MECHANICAL PROPERTIES OF STEEL P91 AND STEEL 12X18H12T IN DISSIMILAR PIPE WELDS USED IN BOILER COMPONENTS

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Abstract

The various welded joints used in production, most often in piping systems, always represent a special critical place in the system itself, seen in terms of possible occurences of damage (defects). In the case of welding various joints of low-alloy and high-alloy steels, problems often arise due to the choice of additional materials, because the additional material according to the carbon content may more suit only one of the steels in the joint, usually the lower grade. The selected additive material, on the other hand, determines the properties of the welded joint, because it dictates the development of specific metallurgical processes in welding in which certain phases take place, which in turn are characterized by certain properties.
The experimental investigation was made of dissimilar metal weld (DMW) joints between martensitic steel type P91 and austenitic steel type 12X18H12T using ERNiCr-3 filler metal. The as received P91 steel has been buttered using ERNiCr-3 filler metal, subjected to post weld heat treatment (PWHT) at 760°C for 120 min followed by air cooling and then welded with steel 12X18H12T by tungsten inert gas welding process without any PWHT after welding. Mechanical properties (tensile strength and hardness) and microstrucure were investigated on the welded joints.

Keywords: P91, 12X18H12T, ERNiCr-3, dissimilar welded joint, mechanical properties

1. Introduction

Steel P91 is widely used steel in the power industry because of its great mechanical properties at high temperatures. It has higher creep strength than low alloy steels such as 2.25Cr-1Mo steel and better thermophysical properties [1]. The steel is used in new and revitalized power plants, for steam pipes,

header and tube in coal-fired ultra-supercritical power plants [2]. Austenitic stainless steels are characterized by high heat resistance in elevated temperatures. For boiler super heater tubes experiencing 630°C, austenitic stainless steels 304H, 316 or 347H are used [3].
Critical issues for long term safe operation of steel P91 and dissimilar welded joint with austenitic steels are long term creep rupture strength of welded joints and base material, oxidation resistance and the resistance of type IV cracking, especially for thick section components.
In this research paper thick pipes 32x5 mm are investigated. From the 5 probes, 4 are made with buttering technique of the P91 steel and one probe welded directly to austenitic steel without buttering and preheating. As additional material is used nickel-alloy ERNiCr-3 (Thermanit Nicro 82). The other 4 probes are welded on the following way:
- 2 probes were welded without preheating and with PWHT (760 ˚C/2h) of the P91 steel side.
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2. Research methodology

The research methodology will include static tensile testing of the probes, hardness measurement and investigation of microstructure. Mechanical properties of the tested probes were determined at room temperature using the following equipment: static tensile test – WPM Leipzig ZD 40 tensile testing machine, according to EN ISO 6892-1 [4], Vickers hardness measurement – WPM Leipzig HPO 250, hardness testing machine, according to EN ISO 6507-1 [5].
Investigation of microstructure were performed on prepared metallographic microsections, according to EN ISO 17639:2013 [6]. Due to the different structure of base materials of the joint, different reagents to the disclosure of metallographic microstructure were used. For P91 steel was used Nital, and for 12X18H12T and weld is used Aqua regia (mixture of nitric acid and hydrochloric acid). The microstructure images were observed and recorded using an optical microscope (OM).

3. Welding technology

The analyzed steels can be welded with manual metal arc welding and tungsten inert gas welding as most used processes for joining heat resistant steels [7]. For the creation of joints between martensitic and austenitic steel with acceptable structural characteristics all recommendations and parameters of the welding process and heat treatment needs to be followed. Special attention should be dedicated to steel P91 for obtaining the required toughness and creep resistance. Well controlled preheat, interpass temperature and PWHT are mandatory to ensure that the required creep rupture properties and toughness are obtained in the weldment.
The current joint involves buttering one end of the steel P91 with a suitable nickel-base filler metal. The buttering is used to provide compatible weld metal for the subsequent completion of the weld.

