Application of New GMAW Welding Methods used in Prefabrication of P92 (X10CrWMoVNb9-2) Pipe Butt Welds

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Abstract

Welding of collector pipes, flat heads, dished ends and connector pipes performed with high temperature and creep-resistant steels most often has been performed using TIG process combined with MMA processes. Progress in MAG process and availability of high quality filler materials (solid wires) enables welding of the above connections also using this method. In order to prove its efficiency, this article presents the results of related tests. The range of tests was similar to that applied during the qualification of welding technology. The investigation also involved microscopic and fractographic examinations. The results reveal that welding with new methods such as GMAW is by no means inferior to a currently applied MMA method, yet the time of the process is shorter by 50%. The article presents the world’s first known positive results in welding of P92 grade steel using GMAW welding method.

Keywords: P92, MAG, TIG, pipe butt welds, welding.

Introduction

The production of critical structures of power boiler pressure elements requires special attention to be attached to the quality of welded joints. In order to accomplish this objective, the manufacturer of power engineering equipment must be supported by advanced technological solutions as steel grades intended for operation at higher temperature are characterised by limited weldability and thus demand complete supervision and monitoring at pre-weld, welding and post-weld stages. Most steel grades used in operation at high temperature and, in particular, martensitic molybdenum-chromium steels require pre-heating, maintaining proper inter-run temperature and post-weld heat treatment of the joint usu. through stress relief annealing. The whole process of production of butt joints, especially in case of collector pipes of diameters exceeding 114.3 mm and wall thickness over 10 mm, using standard technologies applied today proves time-consuming and costly. Therefore, it remains desirable to further improve the welding process, reduce joint production time, significantly decrease labour costs without compromising high mechanical and plastic properties of welded joints, process purity and low noxiousness to the welder [1, 2].

Until today collector pipes of water-tube steam boilers are TIG-welded (fusion layer) with covered electrode (filling layers). The combination of both methods guarantees high quality of joints but, unfortunately, increases their production time. The major factors prolonging the welding process time are additional operations such as removal of slag or post-weld spatters. In addition, welding with covered electrodes is connected with significant emission of welding fumes and gases known to be detrimental to welder’s health [2].

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The availability of welding consumables in the form of solid wires as well as access to modern welding equipment enabled the MAG-, and in particular, pulse current-based investigation focused on welding of materials exploited at higher temperature [2, 4].

Subject of investigation

The subject of investigation included butt-welded joints of pipes (ø219.1 x 31.75mm) made of X10CrWMoVNb9-2 (P92) steel. The chemical composition of the steel as delivered is presented in Table 3, whereas its mechanical properties are detailed in Table 4.

Table 3. Chemical composition of tested P92 steel grade [5]

Grade	Chemical composition, %									
	C	Si	Mn	Cr	Mo	V	W	Co	Others	
P92	0.103	0.223	0.484	8.986	0.456	0.164	1.900	0.027	B-0.002 N-0.047 Ti-0.002	Nb-0.053 Ni-0.116 Cu-0.111

Table 4. Mechanical properties of tested P92 steel grade [5]

Grade	Mechanical properties				
	Re, MPa	Rm, MPa	A min., %	HV	KV, J
P92	666	805	23	228	255

Welding consumables

Properly selected welding consumables are decisive for obtaining required joint properties. Their role is to ensure that the chemical composition of the weld and its mechanical properties will be as close to those of the parent metal as possible. Table 5 presents welding consumables while welding test joints [5, 7].

Table 5. Welding consumables used for P92 steel grade

Method	**Filler metal**	**Diameter**	**Manufacturer, designation**
Welding consumables used with P92 steel (X10CrWMoVNb9-2)			
111	E ZCrMoWVNb 9 0.5 2 B 4 2 H5	3.2; 4	Böhler Thyssen Thermanit MTS 616
135 (TP)	G ZCrMoWVNb 9 0.5 1.5	1.2	Böhler Thyssen Thermanit MTS 616
141	W ZCrMoWVNb 9 0.5 1.5	2.4	Böhler Thyssen Thermanit MTS 616

Investigation plan

The production of welded joints was followed by non-destructive tests i.e., VT, PT and RT in 100% scope. The tests were performed taking into consideration quality level B pursuant to standard PN-EN ISO 5817 [11]. After obtaining positive NDT results, the joints were sampled for specimens for destructive tests (see the diagram in Figure 3).

