15th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2011, Prague, Czech Republic, 12-18 September 2011

# INFLUENCE OF TENSILE FLOW ASPECTS ON THE FRACTURE OF AUSTENITE – FERRITE WELDING JOINTS

**Radomir D. Jovičić, Aleksandar S. Sedmak, Olivera D. Popović, Srđan S. Tadić, Aleksandar G. Bukvić**
**Faculty of Mechanical Engineering, University of Belgrade**
**Kraljice Marije 16, Belgrade**
**Serbia**

**Katarina R. Jovičić**
**Faculty of Technology and Metallurgy, University of Belgrade**
**Karnedžijeva 4, Belgrade**
**Serbia**

**ABSTRACT**
*Welded joints between austenite and micro-alloyed steels are widespread in mechanical constructions. Usually, filler metal for welding is chosen according the chemical composition of base materials and with the aid of Shefler diagram. During the operation of pressure vessel, crack were found in austenite – ferrite welded joints. Apart the chemical composition, propensity toward the cracking is influenced by stress conditions. It is the result of strength and plasticity in base materials and filler metal. feature*
*In this paper, tensile characteristics of welded joints as well as overall weld joint are concerned. It is concluded that behavior of overall weld joint depends on strength and plasticity of mutual relationship between base materials and filler metal. However, filer metal is not the weakest point in the joint, even in the presence of micro cracks.*
**Key words**: ferrite – austenite welded joints, strength, plasticity, cracs

## 1. INTRODUCTION

During the exploitation of liquid carbon dioxide reservoir, crack were revealed in welded joints [1]. Reservoir is cylindrical, horizontal, heat insulated, volume of 12,5m$^3$. Shield and bottom of reservoir are made of micro alloyed steel P 460NL1 (NIOVAL 47), thickness 14 mm. Connector is made of highly alloyed austenite X7CrNiNb18.10 steel, thickness 12 mm, [2]. Lower working temperature of reservoir is -55$^o$ C and the upper working pressure is 30 bars. Reservoir belongs to the II class of pressure vessels. Drawing of reservoir and the connector position is shown in Fig. 1. According the literature data [2], connector is welded by E process, with filler metal INOX 29/9.

In Fig. 2, cracks replica, revealed by black magnetic powder, is shown. Three cracks, parallel to fusion line, 60, 46 and 9 mm long, can be seen. In addition, two cracks orthogonal to fusion line, 10 mm long, are distinctive. Cracks parallel to welding line are 10 to 25 mm apart from fusion line, in the base material (BM). This type of cracks is not common in the weldements of micro alloyed steels. In this steels, crack are generated in heat affected zone (HAZ) due to the micro structural changes. However, above mentioned cracks are out of HAZ. Position of cracks imply, unexpectedly, that among the tree welded materials, (P460 NL1, INOX 29/9 and X7CrNiNb18.10), the weakest one is P460 NL1.

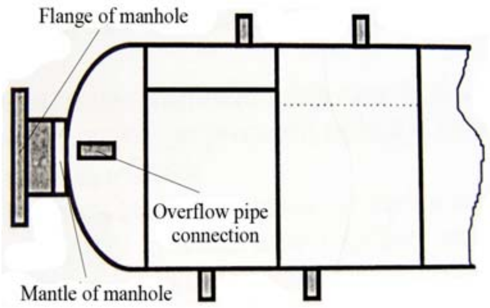


*Figure 1. Reservoir drawing and the position of the connector at the bottom .*

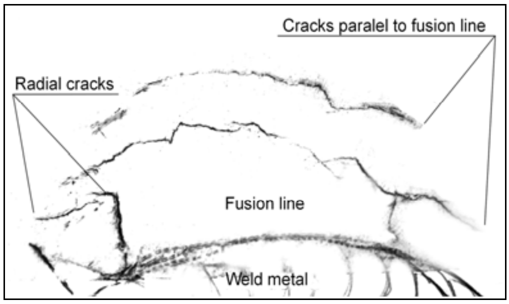


*Figure 2. Replica of cracks near the safe pipe connection.*

**2. EXPERIMENTAL**

To understand the nature and origins of above described cracks, tensile test specimens are made from previously welded plates of: micro alloyed steel P460 NL1, thickness 14 mm (hereafter steel M) and highly alloyed X6CrNiMoTi 17 12 2, thickness 12 mm, (hereafter steel V). E process is used in welding and filler metal was INOX R 29/9. Chemical composition and mechanical properties are given in ref. [3]. Electrodes were rutile shielded and are proposed for welding of high strength steels, low weldability steels and mutual welding of dissimilar steels. This welding process and filler material are also used in the welding of reservoir and connector. Welding plates were 500 x 200 mm with V groove. Only M steel was preheated up to $200^{o}$ C. Heat amount during the welding was calculated to be 10,5 kJ/cm [4].

