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The Influence of Temperature-Time Parameter of Welded Joints Thermal Treatment on Strength-Related Characteristics of Chromium-Molybdenum and Low-Alloy Manganese Steels

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The article deals with the analysis of the dependence of strength-related characteristics of welded joints from chromium-molybdenum steel (ASTM A335 Grd. P5) and low-alloy manganese steel (S355J2G3 EN10025-2) upon the parameters of heat treatment. Steel mechanical properties after post-weld heat treatment were analyzed. Chromium-molybdenum (Cr – 5 %) steel and structural low-alloy manganese steel (Mn – 1.4 %) was selected as a target. The steels of various classes widely applicable in oil industry were selected.

At the beginning, samples were welded applying the same process. When welded, all the samples were heat treated. Tempering for each sample was performed by applying different temperature and exposure time. For analysis systemization the parameter of temperature-time *P* was applied. It was calculated for each heat treatment mode. After post-weld heat treatment each sample was tested subject to tensile and impact strength.

P-dependence of mechanical properties of each steel sample was examined. It was determined that tensile strength and impact strength decreases by increasing *P* value. It showed the drop of mechanical properties value upon considerable increase of tempering temperature or application of a very long exposure time.

Keywords: welded joints, temperature-time parameter, tempering, tensile strength, impact strength.

INTRODUCTION

When welding or mechanically deforming of various constructions the residual internal stresses can reduce the reliability of structure or can provoke the structure's disintegration. In order to reduce of such internal stresses influence, the most welded or deformed structure are cured by heat treatment operation – tempering [1, 2]. Heat treatment, once performed after welding, provides welded joints with numerous positive properties such as softened hardened areas of metal, increased ductility, positively modified microstructures of heat treated areas of metal, reduced internal stresses. Heat treatment improves corrosion resistance as well as stress-corrosion cracking resistance under the influence of internal stresses. Heat treatment of welded may also have some negative impacts such as reduced tensile and impact strength, precipitation hardening of certain steels which may cause fractures on heat-exposed areas of metal. The cumulative effects of time and temperature during post weld heat treatment have a deleterious effect on normalized base metal properties [2]. Some scientific works report that mechanical properties of various steels are strongly connected to their complex microstructure obtained after heat treatment that are generally performed in order to achieve a good hardness and/or tensile strength with sufficient ductility [3, 4]. The deterioration of mechanical properties caused by post weld heat treatment in carbon steels has been well documented in 1972, as has the association of those changes with time-temperature parameters [5]. During the later eighties studies by Konkol detailed the effects on carbon steels of tempering and showed the deleterious effects of 650 °C for just 5 hours to be a 7 °C shift in the transition temperature [6]. As a matter of convenience, and because data seemed to fit, the conventional Larson-Miller parameter (*LMP* without dimension value) has been used to compare post weld heat treatment cycles [5, 6]. This formula is shown as:

$$LMP = \left(T(°\mathrm{F}) + 460\right)\left(C + \log t\right) \times 10^{-4}, \qquad (1)$$

where C equals 20 and t is the time held in hours at temperature T.

For quantitative evaluation of the heat treatment parameters, European Union normative documents [6] provide temperature-time dimensionless parameter *P* analogous to *LMP* parameter, which is calculated according to the formula:

$$P = T\left(20 + \lg t\right) \times 10^{-3}, \qquad (2)$$

where T is the thermal treatment temperature (Kelvin), t is the time (hours) of exposure to thermal treatment temperature.

When executing the tests required to certify welding procedures for the particular steels (the tests were executed at Mechanical Testing Laboratory of AB "Mažeikių Nafta"), the changes of strength-related characteristics of welded joints in response to varying parameters of the heat treatment were noticed.

The aim of analysis is to determine the mechanical properties dependence of chromium-molybdenum and low-alloy manganese steel welded joints upon thermal treatment parameters: i. e. the variation of tensile strength and impact strength of joints by ranging of temperature time parameter *P* and the variation of mechanical properties of joints when thermal treatment parameters are different but *P* parameter is steady.

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MATERIALS

Chromium-molybdenum steel (ASTM A335 Grd. P5) and low-alloy manganese steel (S355J2G3 EN10025-2) were selected for the analysis [7, 8]. These different alloyed structural steels were selected in order to determine the influence of heat treatment on the welded joints from differently graded steels. Structural low-alloy manganese steels are mostly used for manufacture of units operated within the range of – 40 °C to +475 °C temperature. Heat-resistant chromium-molybdenum steels are used for manufacture of structures operated at higher temperatures. The experimental research was performed on specimens made from a 12 mm thick sheet S355J2G3 EN10025-2 steel and a weldless hot-rolled pipe (∅ 219.1 × 12.7) steel ASTM A335 Grd. P5 (Tables 1 – 2).