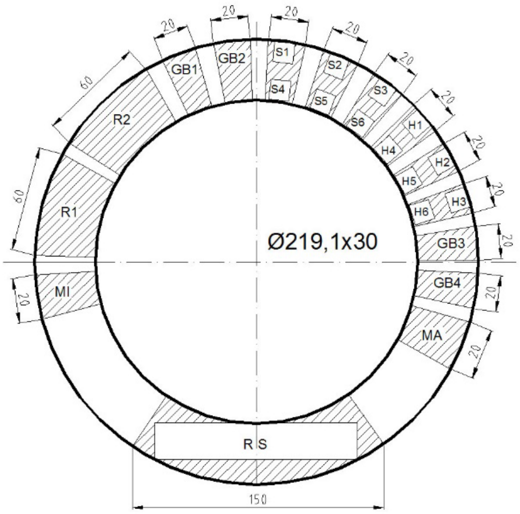

Figure 3. Manner of cutting specimens out of butt-welded joints of tubes

The scope of mechanical tests included the static tensile test of the welded joint (samples R1 and R2), bend test (samples GB1÷GB4 – side bend tests), impact tests (samples S1÷S6 – notch cut in the weld; samples H1÷H6 – notch cut in HAZ), macroscopic examination (sample MA), microscopic examination (sample MA), hardness measurements (sample MA) and fractographic examination from break tests.

Results of joint static tensile tests

The tests were performed pursuant to standard PN-EN 895 [12] and aimed to determine the tensile strength (R_m) of the welded joint as well as verify the results in relation to the minimum R_m value for the parent metal (PM), which pursuant to PN-EN 10216-2 [6] standard stands at 620 Mpa. In the diagrams the value was marked with a thick line (Figure 5). The tests revealed that all the welded joints underwent rupture outside the weld and therefore met strength- and quality related requirements.

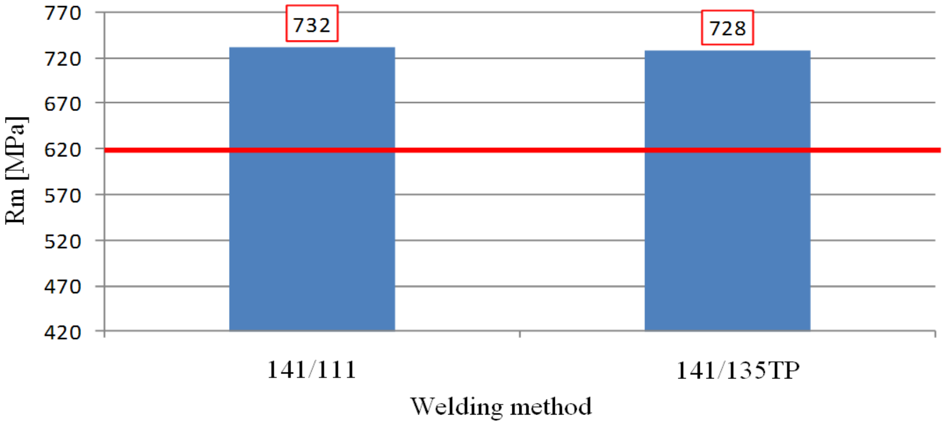

Figure 5. Results of tensile test of butt welded joints

Results of weld and HAZ impact tests

The tests in question were performed in order to determine the impact energy of weld and that of HAZ. Standard PN-EN 12952-6 [13] sets the minimum value of impact energy in HAZ at 24J and that in the weld at 27J; both values being provided for ambient temperature conditions. In the diagrams the said values were marked with thick lines (Figure 6).

The impact energy results concerning the weld and HAZ are higher than the values specified in the cited standard and the minimum values declared by the manufacturer.

