EFFECT OF LONG-TERM EXPOSURE ON MECHANICAL PROPERTIES OF WELDMENTS FOR USC APPLICATION EVALUATED BY SPT

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Abstract

The paper deals with the possibility of using the SPT - (small punch test) method for evaluation of material properties of the individual areas of welded joints. The homogeneous and heterogeneous welds for USC power plants were assessed. The selected combination of welded joints made of austenitic creep resistant steels of the TP347 HFG, HR3C, Super304H and P92 grades in as-received state and after exposure in the real boiler conditions for one year were studied. The mechanical and fracture properties were assessed using small punch test of welds under investigation. The mechanical properties and fracture properties were studied using miniaturized tests, too. From the results it can be concluded that especially fracture properties were influenced significantly due to one-year exposure, which can be demonstrated on the Charpy impact tests, where the impact energy dropped down to only 1/3 of the original value.

Keywords: Austenitic steels, small punch test (SPT), welded joints, sigma phase, mechanical and fracture properties

1. INTRODUCTION

A lot of effort was devoted in the past decades to develop new steels for the most demanding steam parameters used in the newly build ultra-super critical (USC) power plants. Low price of austenitic heat resistant steels in comparison to high alloyed Ni-based superalloys was the principal motivation to develop materials with better hot corrosion resistance that overcomes mostly used AISI 316H steel especially for tubes of superheaters and/or reheaters working at more than 700 °C [1]. Extensive analysis of three steel grades intended for application in USC boilers was performed. The change of material characteristics after technological operations used during production of final stages of superheaters of USC boilers and their subsequent exposure at working temperature was assessed. Study was focused on new grades of austenitic heat resisting steels most frequently used in modern USC boilers:

- Super 304H,
- HR3C,
- TP347HFG

and their weld joints and bends made without post bend heat treatment of tubes with various bend radii. This paper is focused on assessment the mechanical and fracture properties of above mentioned weld joints. Owing to very small size of weld joint samples the study used miniaturized specimens and SPT method.

The goal of the paper is to show assessment of actual material properties of weld joints and basic materials of thin wall tubes determined for USC application using SPT method.

2. SMALL PUNCH TESTING AND ITS APPLICATION IN TESTING SUPERHEATER TUBES

Owing to thin wall of superheater tubes it was necessary to use testing assessment based on miniaturized test techniques Tensile Test (TT), Small Punch Test (SPT) and Fracture Toughness Test (FTT). SPT is a unique method that enables to determine material properties from very small material volume. It is possible to do chemical and microstructure analyses, to determine yield and tensile strength, transition temperature, fracture toughness and creep properties. Big advantage of this method is possibility to sample experimental material directly from the running components without any following repair or everywhere, where is the problem to remove material by destructive sampling method (bridges, steel structures, power plants, hydro-electric plants, etc.). The wide use of SPT shows the possibility of assessment of material properties through the wall thickness, where it enables to obtain fracture behaviour data through the wall thickness (outer and inner surface, middle part) or in various orientation of specimen (axial, tangential, radial direction). The method also can be used is assessment of material properties of very small volume, for example individual parts of weldments and even heat affected zone, decarburization layers, deposit welds, macro segregation, or welded joints of thin wall tubes. This article gives example of assessment of material properties of thin-wall welded tubes from austenitic steels.

An example of sampling a very small volume of experimental material, that is extracted from the component surface without any mechanical and/or heat impact, is shown in **Figure 1 (a)** altogether with a sample removed from the surface of tested component **(b)** and specimen test discs cut from removed material **(c)**. A small disc specimen, 8 mm in diameter and 0.5 mm in thickness is clamped around its circumference and indented by a spherical punch up to failure [2]. Monotonic load vs. displacement record is used to derive tensile properties and fracture toughness parameters as well as fracture energy evaluated as the area under load-displacement curve [2].

