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SOME ASPECTS OF WELDING OF LOW CARBON LOW ALLOYED STEEL FOR HIGH TEMPERATURE APPLICATION

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Abstract: *The aim of this work was to establish the influence of initial state of base metal on properties of welded 14MoV 6 3 steel. This low carbon low alloyed steel is used for pipes operating at temperatures up to 500°C for long periods. After 52600 hours in exploitation, during retrofitting of these installations, new pipes (new material) are being welded to original parts (used material) in power plant. Therefore, three combinations of specimens were welded: (i) new-new (N-N); (ii) used-used (U-U); (iii) new-used (N-U). Welding was performed using combination of TIG/MMA, two root passes using TIG (Tungsten Inert Gas), and two filling passes using MMA. Microstructures in HAZ are characterized by presence of bainites. Weldments were tested by means of tensile testing. It has been established that ultimate tensile strength is highest in N-N weldments. Strength of N-U weldments showed some lower value, while strength of U-U joints is lowest. In N-U weldments, the fracture is initiated on the side of used part. It is assumed that the critical conditions were achieved as the consequence of creep induced grain growth and particle coarsening. This behavior can not be revealed in routine qualification of welding technology.*

Keywords: *Creep resistant 14MoV 6 3 steel; TIG welding;MMA welding; properies of weld joint.*

1. INTRODUCTION

Creep resistant low alloyed steel 14MoV 6 3 operates up to 150000 hours on temperatures over 500°C. Initial microstructure of this steel consists of martensite or bainite. Long service at such high temperatures introduces creep. Molybdenum is added in order to increase strength at grain baundaries and prevent grain baundary glide, while vanadium is added in order to force precipitation of VC, which will decrease rate of strength degradation. After creep, microstructure is changed, exhibiting increase of grain size, accompanyied with carbide precipitation. Many results describe this steel as acceptable solution [1-8].

Welding is the most usual procedure for assembly pipes and/or heat exchangers. Welding as a process, introduces non homogenities in microstructure. Post welding heat treatment is focussed only on stress relieve. Therefore, HAZ and weld metal are expected to have different response to creep [9-12].

On the other hand, when a reparature is necessary, obligatory qualification of welding technology should be done in accordance with standardized procedure, but on steel that was not in service – new (virgin) steel. Due to the changes in microstructure triggered by long service at elevated temperatures, there is an uncertainty on the reliability of obtained results, since mechanical properties are expected to be changed [1-3].

In order to investigate the problem, three combinations of 14MoV 6 3 steel specimens were welded: (i) used-used (U-U); (ii) virgin-used (N-U); (iii) virgin-virgin (N-N).

Specimens were welded TIG for root pass and MMA for filling pass, using adequate filler materials .

Table 1. Chemical Composition of 14MoV63 steel and filler materials (mas. %)

	C	Si	Mn	P	S	Cr	Mo	V
DIN 17175	0,10 0,18	0,15 0,35	0,30 0,60	0,040 max	0,040 max	0,30 0,60	0,50 0,65	0,25 0,35
Used (U) pipe	0,14	0,30	0,56	0,019	0,015	0,58	0,39	0,23
New (N) pipe	0,15	0,22	0,48	0,012	0,010	0,39	0,47	0,24
TIG – pass – wire	0,08	0,60	0,90	-	-	0,45	0,85	0,35
MMA pass - electrode	0,065	0,35	1,2	-	-	0,4	1,0	0,5

Table 2 Welding Parameters

Pass		Filler material dimeter (mm)	Welding Current, (A)	Welding Voltage, (V)	Ar Flow (l/min)	Welding speed(mm/s)	Heat Input E(kJ/mm)
1	TIG - root	Ø2,4	100	11,9	6-8	0,88	1,35
2	MMA - filling	Ø3,25	113	23,8	-----	2,26	1,19

2. EXPERIMENTAL

Used steel, 14MoV 6 3 , tested in this work was more than 52000 hours in service in Thermoelectric power station. Its chemical composition, together with standard requirements, chemical composition of new steel, as well as compositions of tho filler materials is given in table 1.