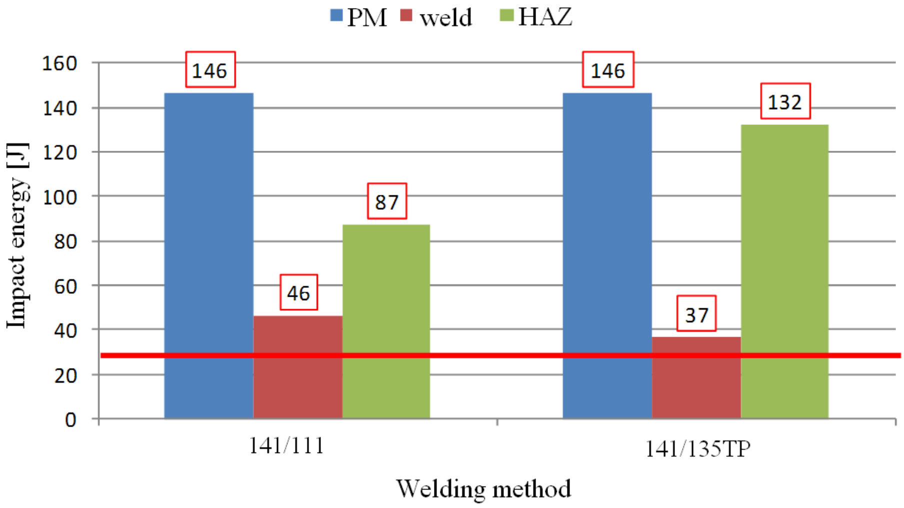

Figure 6. Impact strength of weld metal in butt welded joints

Hardness measurements results of weld

The hardness tests were conducted pursuant to standards PN-EN 15614-1 [14] and PN-EN 12952-6 [13]. In the aforementioned standards the maximum value specified for joints subject to heat treatment stands at 350 HV10. Figure 7 presents the arrangement of hardness measurement points, whereas Figures 8-9 present the results of corresponding measurements. All the results are considerably lower than the allowed values and thus confirm the proper selection and performance of welding process and heat treatment.

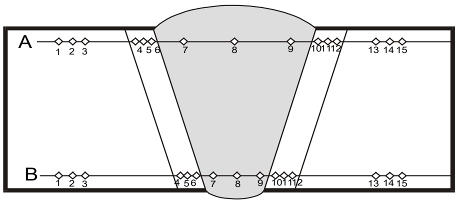

Figure 7. Hardness measurement points in butt welded joints

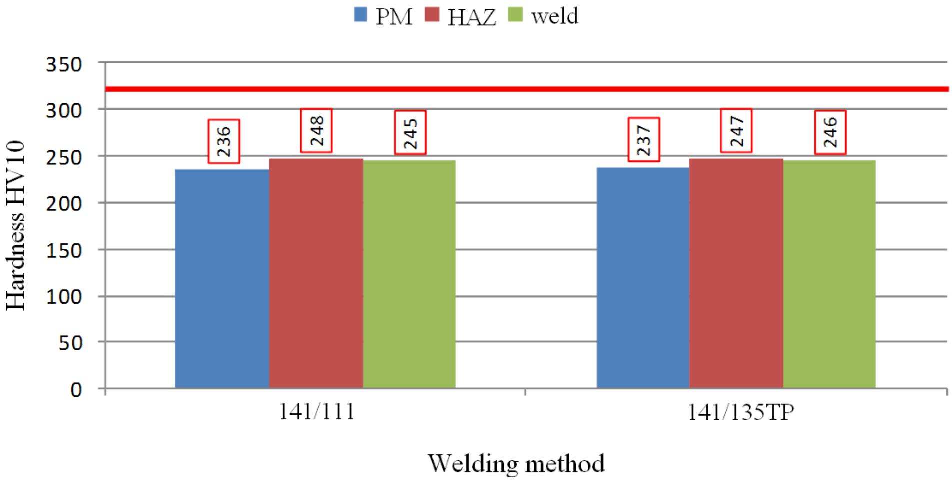

Figure 8. Comparison of hardness results in measurement line A

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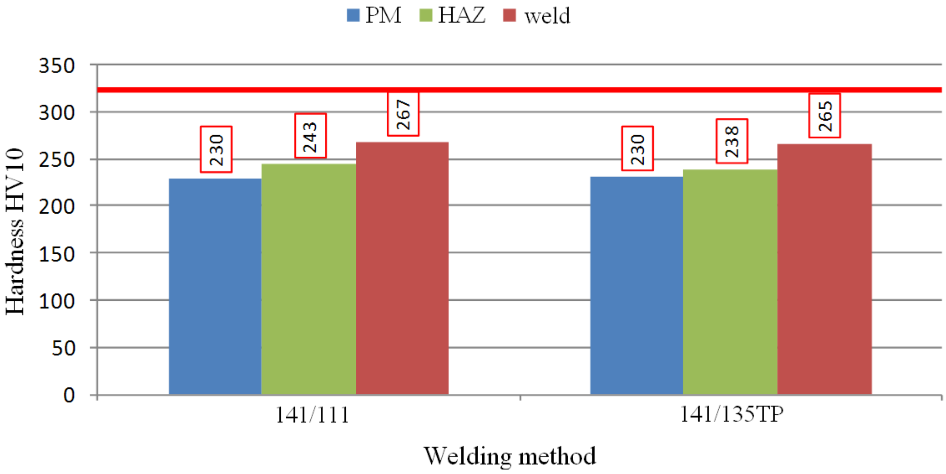


Figure 9. Comparison of hardness results in measurement line B

Macroscopic test results

The examination was performed pursuant to standard PN-EN 1321 [15]. The criterion applied for assessment-related purposes was quality level B pursuant to standard PN-EN ISO 5817 [9]. The aforesaid quality requirement was met in case of all of the joints. Figure 10 presents the results of macroscopic examination of the joint welded with 141/111 method (left) and those related to the joint produced with 141/135 method (right).

