CONTRIBUTION TO RESEARCH OF WELDABILITY OF MODERN LOW-ALLOY CREEP RESISTANT STEELS

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PŘÍZPĚVEK K VÝZKUMU SVAŘITELNOSTI MODERNÍCH NÍZKOLEGOVANÝCH ŽÁROPEVNÝCH OCELÍ

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Abstrakt

V článku jsou prezentovány výsledky zkoušek svařitelnosti provedených na ocelích T23, T24 a T25. Na základě těchto zkoušek byla navržena vhodná teplota předehřevu při svařování uvedených ocelí o tloušťkách 6 až 20 mm. Další část článku je věnována vytvrzování svarových spojů perspektivních ocelí T23 a T24 během dlouhodobé expozice při pracovní teplotě 500 °C. Velikost sekundárního vytvrzení závisí na aplikaci popouštění po svařování. U nepopuštěných svarových spojů dochází k nepřípustnému zvýšení tvrdosti v průběhu expozice při provozní teplotě. Na základě dosažených výsledků byl navržen vhodný teplotní režim pro svařování membránových stěn z ocelí T23 a T24.

Abstract

This article presents the results of weldability tests performed on T23, T24 and T25 steels. Based on these test results a suitable preheating temperature was calculated for welding the said steels of 6 to 20 mm thickness. Further, this article deals with hardening of weld joints in perspective steels T23 and T24 during extensive exposure at operating temperature 500 °C. The extent of secondary hardening depends on application of tempering after welding. Non-tempered weld joints undergo an unacceptable increase in hardness during exposure at operating temperature. Based on test results a suitable temperature profile was calculated for welding membrane walls from T23 and T24 steels.

Key words: low-alloy steel, creep resistant steel, welability, secondary hardening, MX particles

1. Introduction

In recent years, development of low-alloy creep-resistant steels has significantly advanced. The most common traditional Cr-Mo steel based on 2,25%Cr-1%Mo is no longer sufficient in terms of creep resistance; it no longer meets the ever increasing demands on power engineering units. In the 1990´s Japan developed a steel called T23, which is based on CrMoVWNbN alloying, and subsequently steel F-2W with CrMoVWTiN alloying. At the same time, a steel called T24 () was developed in Germany (CrMoVTiN alloying).

T23 and T24 steels are used at 500 to 600°C. Their chemical composition was designed with respect for manufacture of membrane walls without preheating and, if possible, without heat treatment. Their weldability is improved by decreasing carbon content to under

0,1% and economical alloying with Cr, Mo, V, W and B. The reduction of these elements to a bare minimum guaranteeing creep resistance also decreases the carbon equivalent, and thereby the preheating temperature necessary during welding.

Analysis of degradation processes in low-alloy creep-resistant steels shows that precipitation of carbide M_6C is uncalled for. In low-alloy steels, Mo content over 0,5 % initiates precipitation of phases rich in molybdenum (Mo_2C, Mo_6C), which leads to depletion of Mo in the solid solution. Besides this depletion of Mo, carbide M_6C (Mo_6C) also leads to the dissolution of fine vanadium carbide particles and increase in creep rate [5, 6].

Following extensive domestic experience in the development of low-alloy CrMoV steels and high-alloy steels based on 9%Cr, low-alloy CrMoVNbN based steel with a reduced Mo equivalent to 0,5% was developed; the "working title" of this steel is T25.

2. Hardening Mechanism of Modern Low-alloy Steels

The principle behind increased creep resistance of steels alloyed with vanadium, or titanium and niobium is dispersion of MX fine particles which have a significantly increased dimensional stability during extensive heat exposure in comparison to chromium carbide. Ultimately this means a great increase in creep resistance, represented by values for creep strength over 10^5 or 2.10^5 hours. The major effect of dispersion of MX particles is a decrease of plastic properties in steel in relation to so-called secondary hardening [1,2].

