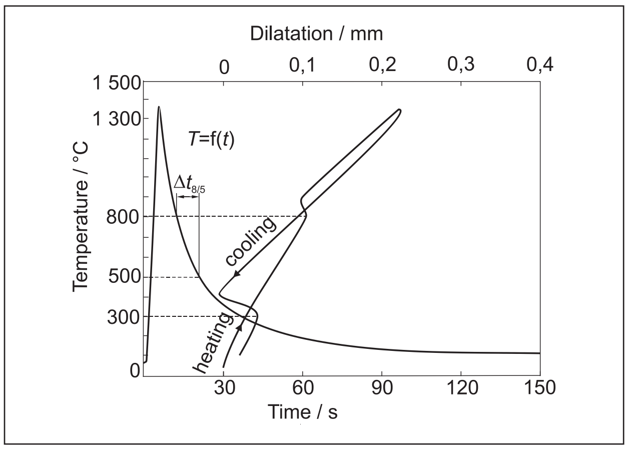

Figure 3 Single weld thermal simulation; temperature – dilatation and temperature – time relations [5]

From Figures 6 and 7 it is possible to determine transition temperatures (A_1 and A_3) during heating and cooling base on dilatation measuring at weld thermal cycle simulation.

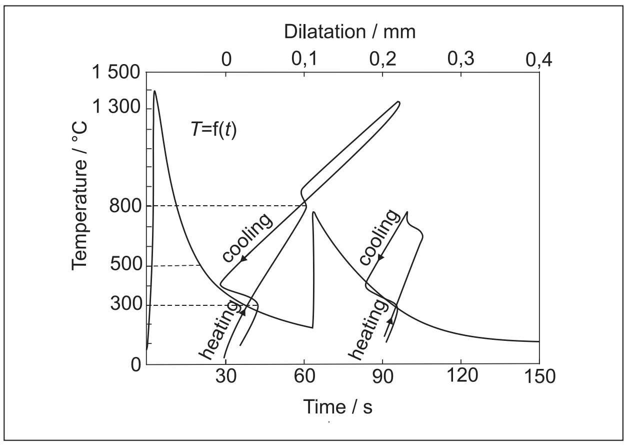

Figure 4 Double weld thermal simulation; temperature – dilatation and temperature – time relations [5]

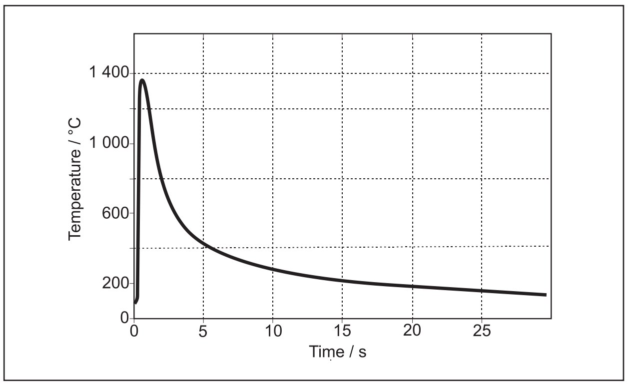

Figure 5 An example of recorded temperature – time diagram for the peak temperature amounting to 1 350 ºC

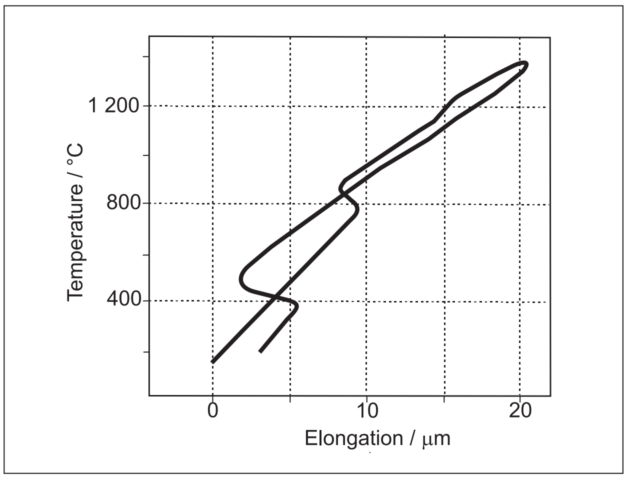

Figure 6 An example of recorded temperature – elongation diagram for the peak temperature 1 350 ºC