**3. RESULTS**

After welding, both of base metals and welding zones are subjected to visual and radiographic inspection by penetrants and ultra sound. Tensile tests specimens were made according the plan given in Fig. 3. For steel M, strength and plasticity are examined on specimens $N^{o}$ 1-3. For a V steel, specimens $N^{o}$ 4-6 ere examined. Overall tensile characteristics of welding joint are examined on samples $N^{o}$ 7-9 while the weld metal is tested on $N^{o}$ 10-12. Metallographic characterization and hardness tests were made on specimen $N^{o}$ 13.

Strength and plasticity of Steels M, V and weld metal are given in Table 1., as an average value of three measurements. Both base metals and overall welding joints are tested on tensile test machine Schenk Trebl RM 400. However, weld metal is examined on a Schenk Trebl RM 100. Round tensile specimens were used (Ø 6mm).

*Table 1. Strength and plasticity of steel M, steel V and weld metal.*

| | Uper yield strength, $R_{EH}$, MPa | Lower yield strength, $R_{EL}$, MPa | Limit of proportionality $R_{p\,0,2}$ MPa | Ultimate yield strength, $R_m$ MPa | Elongation A % | Contraction Z % |
|---|---|---|---|---|---|---|
| steel M | 453 | 435 | - | 565 | 25 | 58 |
| steel V | - | - | 324 | 595 | 37 | 53 |
| weld metal | - | - | 550 | 751 | 42 | 42 |

Overall weld joint strength and plasticity are given in Table 2. All the three specimens reveal good reproducibility of results. Also, in all specimens, the fracture have occurred in a base metal of the steel M, Fig. 6. Flow stress of a four characteristic points depicted A-D on a Fig. 5 are given in a Table 2. The fracture of tensile specimens is accompanied by inhomogeneous deformation. This is shown on Fig. 6 as a contraction measurements *vs*. axis of welding joint line.

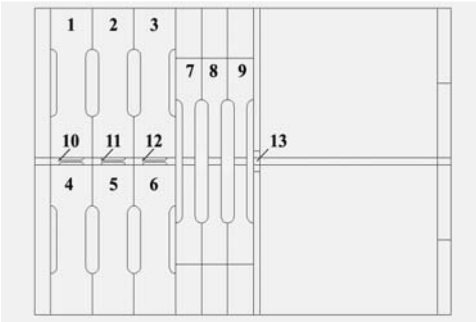


Figure 3. Schedule of tensile specimens cutting.

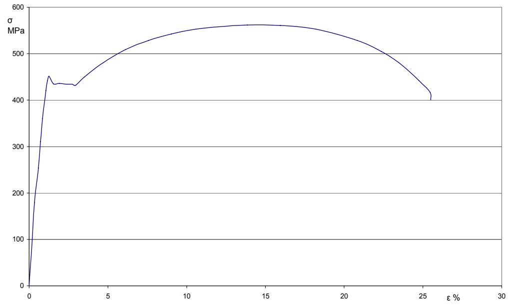


Figure 4. Stress – strain curve from steel M, specimen 2.

Table 2. Flow stress in specific points A-D on a σ – ε diagram of Fig. 5.

| Specimen N° | Flow stress in A | | Flow stress in B | | Flow stress in C | | Flow stress in D | | Elongation A % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | exactly | mean | exactly | mean | exactly | mean | exactly | mean | exactly | mean |
| 7 | 337 | 341 | 458 | 462 | 450 | 450 | 579 | 584 | 32 | 31 |
| 8 | 337 | | 463 | | 450 | | 579 | | 31 | |
| 9 | 350 | | 465 | | 450 | | 595 | | 31 | |

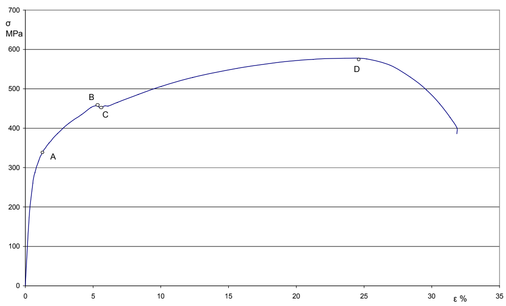


Figure 5. Stress – strain curve of overall welding joint, specimen.7.