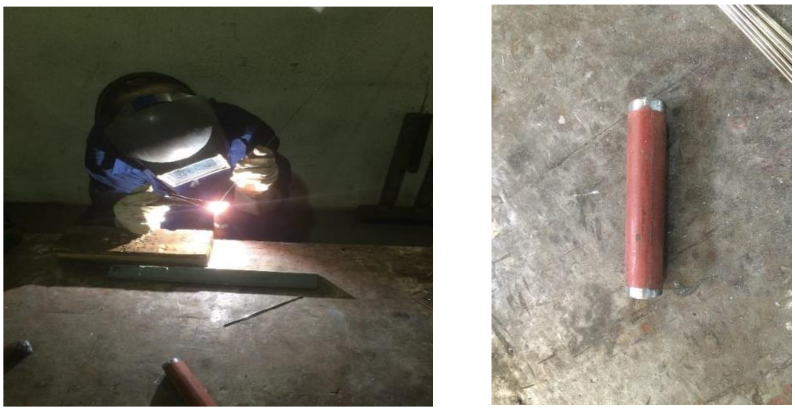


Fig. 1: Buttering of probes

The nickel-based filler material provides transition in coefficients of thermal expansion as well as proven to be beneficial for stopping the carbon diffusion from ferritic to austenitic side compared with conventional austenitic base filler [8]. After buttering the base material, P91, on the steel is performed PWHT of 2h at temperature of 710°C, fig. 2.

Fig 2. PWHT of steel P91 for 2h

After all welding procedures are fulfilled for steel P91 it can be welded with austenitic steel 12X18H12T without any further PWHT. For creation of dissimilar weld joint between both steels it was used tungsten inert gas welding process with the following parameters: 90A and 10V. The unit for welding was Cebora AC-DC 2540/T.
With welding technologies, as with any other process, defects occur. To be sure that no error occur during welding radiography testing of all joints was also performed, fig 3.

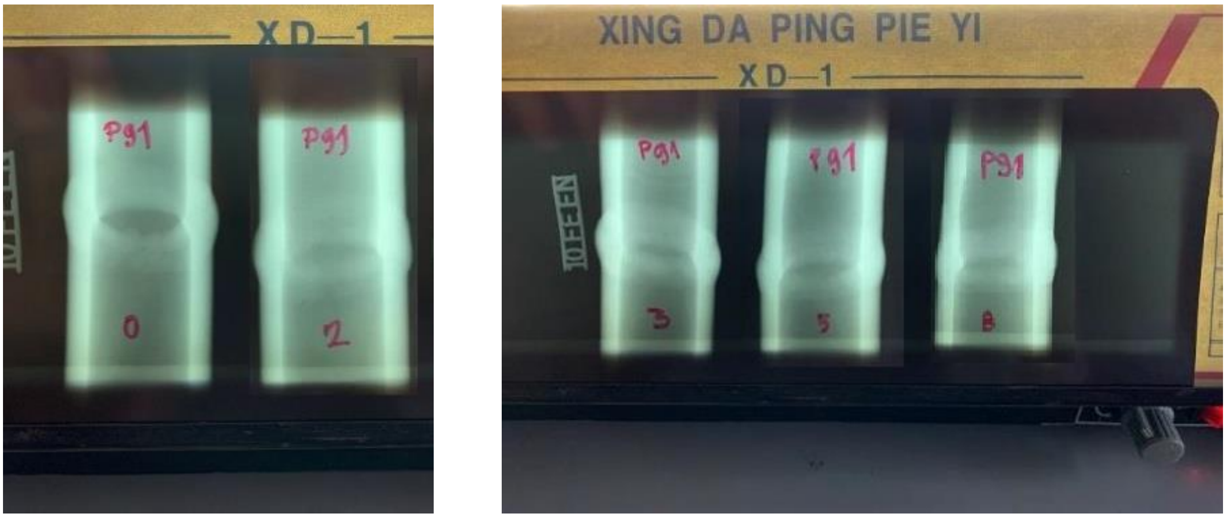


Fig 3. Radiography testing

3. Results of investigations

3.1 Tensile testing

The technological probes, regarding the diameter are tested without making tensile specimen, according to the standard for tensile test. On fig. 4 are presented the tested technological probes. Those samples that did not satisfy in terms of mechanical criteria are marked with an arrow (the failure occurred in the heat affected zone (HAZ or after tensile test are noticed serious cracks in the HAZ).

