24th International Conference
ENGINEERING MECHANICS 2018
Svratka, Czech Republic, May 14 –17, 2018
Paper **#39,** pp. 925–928, doi: 10.21495/91-8-925

INFLUENCE OF HEATING RATE ON AUSTENITIZATION TEMPERATURES OF S355J2G3 STEEL

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Abstract: *In this work, the research results of heating up rate influence on S355J2G3 steel austenitization temperatures are presented. Dilatometric tests were carried out on the thermal cycle simulator Smitweld TCS1405 for a heating speed ranging from 1 to 150 ^{0}C s^{-1}. On the basis of the achieved results, the functions associating start and end temperatures of austenitization with the heating up speed are proposed.*

Keywords: heat treatment, austenitization conditions, S355 steel, welding

1. Introduction

S355J2G3 steel is widely used as a material for steel structures, elements of which are often joined with welding technology. Technologies based on the action of a concentrated mobile heat source, which is welding, are characterized by high heating rates of the material. The speed of heating up can significantly affect the transformation kinetics of heated steel during austenitization (Elmer et al., 2003, Danon et al., 2003, Miokovic et al., 2004, Winczek et al., 2017), as well as during heating from the quenching state - tempering (Pacyna et al., 1997). The speed of heating may have an influence on start and end temperature values of austenitization, as well as duration of austenitization (Piekarska, 2007). The austenitizing time determined by the welding thermal cycle in the form of a characteristic peak is short, which in connection with the increase in the temperature range of austenite homogeneity (undissolved carbides inhibit grain growth), does not favor the process of austenite homogenization (Piekarska et al., 2012).

2. Experimental research

The tests on the heating rate influence on the start and end of austenitization temperatures were carried out on the Thermal Cycle Simulator Smitweld 1405 (Fig.1) for the heating speed ranging from 1 to 150 ^{0}C s^{-1}. The chemical composition of researched steel is shown in Table 1.

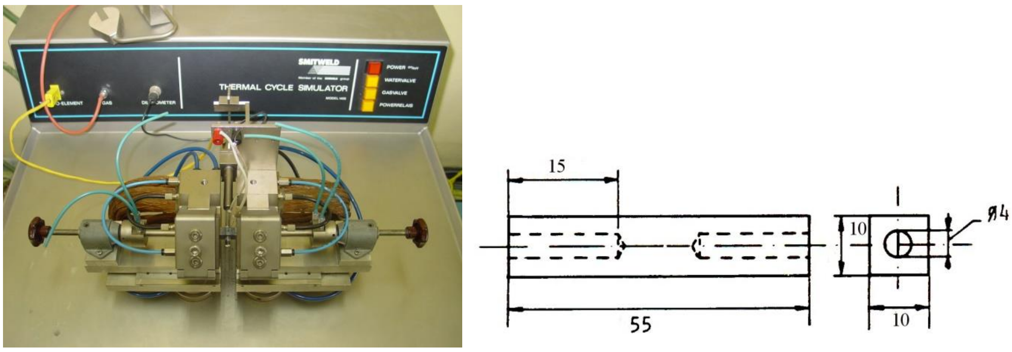

Fig. 1: Thermal Cycle Simulator Smitweld 1405 and dimensions of sample.

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Tab. 1: Chemical composition of steel S355J2G3.

Chemical composition %										
C	Mn	Si	P	S	Al	Cr	Ni	Mo	V	Nb
0.18	1.42	0.40	0.018	0.032	0.050	-	-	-	-	-

For each heating speed, at least 5 dilatometric tests were made. It allowed one to determine temperature average values A_{c1} and A_{c3}, which are presented in Table 2.

Tab. 2: Average temperature values A_{c1} and A_{c3}.