Welding of pipes consisted of two passes: (I) Root pass was welded using TIG (GTAW), Ø2.5mm W MoVSi filler wire , and (II) filling pass was welded using MMA process, Ø3.25mm E MoV B 4 2 H5 electrode. Welding parameters are given in Table 2. Stress relieving post welding heat treatment was done according to following procedure: (i) annealing 1h at 400°C, (ii) heating to 710°C in 2h, (iii) annealing for 2h at 710°C, (iv) furnace cooling to 200°C and (v) cooling to room temperature at still air.

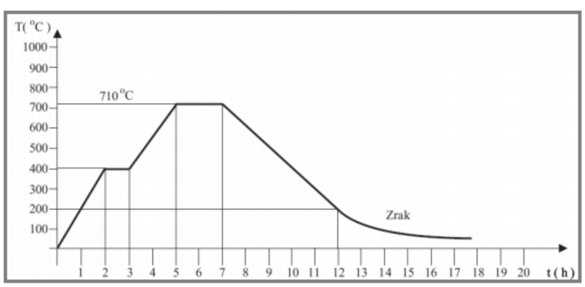


Figure 1. Scheme of applied Post Welding Heat treatment

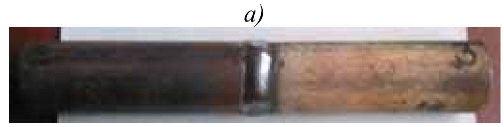
Tensile testing was performed on tensile testing machine at room temperature (RT) and at 450°C.

Microstructural evaluation was done on both initial steels (U and N state) and heat treated welded joints. After preparation by grinding, polishing and etching in nital (2% HNO_3 in ethanol), samples were evaluated using optical microscopy.

3. RESULTS AND DISCUSSION

All three welded samples, i.e., New-New pipe (N-N); New-Used pipe (N-U) and Used-Used pipe (U-U), are shown on Figures 1a, 1b and 1c, respectively. Used pipe has characteristic reddish color, due to long exposure to corrosion atmosphere. Since both visual and radiographic examinations did not reveal any defects in welded joints, samples were taken for mechanical testing and structure evaluation.

a)



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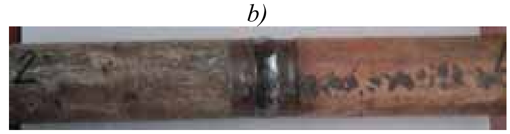
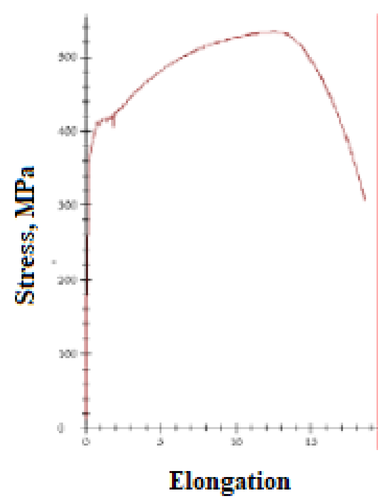


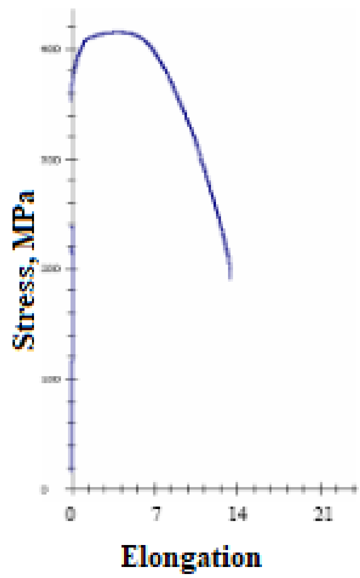
c)

Figure 2. Welded samples (a) New-New pipe (N-N); (b) New-Used pipe (N-U) and (c) Used-Used pipe (U-U)

Tensile testing. Typical Stress-strain curve obtained in these tests is shown in figure 2.