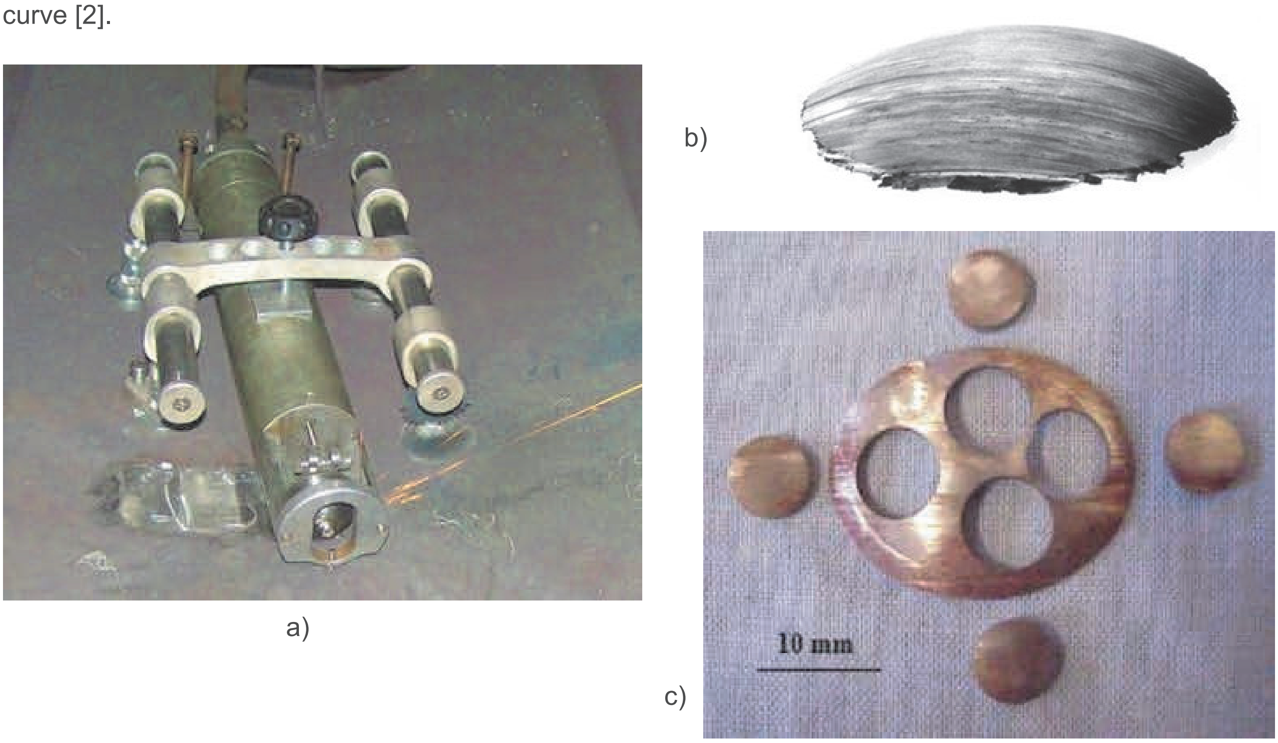
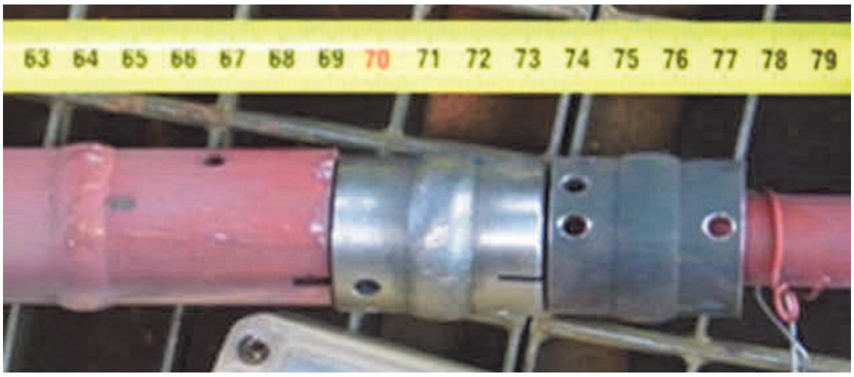