After typical heat treatment, which comprises normalisation and subsequent tempering at 760°C, the structure of these steels is not absolutely uniform. During subsequent extensive exposure at operating temperature, which is lower than the tempering temperature, partial precipitation of MX particles occurs as a result of solid solution saturation. This process is most significant around the weld joints, where due to the welding process the degree of dissolution of dispersed particles varies. Subsequently, the tempering temperature may not be maintained correctly, which causes imperfect precipitation of MX particles in weld metal and in the heat affected zone (HAZ). The result being an unbalanced structure. However, during manufacture of membrane walls the aim is to avoid tempering after welding altogether.

3. Wedlability of T23, T24 and T25 steels

In the first stage of the experimental program the preheating temperature for T23, T24 and T25 steels was calculated based on empirical equations according to three methods: Seférian, Ito-Bessy and AWS. Calculated thicknesses correspond to the thicknesses of test plates, i.e. 6 and 20 mm. Calculations take into account 5 ml hydrogen per 100 g weld metal. Calculation results are presented in Table 1.

Table 1 Calculated preheating temperatures

Steel	T23	T24	T25	T23	T24	T25
Thickness	6 mm			20 mm		
Seférian	140	151	111	152	163	123
Ito-Bessy	146	190	99	180	224	132
AWS	154	178	117	206	235	161

Following the calculation of preheating temperatures for T23, T24 and T25 steels, weldability tests were performed. 6 mm thick plates were subjected to an RD test, at room temperature and also at 150°C. 20 mm thick plates underwent a TEKKEN test at preheating temperatures of 150°C and 200°C.

The test weld for the RD test was performed by welding method 111. Coated electrode Thyssen Chromo 3V was used for steels T24 and T25; electrode Thyssen Cr2VW was used for steel T23. First, the RD test was performed with the test plate in an absolutely rigid mounting and without preheating. All tested weld joints showed cracking of the weld metal immediately after welding. A dominant crack occurred from the end crater parallel to the weld axis, and the entire joint fractured within several seconds. Crack propagation was slower in the T23 steel. Figure 1 shows a view of the crack after the RD test in the T24 steel.

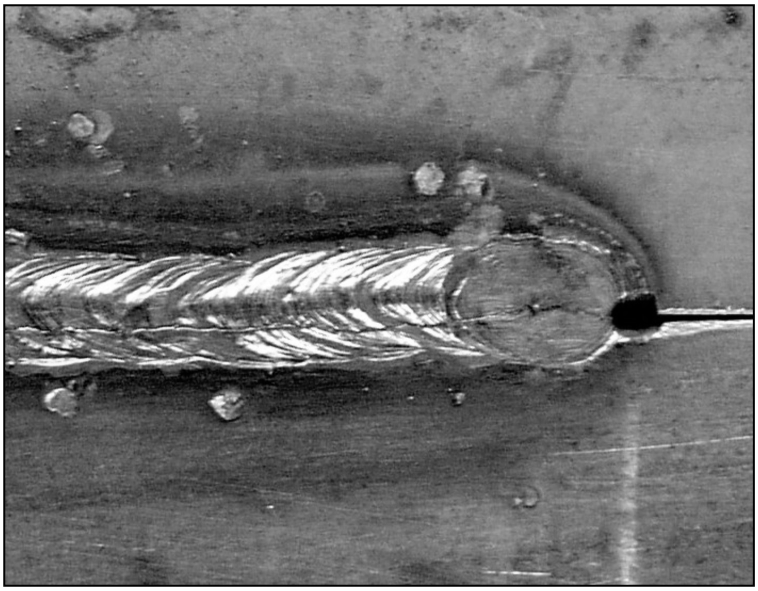

Fig.1 Crack in weld metal after RD test, T24 steel, filler material Thyssen Chromo 3V, rigid mounting, and no preheating

The second stage involved performance of RD tests with the test plate rigidly mounted, but with preheating to 150°C (interpass temperature: 300°C, postheating: 150°C/2 h). Test weld joints were subject to metallographic evaluation in cross sections. The test result was satisfactory.