Fig 4. Tensile tested technological probes

3.2 Hardness testing

Hardness testing was carried out according to the recommendations of the European Standard EN ISO 6507-1. The measurements, based on the Vickers method, were made on WPM Leipzig HPO 250 hardness testing machine fig. 5, using a load of 10kg (HV10).

Fig 5. Measurement of hardness in line of the welded joint

The obtained values of the measurements are in table 1, and they are within permissible limits according to the Specification and qualification of welding procedures for metallic materials standard EN ISO 15614-1 (P91 in HAZ < 320HV).

Table 1. Hardness measurement of technological probes HV10

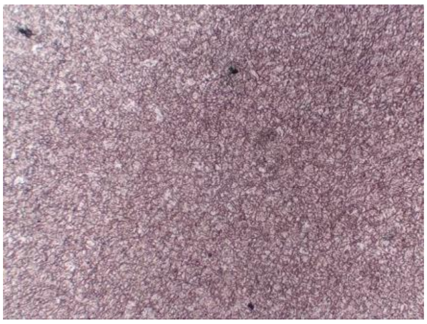
Probe	P91 – BM1	HAZ1	Buttered layer	Weld metal	HAZ2	12X18H12T – BM2
0	220	306	/	222	211	211
2	200	218	211	203	219	218
3	212	225	208	203	225	222
5	216	222	214	206	230	226
8	211	226	220	199	218	220

Due to limited testing resources, the hardness measurements were performed after the tensile test, which entails strengthening of the metal. According to previously stated, if a technological probe is made only for hardness measurement without prior tensile testing, the measured values of the hardness shown in tab. 1 will be with lower values, cca. 10÷15HV units.

3.2 Metallurgical testing

During metallographic testing, it was determined that the main cause of fracture in the heat-affected zone (HAZ) of the P91 steel is overheating of the structure during welding of the layer with an austenite electrode. Fig. 6 shows probes from a macroscopic analysis of destruction in the HAZ of P91 where the effects of overheating are visible.

Fig 6. Fracture in HAZ of P91 as result of overheating during buttering with Thermanit Nicro 82



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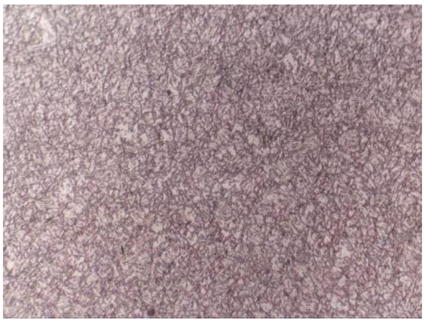

x 200

Fig 7. Microstructure of P91 (tempered martensite, fine grain structure)

On fig. 7 is show the microstructure of P91 steel (acid erosion using nital). It is a fine-grained structure, which provides high strength, low ductility, and high creep resistance. On fig. 8 is shown the microstructure of 12X18H12T (acid erosion using aqua regia). It is an austenitic structure, significantly coarse grain than P91 which provides high ductility, relatively high strength (less than P91) and excellent creep resistance. Figure 9 shows the transition from steel P91 towards buttered joint (acid erosion using nital). The mixing between the austenitic weld layer and P91 is poor, and therefore the HAZ is a critical place for fracture to occur.