(a)



(b)

Figure 2. Stress-strain curves obtained in tests at (a) room temperature; (b) +450°C: sample New-Used pipe (N-U)

Stress strain curves are exhibiting clear start of plastic deformation. Increase of elongation is accompanied with stress increase. Strain hardening rate is higher in test at RT, because cross slip is activated at larger elongation. Therefore, necking at RT occurs at higher elongation, so that Ultimate tensile stress and elongation have higher values in tests at RT [13-15].

Mechanical properties of welded joints tested at room and elevated temperature are presented in table 3. In all three weldments, ultimate tensile strength is higher than in base metal.

The intention in selection of filler material and welding parameters for welding of 14MoV6 3 steel is to provide higher level of mechanical properties in comparison to all samples was located in in base material, while in N-U base metal, i.e. make an attempt to force fracture in base higher level of mechanical properties in comparison to all samples was located in in base material, while in N-S base metal, i.e. make an attempt to force fracture in base metal. This approach was successful, so that fracture in weldment it is placed in used part. This is very important fact, because it can not be revealed in Weld Process Quality Request (WPQR), since for this test two samples of new pipe are welded! Here has to be pointed out that in used pipes, initial microstructure was changer. Long exposure at high temperatures, combined with present high pressures has triggered grain coarsening. Therefore, this grain growth leads to lowering of yield strength, in accordance with Hall-Petch equation [13-15].

It is worth noting that in all samples, fracture initiation is moved out of weld metal and heat affected zone, zones characterized with very non-homogenous microstructures, because the repeatability of structures in heat affected zone is not reliable.

Ultimate tensile strength in weldments tested at 450˚C shows slight decrease following the line: N-N, N-U and U-U. Resistance to deformation at high temperatures decreases with increase of temperature [13-15]. As mentioned, this behavior is attributed to more intensive cross-slip. Also, presence of high dislocation density accelerates the diffusion of alloying elements promoting carbide formation, preferentially at grain boundaries. In this manner, the solid solution becomes depleted. This decreases the solid solution strengthening effect due to easier dislocation movement, and lowers the strain hardening rate which results in decrease of ultimate tensile strength. This effect is most pronounced in steels that were exploited for long time since the amount of formed carbides is the greatest [1,2,6,7,16]. Initial microstructures in used and virgin materials are significantly different, dominantly in grain size. Used steel is characterized with larger grains and lower strength.

Table 3. Results of tensile testing

SAMPLE	Testing Temperature, (°C)	Ultimate Tensile Stress (MPa)	Yield Stress (MPa)	Place of fracture in welded joint
Standard DIN 17175	+20	490-690	365	
Used pipe (U)	+20	567	377	
New pipe (N)	+20	564	444	
New-New	+20	552	426*	Base metal
New-New	+450	423	296*	Base metal
New-Used	+20	533	412*	Base metal – USED
New-Used	+450	415	391*	Base metal – USED
Used-Used	+20	495	347*	Base metal
Used-Used	+450	407	311*	Base metal

* - Yield stress of welded joint has no physical meaning, therefore this value is apparent and determined as offset stress at 0.2% deformation[9]