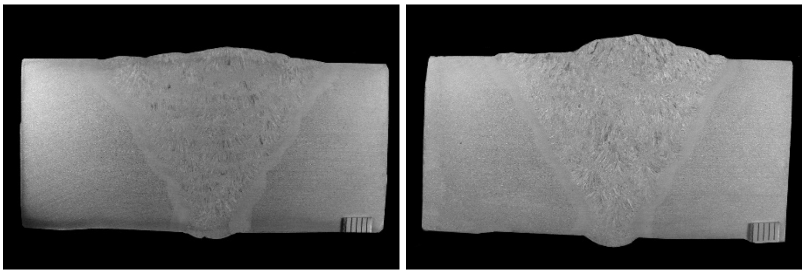


Figure 10. Macrostructure of butt welded joint; methods: 141/111 (left), 141/135 (right)

Microscopic test results

The microscopic examination, which was performed pursuant to standard PN-EN 1321 [15], did not reveal any microcracks and confirmed the presence of proper microstructure in all the zones of the joints made of P92 martensitic steel. Figure 11 contains microscopic examination areas (marked). Table 6 presents the results of microscopic examination in the form of photographs and description of the structures present in the characteristic areas of the welded joint.

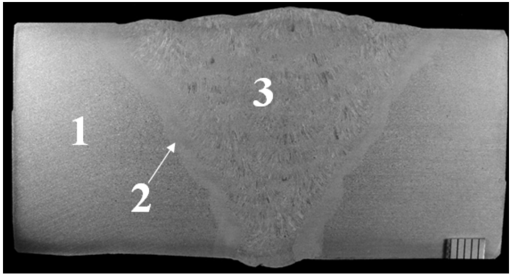
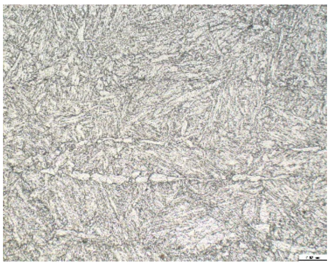
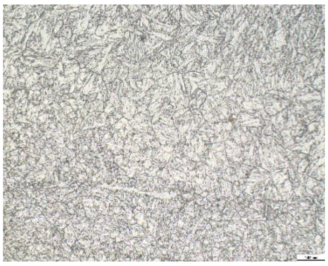
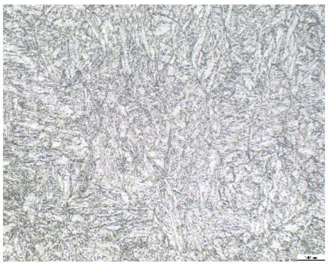


Figure 11. Areas of microscopic examination in butt welded joint

Table 6. Examples of result of microscopic examination of butt welded joint

	141/111	141/135
parent metal **area 1**, mag. 500x, etch. $FeCl_3$	 tempered martensite	 tempered martensite
HAZ **area 2**, mag. 500x, etch. $FeCl_3$	 tempered martensite	 tempered martensite
weld **area 3**, mag. 500x, etch. $FeCl_3$	 tempered martensite	 tempered martensite

Fractographic examination results

The fractographic examination was conducted on the fractures following the impact test and involved the samples welded with method 135 (sample series 1) and joints welded with method 111 (sample series 2).

The topography of fractures of welds welded with method 135 following the impact test are presented in figure 12a), whereas the HAZ fractures are presented in figure 12b). Figures 13a) and 13b) present the fractures of the weld and HAZ welded with method 111 respectively.

The fractographic analysis and microanalysis of the chemical composition of precipitates in the weld welded with the covered electrode reveals that the joint was produced properly and should meet the requirements of operation at higher temperature. The aforesaid fact is confirmed by impact energy values, which for the weld and HAZ amounted to 49J and 87 J respectively. Also, the hardness of the joint, which did not exceed 280 HV, confirms the correctness of the applied technology.

During fractographic examination both MC carbides and MX carbonitrides were found. Both precipitates were analyzed with chemical microanalysis, and it was found that chromium carbides and tungsten carbides were present in weld and HAZ.