The described experiments were complemented by a RD test performed on test samples without preheating and with no mounting on an auxiliary rigid plate. This most closely resembles the situation during welding of membrane walls. In the case of T24 and T25 steels, the entire weld joints cracked within a few minutes after welding, as in the first experiment. T23 steel underwent metallographic testing. Evaluation of RD tests is contained in Table 2.

During TEKKEN weldability tests the test weld, symbolising a root run, was performed by method 141 (TIG). T24 and T25 steels were welded using Union S1 CrMo2V (Thyssen) wire, T-HCM2S wire was used for T25 steel. Susceptibility of weld joints to cold cracking was evaluated on metallographic samples. TEKKEN weldability test results are shown in Table 3.

Table 2 Evaluation of RD tests of weld joints in T23, T24 and T25 steels

Steel	Weld joint ref. No.	Filler material	Preheating	Rigid mounting of test plate	Evaluation	Result
T23	2.1	Thyssen Cr2VW	no	yes	Weld joint fracture along entire length	Failed
T24	1.1	Thyssen Chromo3V	no	yes	Weld joint fracture along entire length	Failed
T25	3.1	Thyssen Chromo3V	no	yes	Weld joint fracture along entire length	Failed
T23	2.2	Thyssen Cr2VW	150 °C	yes	No cracks	Passed
T24	1.2	Thyssen Chromo3V	150 °C	yes	No cracks	Passed
T25	3.2	Thyssen Chromo3V	150 °C	yes	No cracks	Passed
T23	2.3	Thyssen Cr2VW	no	no	Isolated short cracks in weld metal (max. 1,9 mm)	Failed
T24	1.3	Thyssen Chromo3V	no	no	Weld joint fracture along entire length	Failed
T25	3.3	Thyssen Chromo3V	no	no	Weld joint fracture along entire length	Failed

Table 3 Evaluation of Tekken tests of weld joints in T23, T24 and T25

Steel	Weld joint ref. No.	Filler material	Preheating	Evaluation	Result
T23	2.1	T-HCM2S	150 °C	Crack in weld metal (only in end crater, max. 2,0 mm),	Failed
T24	1.1	Union S1 CrMo2V	150 °C	Crack in weld metal (max. 0,8 mm)	Failed
T25	3.1	Union S1 CrMo2V	150 °C	Minor cracks in weld metal	Failed
T23	2.2	T-HCM2S	200 °C	No cracks	Passed
T24	1.2	Union S1 CrMo2V	200 °C	Crack in weld metal (max. 1,5 mm)	Failed
T25	3.2	Union S1 CrMo2V	200 °C	No cracks	Passed

We can draw several conclusions from the tests performed:

- Welding of T23, T24 and T25 steels 6 mm thick requires preheating of minimum 150°C. Welding without preheating runs the risk of initiating cracks in the weld metal, even in a non-rigid weldment with possible dilatation.
- Weld metal from the Thyssen Cr2VW electrode is more plastic than that of electrode Thyssen Chromo3V.
- A preheating temperature of 200 °C is sufficient for welding T23 and T25 steels 20 mm thick. The preheating temperature must be raised to 200 °C for steel T24.

The attained results correcpond to the recommendations made by standard ČSN EN 1011-2 for creep-resistant steels. This standard recommends, for steels of similar chemical composition, a minimum preheating temperature of 150 °C for thicknesses up to 15 mm and 200 °C for thicknesses over 15 mm. This recommendation applies to a diffusion hydrogen content in weld metal 5 of 10 ml.100g $^{-1}$ [4].

4. Hardening processes of weld joints in T23 and T24 steels

Besides weldability tests the experimental program also included monitoring hardening processes in weld joints of T23 and T24 steels. This was based on measuring hardness in weld metal, i.e. in the HAZ during high-temperature exposure. Measuring was performed in weld joints without tempering after welding (condition after welding), as well as in welds tempered at 750, or 760°C. Figure 2 shows hardening curves for the overheated zone of the HAZ in steel T23 during simulated operation at 500°C. Figure 3 shows the same for steel T24.