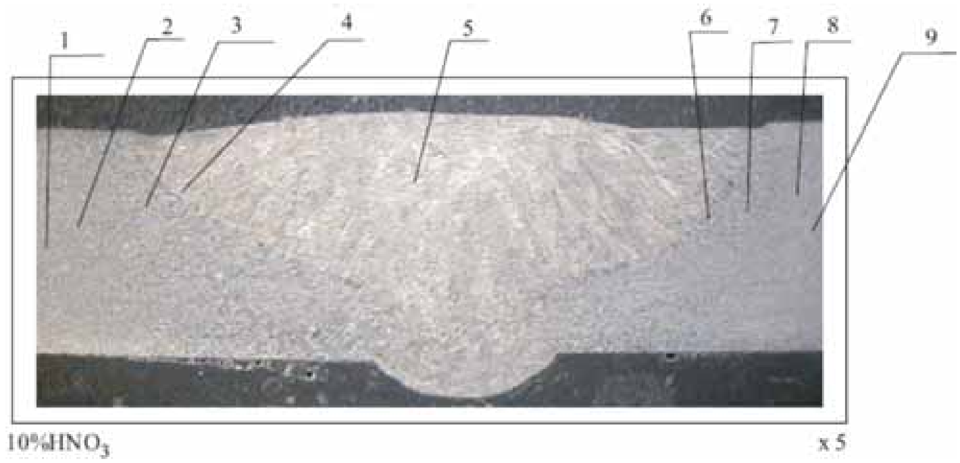
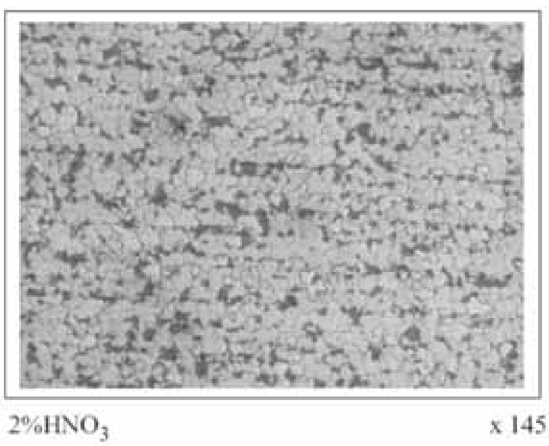
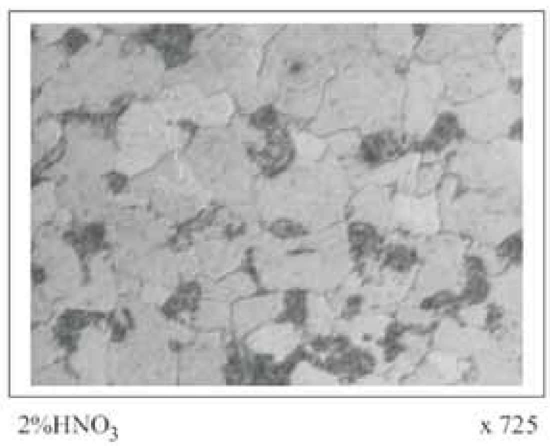


Figure 3. Macrostructure of weld joint: sample New-Used pipe (N-U)

Macrostructure of weld joint is shown in figure 3. Different zones are clearly visible, i.e. weld metal – root pass, weld metal – filling pass, heat affected zone in used steel, heat affected zone in new steel, base metal in new steel and base metal in used steel. Since weld joint is symmetrical, characteristic microstructures are shown in figure 4. Figure 4a, 4b and 4c, 4d represents microstructure of new and used pipes, respectively. Both microstructures exhibit the same phases, ferrite and pearlite. In both areas, grains are equiaxial and with similar size. The most evident difference is that the grain size in used pipe is much larger in comparison to new pipe. It is assumed that this difference is introduced because of 52600 hours in exploitation at high temperature [6,7,16]. This interpretation is in good agreement with results of tensile testing.