Table 1. Chemical composition of the main component of the specimens, manufacturer's data

Steel grade	Composition (mass), %							
	C	Si	Al	Cr	Mn	Mo	S	P
S355J2G3 EN 10025	0.18	0.26	0.032	0	1.39	0	0.014	0.021
P5 ASTM A335	0.13	0.34	0	4.31	0.46	0.51	0.003	0.012

Table 2. Mechanical properties of the main component of the specimens, manufacturer's data

Steel grade	Tensile strength, R_m, N/mm^2	Yield strength, R_e, N/mm^2	Elongation, A_5, %
S355J2G3 EN10025	600	467	21
P5 ASTM A335	515	333	40

Table 3. Chemical composition of the weld metal, manufacturer's data

Wire grade	Composition (mass), %				
	C	Si	Mn	Cr	Mo
BÖHLER EMK 8	0.10	1.0	1.7	0	0
BÖHLER CM 5-IG	0.08	0.4	0.5	5.8	0.6

Table 4. Mechanical properties of the weld metal, manufacturer's data

Wire grade	Tensile strength R_m, N/mm^2	Yield strength R_e, N/mm^2	Elongation, A_5, %	Impact work ISO-V KV, J
BÖHLER EMK 8	600	470	26	50 (at – 40 °C)
BÖHLER CM 5-IG	620	510	20	200 (at +20 °C)

Specimens from S355J2G3 EN10025-2 steel were welded using gas shielded tungsten arc welding process (141 process LST EN 24063). BÖHLER EMK 8 electrode wire was used, manufacturer – Böhler Schweßtechnik Austria Gmbh. Wire type – EN 1668: G4Si1. Specimens from ASTM A335 P5 steel were welded in the same process (141 LST EN 24063 process). Auxiliary wire type EN12070: W CrMo5 Si (BÖHLER EMK 5-IG electrode wire) was used.

Chemical composition as well as mechanical properties of the weld metal is presented in Tables 3, 4.

RESEARCH TECHNIQUE

All 6 specimens from S355J2G3 EN10025-2 steel and 7 specimens from ASTM A335 P5 steel were welded. All the samples were welded at the same position (PF ISO6947, vertical upward weld). When welded, all the specimens were heat treated under different regimes (Tables 5 and 6). Heat treatment modes for low-alloy manganese steel samples were selected the same as in WRC bulletin 481 in order to compare the results with the analysis performed by K. E. Orie and Ch. R. Roper [2]. Heat treatment modes for chromium-molybdenum steel samples were selected the ones commonly applied by “Mazeikiu nafta” in repair of piping of such steel.

The temperature-time parameters of each regime were calculated according to formula (2). After evaluating the possible tolerances of postweld heat treatment temperature and time measures, the tolerance of parameter P should be equal 0.026.

After thermal treatment process, the analyses of welded metal listed below were carried out:

- to check the quality of the weld the radiographic X-rays analysis was used (level B) [9]. The analysis was performed using X-ray generator RAPAN M200/100.
- to check the tensile properties then cross-tensile test [10, 11] was used. Specimens were cut mechanically. 3 specimens were cut out of each welded joint. The tensile test was carried out in a MIRI-500K tensile machine. The tolerances of cross-tensile test are 1 %.
- strenght properties wereevaluated by impact strength test [12, 13]. 3 specimens were cut out of each welded joint. Specimen type – KVWS 0/1 (Charpy pendulum V-notch, weld-metal notch, notched surface parallel to the specimens surface, notch over central area of weld). The tolerances of impact strength test are 1 %.

RESULTS AND DISCUSSION

After the X-rays analysis we can state that all welded joints conform to technical requirements. We didn’t detect any defects, influencing the results.

As shown in Fig. 1 the tensile strength decreases uniformly with the increase of parameter P. After the heat treatment (tempering) of welded joints from steel S355J2G3, change of parameter P by one unit results the tensile strength decrease by ~18 N/mm^2, that is approximately 3 %. Analyzing results of impact strength test of steel S355J2G3 welded joints (Fig. 3) it is evident that the impact strength decreases almost linearly with the increase of parameter P.