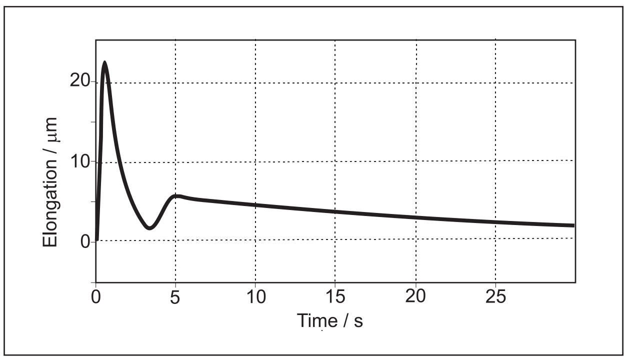

Figure 7 An example of recorded elongation – time diagram for the peak temperature to 1 350 ºC

EXPERIMENTAL WELD THERMAL SIMULATION ON TCS 1405

The experiment encompasses single pass weld thermal cycle simulation of TStE 420 specimens at different peak temperatures (600 ºC, 700 ºC, 780 ºC, 900 ºC, 1 100 ºC and 1 350 ºC) in order to simulate the heat- affected zone (HAZ) and determine hardness and impact strength values for the selected peak temperature in HAZ. Base metal compositions and mechanical properties are given in Tables 1, 2 and 3.

Table 1 **Chemical content of TStE 420 [4]**

C	Si	Mn	P	S	Ni	N	Al	V
0,2	0,36	1,52	0,013	0,006	0,21	0,016	0,016	0,014

Table 2 **Minimum mechanical properties of the TStE 420 base material [4]**

	Yield point for particular plate tickness R_p / MPa				Tensile strenght R_m / MPa	Elongation A_5 / %
Thickness	10	11-15	16-25	25-35		
TStE 420	420	420	410	410	530-680	17

Temperature-time relationship recorded during weld thermal cycle simulation at different peak temperatures are given in Figure 8.

Table 3 **Minimal impact toughness of the TStE 420 base material [4]**

Steel type	Rolling direction	Non-aged condition *KV* / J					
		Temperature / °C					
		20	0	-20	-40	-50	-60
TStE 420	longitudinal	63	55	47	31	27	-
	transverzal	39	31	27	20	16	-

Figure 9 shows microstructures for each level of experiment (peak thermal cycle temperatures amounting to 600 ºC, 700 ºC, 780 ºC, 900 ºC, 1 100 ºC and 1 350 ºC) with magnification 100 x.

After weld thermal cycle hardness HV1 (Figure 10) and impact strength at 20 ºC (Figure 11) are measured. Maximal hardness value was measured on a specimen with the peak temperature amounting to 1 350 ºC. This specimen has the lowest impact strength.

CONCLUSION

The paper explains weld thermal cycle simulation method (Smitweld 1405) which the authors used during previous experimental investigations. As a part of experimental work the authors presented the results of single pass weld thermal cycle simulations performed on TStE 420 specimens at different peak temperatures (600 ºC, 700 ºC, 780 ºC, 900 ºC, 1 100 ºC and 1 350 ºC). Beside microstructures of individual simulated specimens which represent structures of HAZ, the authors presented results of hardness and impact strength investigations. From the standpoint of cold cracks sensitivity one can conclude that the location in HAZ close to the fusion line and weld metal demonstrates the highest