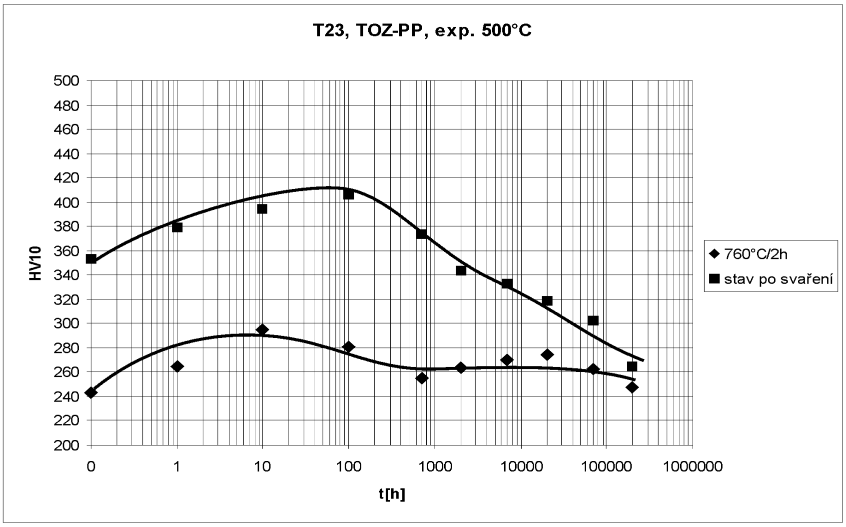

Fig.2 Comparison of hardness profiles in the overheated zone in T23 steel, operating temperature 500°C

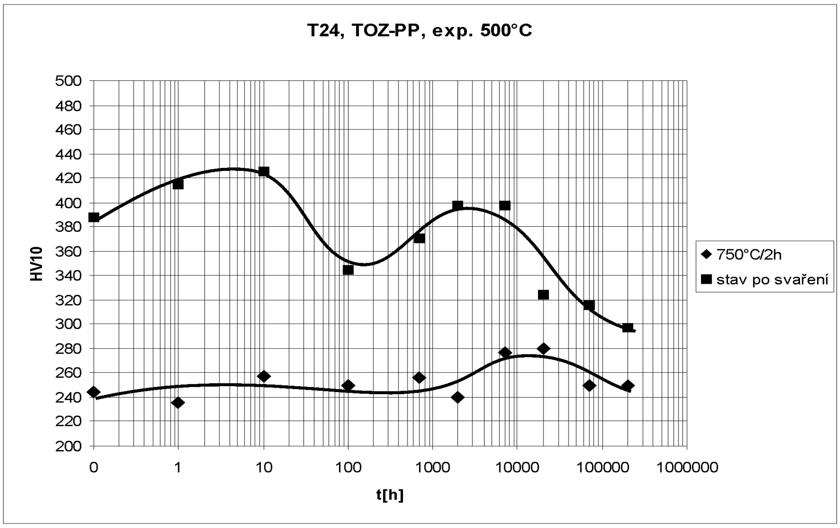

Fig.3 Comparison of hardness profiles in the overheated zone in T24 steel, operating temperature 500°C

The curves quite clearly show that weld joints that were not tempered after welding are subject to significant hardening in a relatively short time of 100, or 2000 hours. However, after longer periods (over 14 000 hours) hardness decreases, which is in line with paper [3]. Maximum hardness values fluctuate between 410 and 430 HV10 units. It must be stressed that these values are unacceptable by standard ČSN EN 288-3. Hardness measurement results show the presence of secondary hardening of weld joints in T23 and T24 steels. We can assume that the hardening mechanism is, as in the case of steel 15 128, induced by supplementary precipitation of dispersion MX particles.