Analyzing the test results of the samples having equal or similar parameter P (samples 3 and 4) the attention

Table 5. Heat treatment parameters of welded specimens from S355J2G3 EN10025-2 steel

Specimen No.	Equipment used for heat treatment	Preheat rate starting from 300 °C, °C/h	Temperature of heat treatment, °C (K)	Time of exposure, h	Cooling rate, °C/h	Temperature-time parameter *P*
1	Electric furnace	150	620 (893)	1	150	17.86
2	Electric furnace	150	650 (923)	1	150	18.16
3	Electric furnace	150	620 (893)	16	150	18.94
4	Electric furnace	150	680 (953)	1	150	19.06
5	Electric furnace	150	650 (923)	16	150	19.57
6	Electric furnace	150	680 (953)	16	150	20.20

Table 6. Heat treatment parameters of welded specimens of specimens from ASTM A335 P5 steel

Specimen No.	Equipment used for heat treatment	Preheat rate starting from 300 °C,°C/h	Temperature of heat treatment, °C (K)	Time of exposure, h	Cooling rate, °C/h	Temperature-time parameter *P*
1	Electric furnace	250	750 (1023.15)	5	150	21.17
2	Electric furnace	250	750 (1023.15)	3	150	20.95
3	Electric furnace	250	750 (1023.15)	8	150	21.38
4	Flexible elements	100	750 (1023.15)	1	200	20.46
5	Flexible elements	400	750 (1023.15)	2.5	200	20.87
6	Flexible elements	100	740 (1013.15)	2	200	20.56
7	Flexible elements	100	730 (1003.15)	3	200	20.54

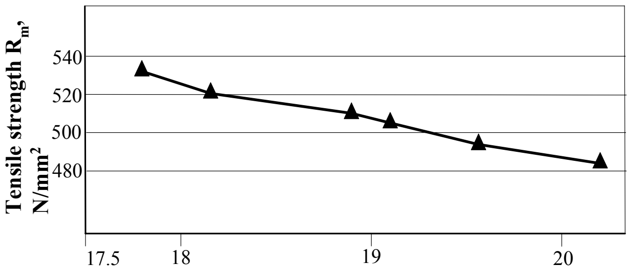

Fig. 1. The dependence of the tensile strength of welded joints from S355J2G3 steel on the temperature-time parameter *P*

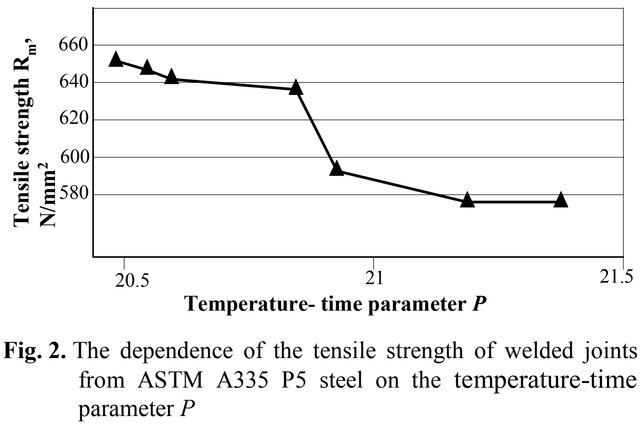

Fig. 2. The dependence of the tensile strength of welded joints from ASTM A335 P5 steel on the temperature-time parameter *P*

should be paid that values of the tensile and impact strength are similar.

However, the samples tempering temperatures and exposure time differ (Table 5):

– for the sample 3 temperature was $T = 620$ °C and exposure time $t = 16$ h;

– for the sample 4 temperature was $T = 680$ °C and exposure time $t = 1$ h.

Tensile test results for the steel P5 (Fig. 2) show that the tensile strength decreases with the increase at *P* as well. When *P* value change from 20.46 to 20.87 the change of a value R_m compounds is ~40 N/mm^2 per one unit of the parameter *P*. The average rate of variation tensile strenght of steel P5 on equal ~70 N/mm^2 per unit *P*, that is approximately 10%.

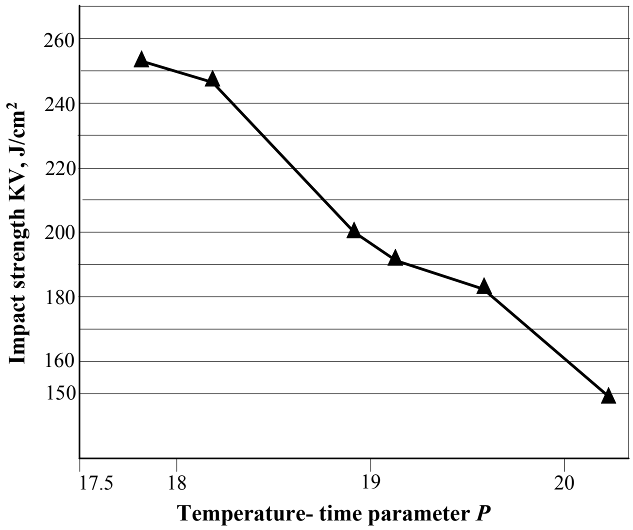

Fig. 3. The dependence of the impact strength of welded joints from S355J2G3 steel on the temperature-time parameter *P*

Steel P5 impact strength varies almost linearly with the parameter *P* (Fig. 4). By increase of parameter *P* value in one unit, the impact strength decreases ~ 24 J/cm^2.