V_H [^{0}C/s]	1	2	5	10	20	30	40	50	60	80	90	100	120	150
A1 [^{0}C]	750	750	754	758	760	765	770	774	780	780	780	780	780	780
A3 [^{0}C]	870	870	884	890	896	900	905	908	910	910	910	910	910	910

3. The analysis of dilatometric experiment results

For the heating speed above 60 ^{0}C/s, the temperature of the beginning of austenitization does not change and comes to 780 ^{0}C. For the heating speed below 60 ^{0}C/s the temperature of the beginning of austenitization rises with the increase of heating speed V_H. This dependence can be described by the Hoerl regression (1) equation or linear function (2):

$$A_{c1}(V_H) = ab^{V_H}(V_H)^c \quad for\ V_H <= 60^0 C/s \quad and \quad 780^0 C \quad for\ V_H > 60^0 C/s \tag{1}$$

$$A_{c1}(V_H) = \{aV_H + b \quad for\ V_H <= 60^0 C/s \quad and \quad 780^0 C \quad for\ V_H > 60^0 C/s \tag{2}$$

For the whole scope of heating speed, the highest correlation gives the approximation by logistic model:

$$A_{c1}(V_H) = a/(1 + b\,exp(-cV_H)) \tag{3}$$

The parameters of equation (1-3), correlation coefficients and standard errors of particular models are collated in Table 3. The comparison of regression models $A_{c1}(V_H)$ with the research results is presented in Fig. 2.

Tab. 3: The parameters of equation (1-3), correlation coefficients and standard errors.

Model	**a**	**b**	**c**	**Correlation coefficient**	**Standard error**
Hoerl (1)	749.45743	1.0005403	0.0015321262	0.996	1.147
Linear (2)	0.48351902	750.62143	-	0.9934	1.3098489
Logistic (3)	782.26369	0.044808365	0.027936958	0.989	1.956

In the case of determining temperature A_{C3} in the function of heating speed, the following equations can be used models: Gompertz (4), Richards (5), MMF (6), Hoerl (7), Rational (8) and shifted power method (9):

$$A_{c3}(V_H) = a\,exp(-exp(b - cV_H)) \tag{4}$$

$$A_{c3}(V_H) = a/(1 + exp(b - cV_H))^{1/d} \tag{5}$$

$$A_{c3}(V_H) = (ab + cV_H^{\ d})/(b + V_H^{\ d}) \tag{6}$$

$$A_{c3}(V_H) = ab^{V_H}(V_H)^c \tag{7}$$

$$A_{c3}(V_H) = (a + bV_H)/(1 + cV_H + dV_H^2 \quad for\ V_H <= 60^0 C/s \quad and \quad 910^0 C \quad for\ V_H > 60^0 C/s \tag{8}$$

$$A_{c3}(V_H) = a(V_H - b)^c \quad for\ V_H <= 60^0 C/s \quad and \quad 910^0 C \quad for\ V_H > 60^0 C/s \tag{9}$$

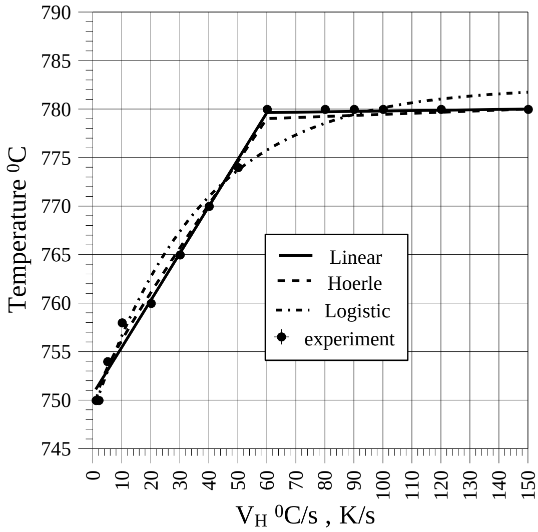

Fig. 2: Comparison of regression models $A_{C1}(V_H)$ with the experimental results.

The parameters of equations (4-9), correlation coefficients and standard errors of particulars models are collated in Table 4. The comparison of regression models $A_{c3}(V_H)$ with the experimental results is presented in Figure 3.

Tab. 4: The parameters of equation (4-9), correlation coefficients and standard errors.

Model	a	b	c	d	Correl. coeffic.	Stand. error
Gompertz (4)	909.86216	-3.0733604	0.060778747	4.6436922	0.9899	2.275
Richards (5)	909.80572	-1.4388623	0.064051358	-	0.9892	2.46
MMF (6)	864.03404	9.5280843	914.6467	0.99363489	0.993	1.957
Hoerl (7)	866.35732	0.99991737	0.012512283	-	0.991	2.123
Rational (8)	861.39767	193.80035	0.21526127	$-5.4266198 \cdot 10^{-5}$	0.995	1.953
Shifted power (9)	861.00704	-0.91517729	0.013384953	-	0.994	1.964