Figure 1 Specimen removal by sampling machine SSam TM-2 (a), specimen removed from the component (b), test discs cut from the specimen (c)

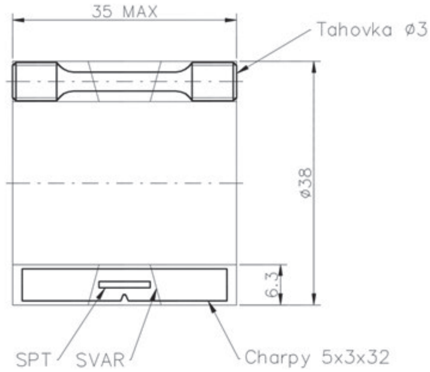
3. EXPERIMENTAL MATERIAL AND EXPERIMENTAL PROGRAMME

Experimental material consists of 21 combinations of welded joints of the homogeneous and heterogeneous welds for USC power plants made of austenitic creep resistant steels of the TP347 HFG, HR3C, Super304H and P92 grades both with post weld heat treatment (PWHT) and without PWHT. All welded joints were studied in as-received state and after exposure in the real boiler conditions for one year [1]. Welding method 141

(GTAW, TIG) with filled material ϕ 0.8 mm UTP A 6170 Co was used. PWHT was made in the case of grades Super 304H and TP347 HFG and its welds at the temperature 1130 °C, in the case of grade HR3C and its welds at the temperature 1230 °C, in case of grade P92 and its welds at the temperature 750 °C [3]. The rings with welded joints of ϕ 38 x 6.3 x 300 mm were available (see **Figure 2a**).



a)



b)

Figure 2 Samples of welded joints before exposure in the boiler

Mechanical properties were evaluated using the tensile test with miniaturized specimens of ϕ 3 mm and measured length 10 mm. Specimens were located into the weld metal such that the measured length contains equally the welded joint including both basic metals. Sample for SPT were removed as from basic material as from weld metal after exposure. Charpy V-notch test was done using test specimens of 3 x 5 x 32 mm with notch located into the weld metal - see **Figure 2b**.

4. CHANGE OF MATERIAL PROPERTIES AFTER ONE YEAR EXPOSURE IN THE BOILER

The samples had been exposed in the boiler without any loading at two working temperature range - one from 635 °C to 695 °C and another one from 726 °C to 775 °C for one year. Test results showed that tensile test is not enough sensitive method to fully reveal the material changes caused due to exposure. **Figure 3** and **4** show effect of exposure at two working temperature range on the yield strength, resp. tensile strength.