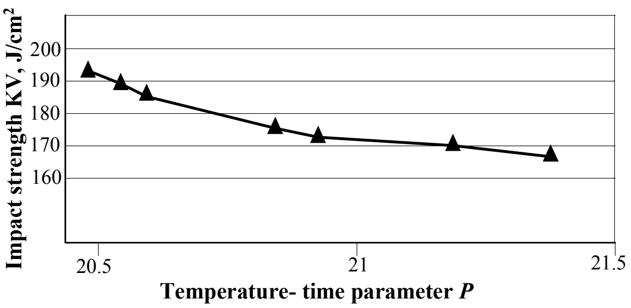

Fig. 4. The dependence of the impact strength of welded joints from ASTM A335 P5 steel on the temperature-time parameter *P*

American scientists K. Orie and Ch. R. Roper [2] investigated the behavior of low-alloy manganese steel plate (ASTM A516 Grade 70) subjected to post weld heat treatment.They found, that the cumulative effects of time and temperature during post weld heat treatment have a deleterious effect on base metal properties. Each increase 1.0 magnitude in parameter *P* above 17.5 in general lowers tensile strength by approximately 2 %. Our results are bit different because studied materials are different, but quantitavely they are agreement with [2].

CONCLUSIONS

1. More intensive (at higher temperature or longer time of exposure – than typically) heat treatment with the increasing temperature-time parameter *P* has a negative impact on strength-related characteristics of welded joints from S355J2G3 EN10025-2 and ASTM A335 P5 steels. Such heat treatment regime decreases the tensile and impact strength of welded joints.

2. The values of strength characteristics of welded joints are alike, when the temperature-time parameter *P* is similar, though the temperature and time of exposure differs.

3. For heat treatment of welded joint from S355J2G3 EN10025-2 steel, it is necessary to apply the processing regime with the temperature-time parameter which would not exceed 19. In case the value of the temperature-time parameter is higher, the tensile strength of the heat treated steel is smaller than the minimum one specified in the standard. The latter is to be taken into account when pre-calculating the strength of constructions.

4. When heat treatment (after welding) is applied to chromium-molybdenum steels with 5 % chromium content, the temperature-time parameter of selected heat treatment must be in the interval 20.4 – 20.6. Such particular value of the temperature-time parameter secure the optimal strength-related characteristics of welded joints.

REFERENCES

1. **Bernshtein, M., Rahshtadt, A.** Metals Science and Heat Treatment of Metals. Manual Book. Moscow: Mashinostroenije, 1991: 384 p. (in Russian).
2. **Orie, K., Roper, Ch. R., Upitis, E**. The Effect of Post Weld Heat Treatment and Notch Toughness on Welded Joints and on Normalized Base- Metal Properties of A516 Steel. WRC bulletin 481. *New York Welding Research Council, Inc.* 2003: 83 p.
3. **Mebarki, N., Delagnes, D., Lamesle, P., Delmas, F., Levaillant, C.** Relationship between Microstructure and Mechanical Properties of a 5 % Cr Tempered Martensitic Tool Steel *Materials Science and Engineering A* 387 – 389 2004: pp. 171 – 175.
4. **Thomson, R. C., Miller, M. K.** Carbide Precipitation in Martensite during the Early Stages of Tempering Cr- and Mo-containing Low Alloy Steels *Acta Metallurgica Inc.* 46 (6) 1998: pp. 2203 – 2213.
5. **Gulvin, T. F.** The Influence of Stress Relief on the Properties of C and C-Mn Pressure-Vessel Plate Steels *Presented at the West of Scotland Iron &Steel Institute One Day Conference*, 1972.
6. **Konkol, P. J.** Effect of Long-Time Postweld Heat Treatment on the Properties of Constructional-Steel Weldments. WRC Bulletin 330 *New York Welding Research Council, Inc*. 1988: pp. 11 – 26.
7. LST EN 10025. Hot Rolled Products of Non-Alloy Structural Steels.
8. ASTM A335. Specification for Seamless Ferritic Alloy-steel Pipe for High-temperature Service.
9. LST EN 25817. Arc-welded Joint in Steels. Guidance on Quality Levels for Imperfections.
10. LST EN 895. Destructive Tests on Welds in Metallic Materials. Transverse Tensile Test.
11. LST EN 10002-1. Metallic Materials. Tensile Testing. Part 1: Method of Test.
12. LST EN 875. Destructive Tests on Welds in Metallic Materials. Impact Tests. Test Specimen Location, Notch Orientation and Examination.
13. LST EN10045-1. Metallic Materials. Charpy Impact Test. Part 1: Test Method.