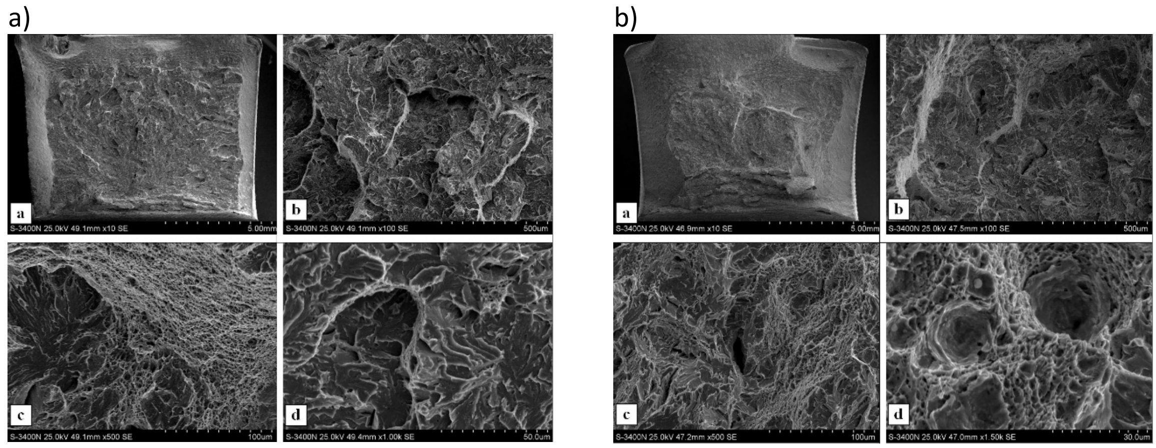


Figure 12. Weld topography for 135 welding method

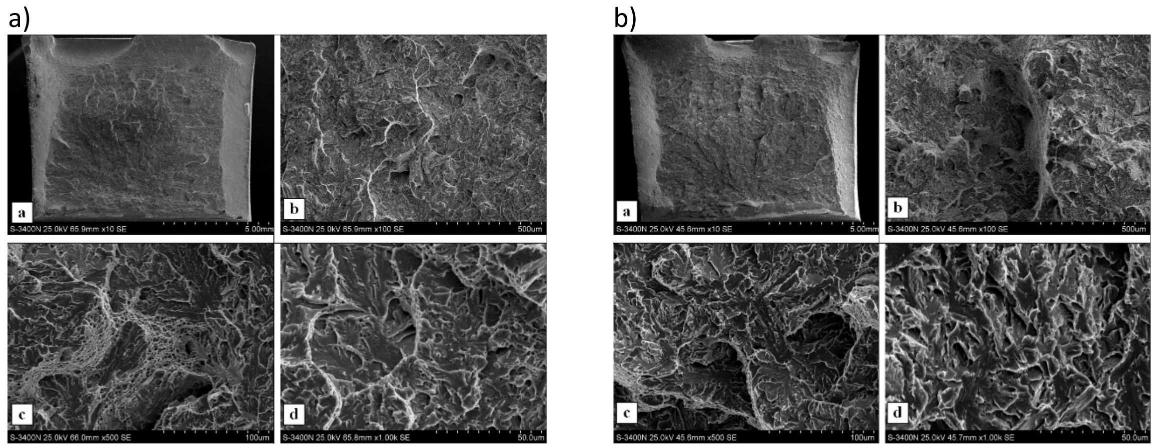


Figure 13. Weld topography for 111 welding method

In all cases it was possible to observe mixed plastic-brittle fracture with rare scrap cracks. Such morphology is characteristic of tempered martensite structures. As opposed to conventional method 141/111 no anomalies were diagnosed for the samples welded with method 141/135TP.

Conclusions

On grounds of the tests, it was possible to formulate the following conclusions:

1. Both NDT and DT confirmed high quality of butt-welded joints made of P92 steel in workshop conditions.
2. In all cases it was possible to observe mixed plastic-brittle fracture with rare scrap cracks. Such morphology is characteristic of tempered martensite structures. As opposed to conventional method 141/111 no anomalies were diagnosed for the samples welded with method 141/135TP.
3. The application of MAG method reduces impurities and increases the comfort of welder's work.
4. The mechanisation of method 135 may lead to a further increase in the effectiveness of production of butt-welded joints and at the same time decrease their manufacturing costs.

The authors of the article wish to express they're thanks to TenarisDalmine for providing the pipes used for the investigations and to BÖHLER Schweißtechnik Deutschland for providing the covered electrodes used for welding P92 steel

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ANNEX III

Article from ISQ

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