(a)



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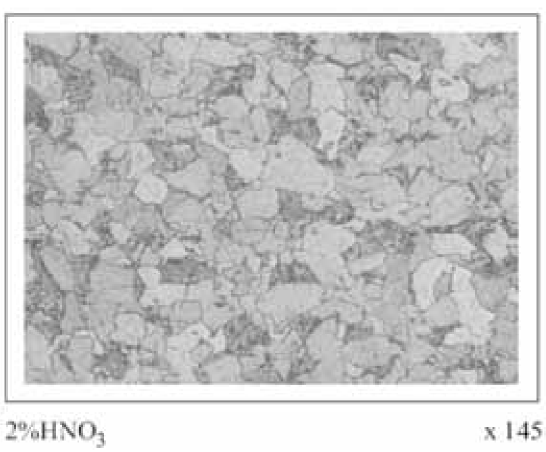

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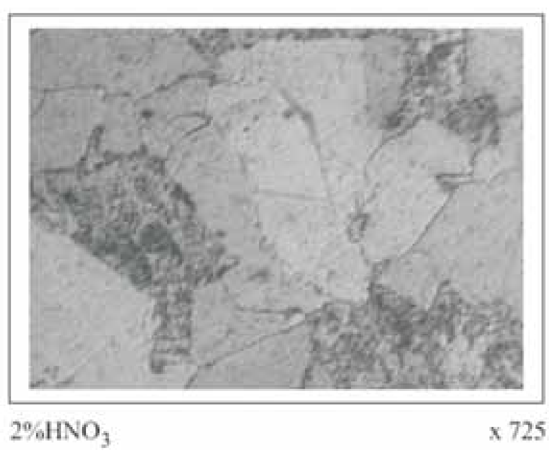

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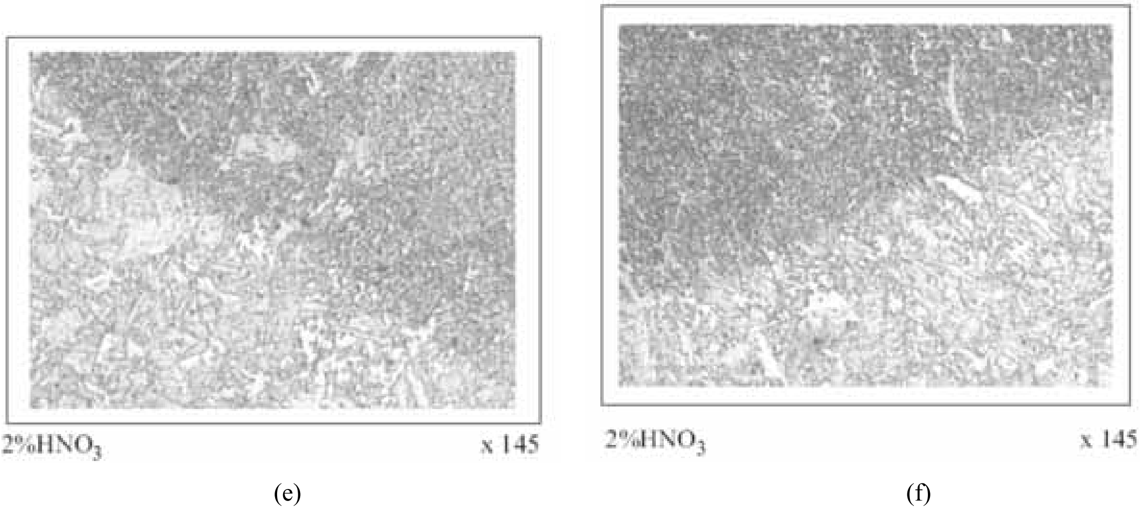

Figure 4. Microstructures in weld joint: sample New-Used pipe (N-U): (a,b) – base metal new pipe, (c,d) – base metal used pipe, (e) fusion line in new pipe and (f) fusiion line in used pipe.

Figures 4e and 4f represents the fusion line in new and used pipes, respectively. The microstructure in both places is practically equal. On both sides of weld metal, heat affected zone undergo identical heat cycle. It means that both regions were firstly heated at temperatures above A_3, i.e. into austenitic region. This means that newly formed austenite grains have "erased" previous grain size [6,7,9,12]. Since both regions had similar cooling regime, it is expected that final microstructure should be similar as shown in figures 4(e) and 4(f). Microstructure in HAZ consists of ferrite (lighter areas) and bainite (grey areas), which leads to increased strength in comparison to base metal.