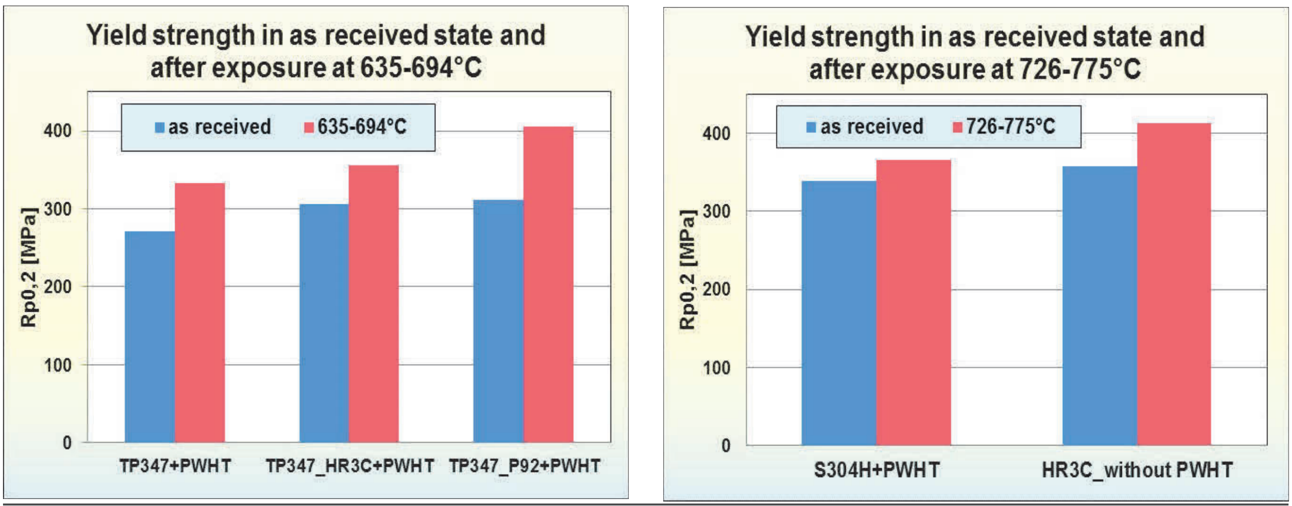


Figure 3 Effect of exposure on yield strength of chosen weld joints

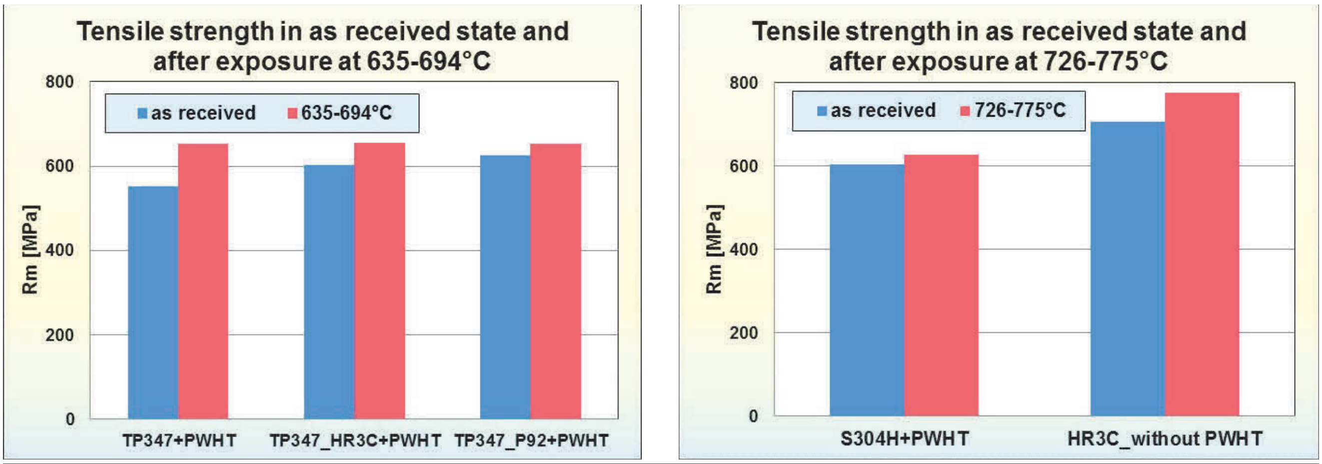


Figure 4 Effect of exposure on tensile strength of chosen weld joints

However material degradation of weld joints has been markedly proved by SPT method and fracture toughness characteristic. **Figures 5** and **6** show significant influence of exposure on material properties for selected combination of weld joints. Decrease of fracture energy (area under curve) of weld metal of TP347HFG-HR3C weld joint dropped after exposure nearly of 50 % compared to as received state (see **Figure 5**). So that it was confirmed that weld metal is the weakest point of weld joints of these materials.