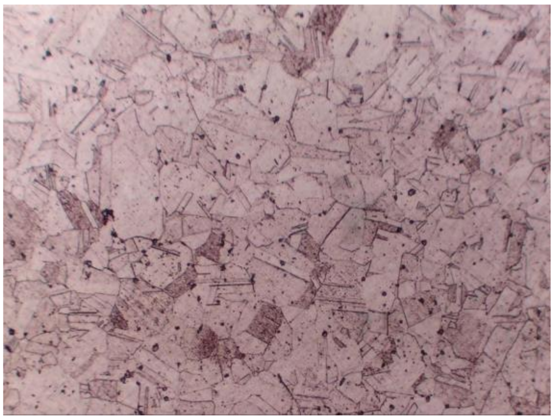

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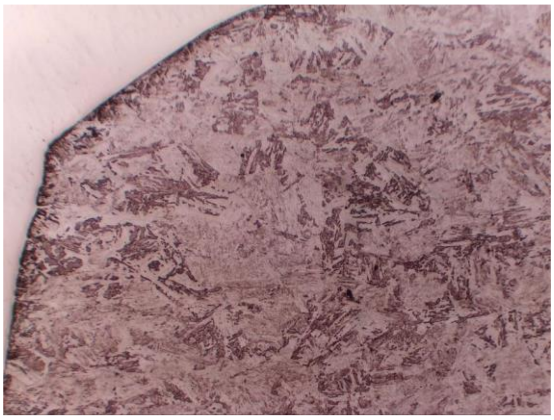
Fig 8. Microstructure of 12X18H12T



x 50

Fig 9. Transition from P91 to an austenitic weld

4. Discussions of the result

Mechanical tensile testing of technological probes gave results that indicate that the critical side of the occurrence of fracture is the side of P91 steel. The most critical is the HAZ next to the weld. If there is a mistake in the welding technology with all its process aspects, the fracture can always be expected on the martensitic steel side, while no fractures are expected on the austenitic steel side.
The probe 3 during tensile test did not fracture in the HAZ1 of the steel P91, the appearance of possible fractures in HAZ1 indicates that during long term service HAZ1 will be the location of facture (during long term use in creep conditions).
The metallographic analysis of the results leads to the conclusion that the thickness of the welded layer, in terms of heat input, as well as post weld heat treatment, can significantly affect the final properties of HAZ1, causing a noticeable degradation of the microstructure that is characteristic of P91. From this point of view, for small thicknesses such as the considered pipes, the best results were given by the technological probe marked 0 (zero) which was welded without preheating and without heat treatment after welding, i.e. with the lowest heat input.
The measured hardness in all technological tests is within the permissible limits, and it cannot be used individually to make a conclusion about the advantage/disadvantage of the chosen welding technology of the dissimilar joint.

5. Conclusions

In the paper is presented research methodology of joining two different steels between X10CrMoVNb9-1 (P91) martensitic steel and 12X18H12T austenitic steel. The experimental investigation relates with destructive testing and metallographic analysis of the welded joint in order to determine the influence of welding technology on a short-term tensile test, and indirectly to draw conclusions about the long-term use of the joint under elevated temperature conditions. Destructive testing included tensile test and hardness measurement, while the microstructure of the joint was examined using an optical microscope.

Welding of materials with different chemical compositions may result in the occurrence of coarse-grained decarburized ferritic zone with low hardness on one side of the line of fusion and hard carburized zone on the other side, which is caused by the formation and growth of carbides. The mechanism responsible for the formation of the abovementioned lines of fusion in dissimilar welded joints is carbon diffusion. For preventing the occurrence of both zones on the line of fusion while welding of steels with different chemical compositions is used additional nickel-based materials and created a buffer zone on the martensitic steel, using additional material Thermanit Nicro 82, nickel alloy in order to prevent the formation of the so-called carbide beam.

From the obtained results, it can be concluded that the influence of heat input during "buttering", welding and PWHT have the greatest impact on achieving a quality joint that will have a long service life.

As a recommendation for future research, the following activities can be considered:

- To investigate welding technology with and without preheating of steel P91 and with and without PWHT of steel P91 to find the way that least damages the microstructure of P91 in HAZ1.
- To investigate welding technology at working temperatures with a short-term test at increased temperature.
- To examine welding technology through an accelerated creep test in laboratory conditions.
- To investigate the welding technology in operation (with installation of a joint in a boiler in a steam superheater) after a significant number of working hours (min.50.000,00h) in order to determine the trend and the rate of degradation of P91 steel.

6. References

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