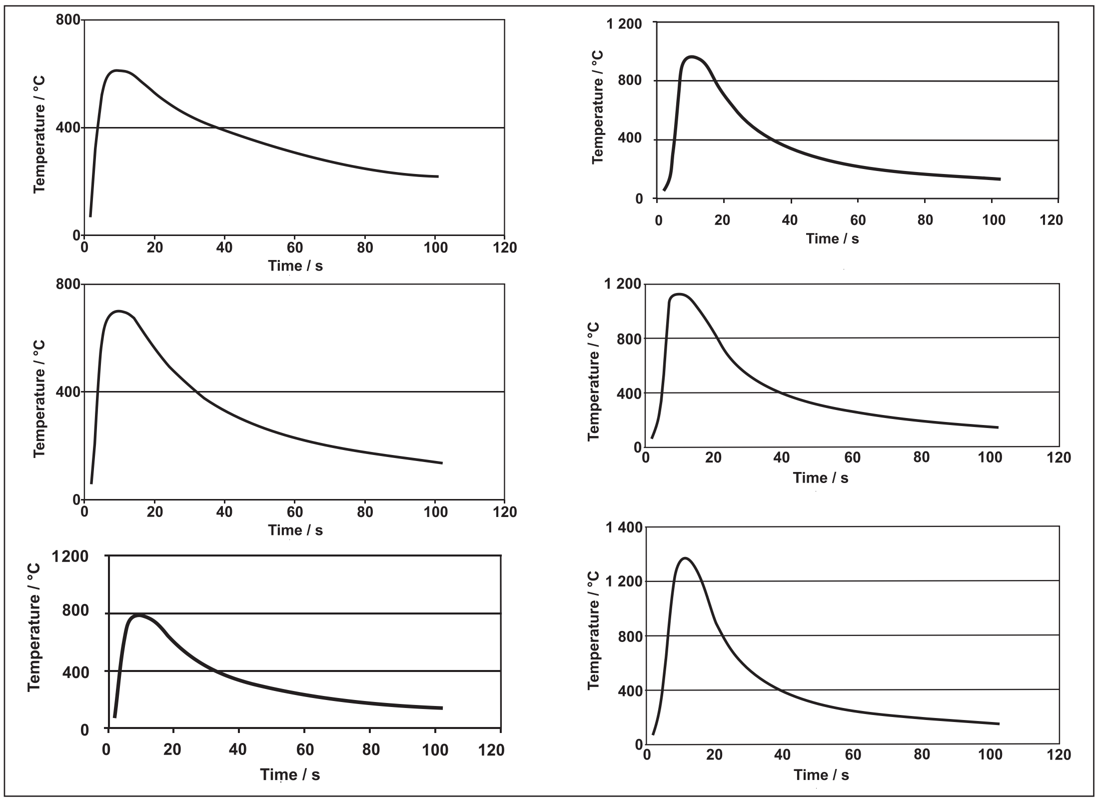

Figure 8 Temperature – time relation recorded during weld thermal simulation at 600 °C, 700 °C, 780 °C, 900 °C, 1100 °C and 1 350 °C

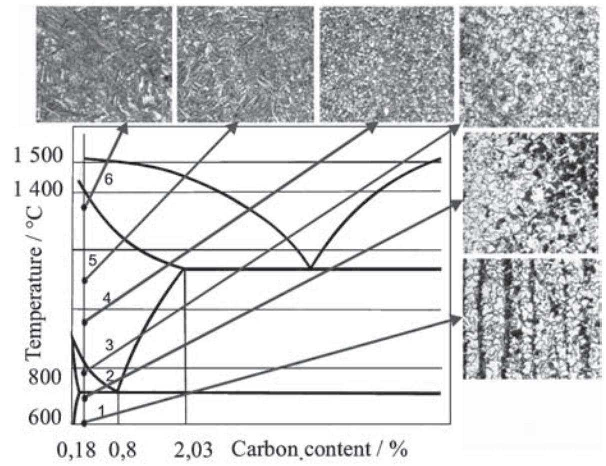

Figure 9 Microstructures for each level of experiment (magnification 100 x)

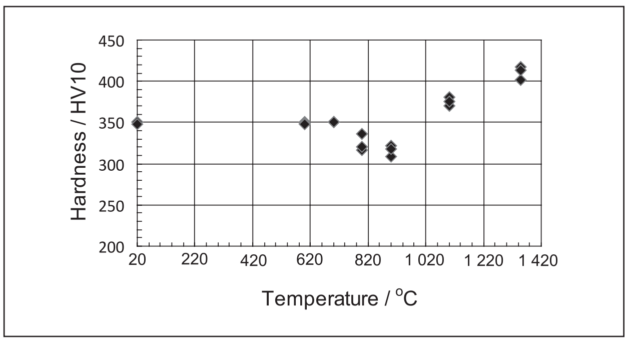

Figure 10 Hardness HV1 values for each level of experiment

sensitivity to cold cracks (the hardness value is the highest). Secondly, the impact strength at this location is the lowest. In that case it is necessary to change the heat input (primarily by preheating or secondarily by welding current and voltage and welding rate) and repeat investigations of mechanical properties.

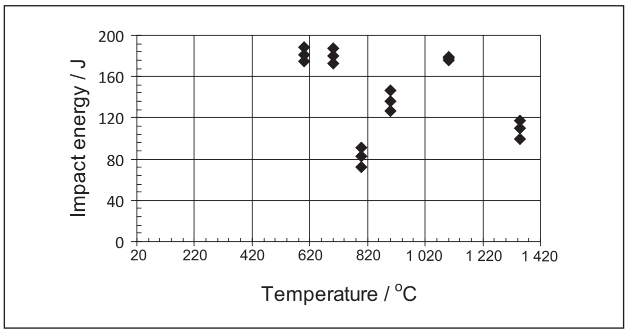

Figure 11 Hardness HV1 values for each level of experiment

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Note: The responsible translator for English language is prof. Ivana Jurković, Technical College in Bjelovar, Croatia