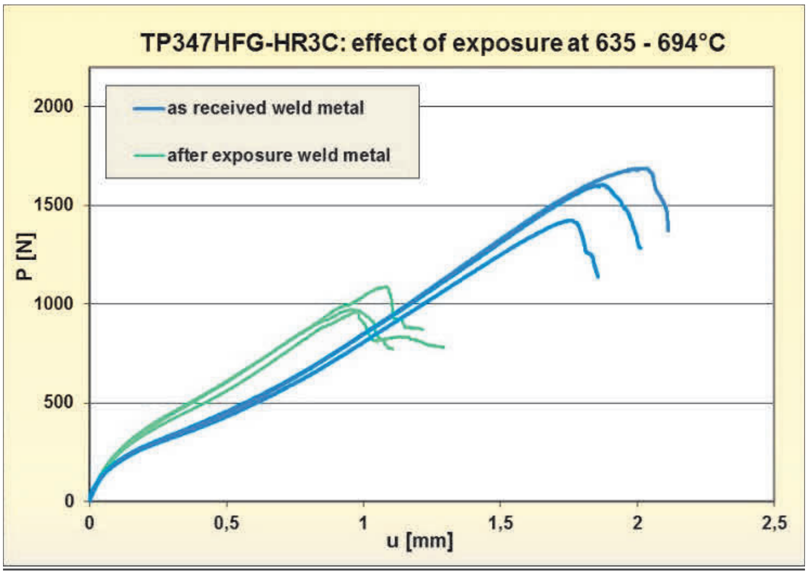


Figure 5 Effect of exposure on fracture energy of weld metal of TP347HFG-HR3C weld joint

Below is documented effect of PWHT and exposure at lower working temperature on fracture energy of the whole TP347HFG-HR3C weld joint (see **Figure 6**). It is evident that PWHT caused increasing of fracture energy of TP347HFG material in state as received, after exposure are values of fracture energy nearly the same. On the contrary HR3C material shows interesting behaviour. PWHT has decreased its fracture energy moderately with bigger scatter of values in state as received. But after exposure fracture energy of HR3C material shows drop to 50 % of values in state as received independently of PWHT. **Figure 6** shows that HR3C fracture energy is at level of weld metal.

Degradation effects of high working temperature and corrosion and corrosion environment of boiler influenced fracture properties of weld joints. The absorbed energy of weld metal dropped to up to 1/3 of state as received value (see **Figure 7**).

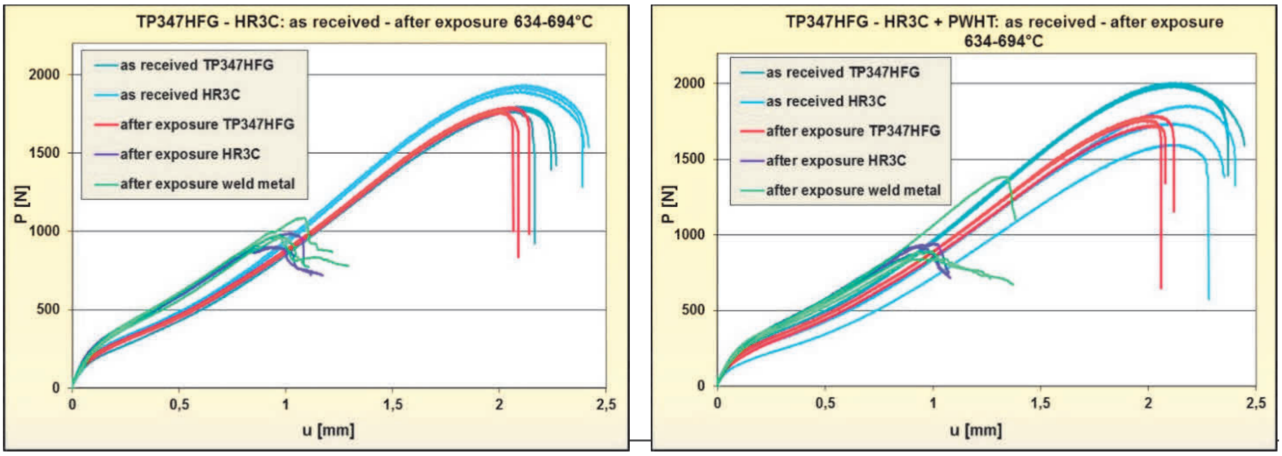


Figure 6 Effect of exposure on fracture energy of weld metal of TP347-HR3C weld joint