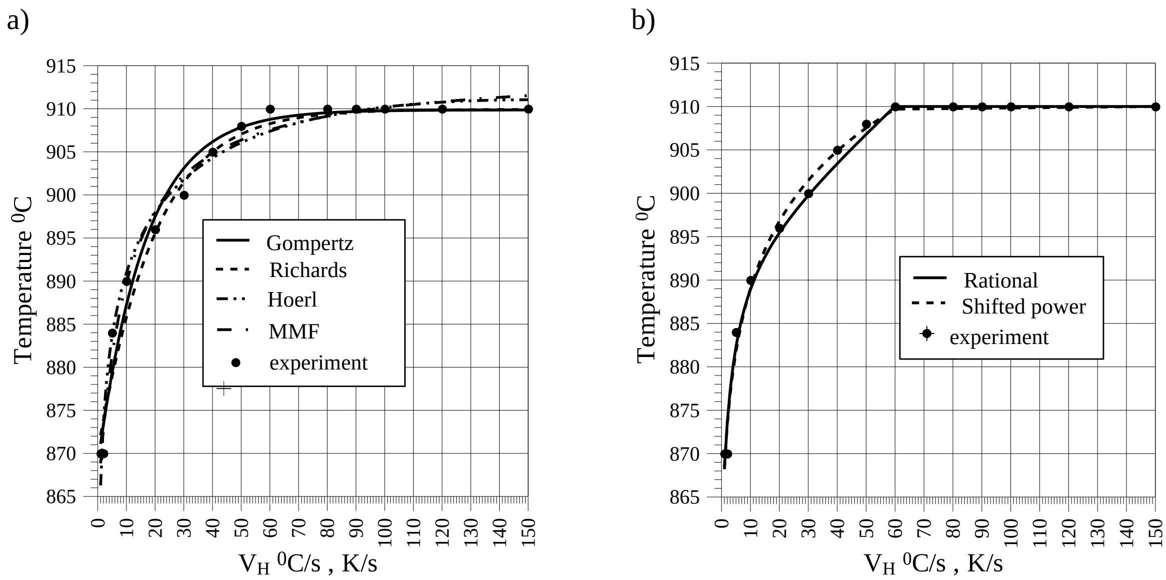

Fig. 3: Comparison of $A_{C3}(V_H)$ regression models with the experimental results: a) equations (4–7), b) equations 8 and 9.

Despite the high correlation coefficients of the models (4-7), the curves for the heating speed from the range of 30 °C/s < V_H <80 °C/s significantly differ from the empirical values (Fig. 3a). Therefore, it is more useful to adopt the rational function (8) for the range V_H < 60 ºC or the generalized linear model (GLM) - shifted power (9) – Fig. 3b.

CHT (Continuous Heating Transformation) diagram of S355J2G3 steel is presented in Fig. 4.

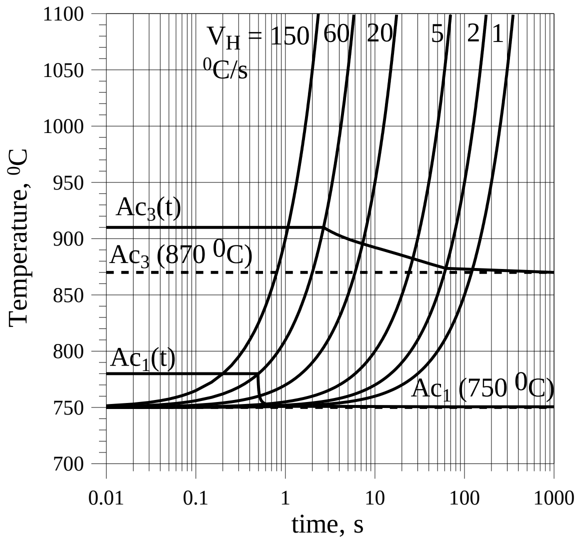

Fig. 4: CHT (Continuous Heating Transformations) diagram of S355J2G3 steel.

4. Conclusions

From the analysis of particular models, it arises that for the heating speed below 60 ºC/s, the best temperature approximation of the initial temperature of austenitization is given by function (1), but the linear function (2) provides a sufficient and more convenient application. The temperature of the end of austenitization is best described by rational function (6). For the heating speed above 60 ºC/s, no increase in the start and end temperatures of austenitization was observed with the increase of the heating speed.

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