5. CONCLUSION

After 52600 hours in exploitation, during retrofitting of installations, new pipes (new material) are being welded to original parts (used material) in power plant. The influence of initial state of base metal on properties of welded 14MoV 6 3 steel is evaluated in this work. Therefore, three combinations of specimens were welded: (i) new-new (N-N); (ii) used-used (U-U); (iii) new-used (N-U). Welding was performed using combination of TIG/MMA, two root passes using TIG (Tungsten Inert Gas), and two filling passes using MMA. Microstructures in HAZ are characterized by presence of bainites and ferrites. Weldments were tested by means of tensile testing. It has been established that ultimate tensile strength is highest in N-N weldments. Strength of N-U weldments showed some lower value, while strength of U-U joints is lowest. In N-U weldments, the fracture is initiated on the side of used part. It is assumed that the critical conditions were achieved as the consequence of creep induced grain growth and particle coarsening. This behavior can not be revealed in routine qualification of welding technology.

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References

[1] Bendick W.V., Weber H., *VGB Kraftwerktechnik* 66 (1986) 63-72.

[2] Nutting R.J., The Structural Stability of Low Alloy Steels for Power Generation, *Advanced Heat Resistant Steel for Power Generation* conference proceedings, San Sebastian Spain (1999) 12-30.

[3] Vodopivec F., O poškodbah jekla v parovodih in metodah za njihovo opredelitev, *Železarski zbornik*, 24 (1990) 145-152.

[4] Sadibašić D., Radović N., Grabulov V., Zrilić M., Influence of Initial State on Properties of MMA Welded 14MoV 6 3 Steel, *Welding and Welded Structures* 57 (2012) 53-60.

[5] Sadibašić D., *Optimizacija tehnologije zavarivanja čelika namenjenih termoenergetskim postrojenjima*, magistarski rad, TMF, Beograd, 2010.

[6] Łomozik M., Brózda J., Optimization of welding methods for the repair and refurbishment of heat resisting steel components after long term service and their life prediction in the polish power plants, Technical Report, *Institute of Welding*, Gliwice, Poland, (2006)

[7] Zieliński A., Janusz D., Dziuba-Kałuża M., Structure of welded joints of 14MoV6-3 and 13CrMo4-5 steel elements after design work time under creep conditions, *Archives of Materials Science and Engineering* 61 (2013) 69-76

[8] *Creep-resistant steels*, Edited by Fujio Abe, Torsten-Ulf Kern and R. Viswanathan, WOODHEAD PUBLISHING LTD, Cambridge England.

[9] Easterling K., *Physical Metallurgy of Welding*, Butterworth-Heinemann Oxford (1992).

[10] Porter D., Easterling K., *Phase transformations in metals and alloys*, Chapman and Hall, London (1992).

[11] Radović A., *Metallurgical and Technological problems of weldability*, International Conference Weldability and weldability testing Proceedings, Vranje, Serbia (1985) 1-9.

[12] Zrilić M., *Primena lokalnog pristupa na procenu preostalog veka komponenti visokotemperaturske opreme*, Doktorska disertacija, TMF, Beograd, 2004.

[13] Drobnjak Dj., *Fizička metalurgija*, TMF Beograd (2016).

[14] Dieter G., *Mechanical Metallurgy*, McGraw-Hill, London (1988).

[15] R.Smallman R., Bishop R., *Modern Physical Metallurgy and Materials Engineering - Science, process, applications*, Sixth Edition, Butterworth Heinemann Oxford (1999)

[16] Bhadeshia H.K.D.H., and Honeycombe R., *Steels - Microstructure and Properties*, Third edition, Butterworth-Heinemann Oxford (1999).