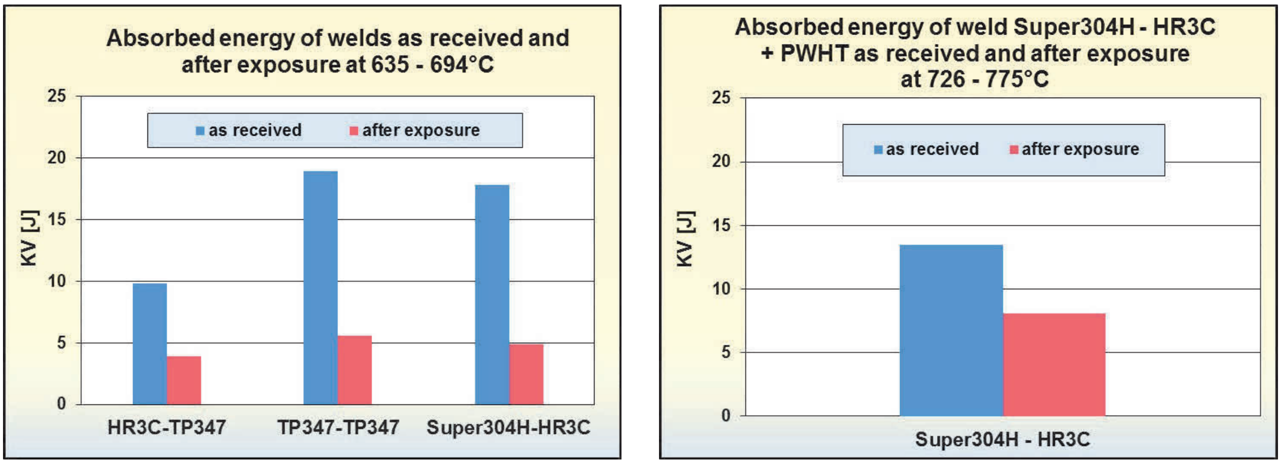


Figure 7 Effect of exposure on absorbed energy of chosen weld joints

5. DISCUSSION

Owing to the small size of welded joints exposed in real boiler it is not possible to make the assessment of mechanical and fracture properties by using standard test specimens. Therefore, SPT method and miniaturized test specimens were applied with the advantage of small test specimen size. SPT method allowed determination of fracture energy of weld metal and base material before and after high temperature exposure in the boiler. In contrast to tensile test, SPT method indicated strong drop of fracture energy of weld metal after exposure. The assessment showed that the weakest point of weld joint was weld metal where values of fracture energy after exposure reached 50 % of fracture energy of base metal as a maximum. This happened regardless of applying PWHT. The big surprise was that the high temperature exposure for one year in the real boiler caused pronounced degradation of material properties of weld joints and in particular fracture energy. It is necessary to emphasize that the exposure without any inner pressure load just at temperature without and corrosion environment was on the matter.

6. CONCLUSION

The paper deals with analyses of the effect of several technological factors on material properties of several weld joints of USC steels and their degradation due to exposure at working temperatures. High temperature exposure itself, in a real boiler for one year in corrosion environment and without any loading caused big drop of fracture and/or absorbed energy with minimum impact on mechanical properties. Absorbed energy of weld joints dropped only to one third of values of weld joint prior to exposure. Paper shows potential application of SPT method, which can be used for quantifying the decline in mechanical properties and especially fracture energy of weld joints intended and frequently exploited in USC applications.

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