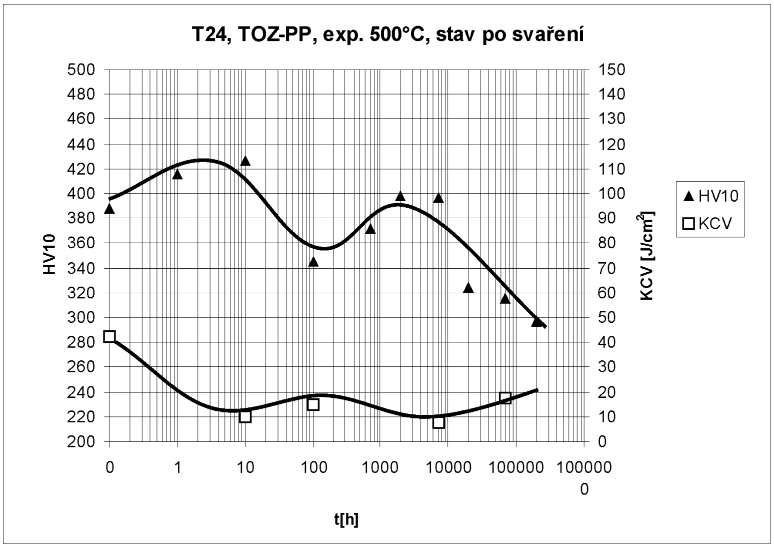

Fig.4 Comparison of hardness and notch toughness profiles, operating temperature 500°C, condition after welding

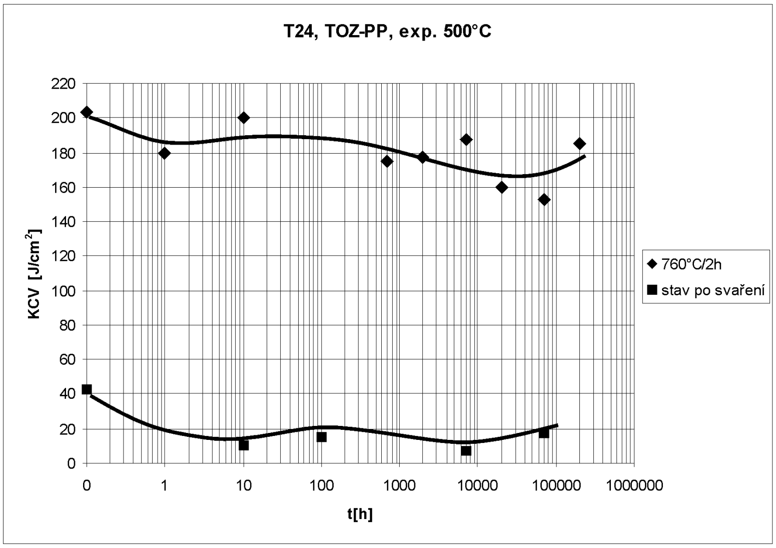

Fig.5 Notch toughness profile in the overheated zone of HAZ in T24 steel at operating temperature 500°C

Furthermore, KCV notch toughness was measured on selected samples. Figure 4 compares hardness and notch toughness in the overheated zone of T24 steel after welding. The notch toughness curve has a minimum more or less corresponding to the maximum hardness and vice versa. The affect of tempering after welding on notch toughness of the HAZ in T24 steel is evident from Figure 5. Measured values convincingly show that the plastic properties of a non-tempered weld joint are compromised. These results are in line with paper [1].

4. Conclusion

In line with papers [1,2] we can draw the conclusion that weld joints of steels hardened by dispersion of MX nanoparticles are subject to secondary hardening during extensive exposure to increased temperatures. The extent of this hardening depends on the tempering temperature after welding and duration of exposure.

Based on conducted weldability tests we can conclude that welding of T23, T24 and T25 steels 6 mm thick must include preheating to minimum 150°C. For greater thicknesses (over 20 mm) it is suitable to increase the preheating temperature to 200 to 250°C.

To achieve acceptable hardness of weld joints during operation, T23 and T24 steels must be subject to tempering after welding. Non-tempered weld joints are prone to drastic compromise of plastic properties.

To achieve enhanced operating reliability, manufacture of membrane walls from T23 and T24 steels must include preheating to minimum 150°C and tempering of weld joints at minimum 750°C immediately after welding.

Acknowledgements

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