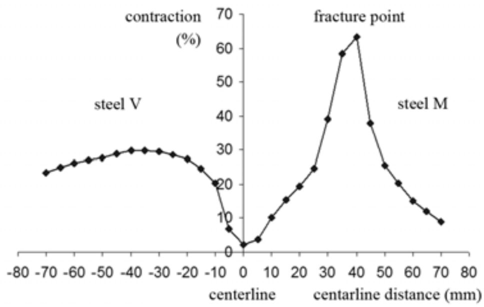


Figure 6. Contraction measurements vs. axis of welding joint line, specimen 7.

In the M steel, hardness values are measured to be 187-193 $HV_{10}$, while in the HAZ of this steel are 206-240 $HV_{10}$. In steel V, hardness is 193-227 $HV_{10}$ and in belonging HAZ 187-238 $HV_{10}$. In a weld metal, hardness is 236-289 $HV_{10}$ [3]. Metallographic examinations revealed fine grained ferrite/perlite structure in steel M and austenite in V steel. In the HAZ of M steel, microstructure is ferrite/perlite but, toward the joint plane, increases the fraction of beinite. Weld metal is austenite with δ ferrite. In the HAZ of V steel, micro structural transformations were not revealed.

## 4. DISKUSSION

Flow stress of characteristic points, given in Table 2 and Fig. 5, might be compared with tensile behavior of base and weld metals in Table 1. Point A corresponds to yield strength of V steel. Points B and C match the upper e.g. lower yield strength of M steel. Point D is close to ultimate tensile strength (UTS) of M steel. These links are specified in Table 3. It can be seen that mutual strength matching are quite close. The data scattering is within the 5%.

It seams that deformation within the overall joint specimens, up to point A, in both BM and WM, is in elastic domain of deformation. Above this flow stress, in V steel commence plastic deformation. However, in WM of M steel, deformation is so far elastic. In point B, plastic deformation starts in steel

M. Between B and C, flow stress drops down due to lower flow stress of steel M, Fig. 4. Further flow stress results from simultaneous plastic deformation in steels V and M. However, deformation of

*Table 3. Flow stress from precise points on a stress – strain curve.*

| Flow stress in points A-D | | Flow stress of base material | | Difference | Difference |
|---|---|---|---|---|---|
| Mark | Mean flow stress, Table 2, MPa | mark / Table N° | Mean flow stress, MPa | Δ R MPa | % |
| $R_A$ | 341 | $R_{p0,2}$ from Tab.3. | 324 | 17 | 5,2 |
| $R_B$ | 462 | $R_{EH}$ from Tab 2. | 453 | 9 | 2,0 |
| $R_C$ | 450 | $R_{EL}$ from Tab 2. | 435 | 15 | 3,4 |
| $R_D$ | 584 | $R_m$ from Tab 2. | 565 | 19 | 3,4 |

WM is still elastic. Point D correspond to ultimate tensile strength (UTS) of M steel where the fracture begin. In Tables 1 and 3, it can be seen that UTS of V steel is higher than flow stress in point D. However, flow stress of WM is somewhat lower than the point D. It might be expected that plastic deformation in WM commence just before the fracture stress in steel V. As it is seen in Fig. 3, contraction in the middle of WM is only 2%, which support above assumption.

## 4. CONCLUSIONS

Concerning results in this paper, it can be concluded:

1. In the base material of the liquid carbon dioxide reservoir, cracks are generated due to exhaustion of deformation capabilities in steel M.
2. Weld metal is not the weakest point in the welding joint, even in the presence of micro cracks. It is so because weld metal deformation begins when fracture initiates in M steel.
3. Contractions of weld metal increase going apart the welding axis. Contractions are not symmetrical, its depend on tensile characteristics of steel in contact with weld metal.

## 5. REFERENCES


[1] Technical report on recuperation and inspection of liquid carbon dioxide reservoir in Minakva, Novi Sad, Faculty of Mechanical Engineering, Belgrade, 1998.

[2] Tech. documentation for liquid carbon dioxide reservoir, Energoinvest TPO, Gorazde, 1979.

[3] Supplementary materials for welding, Jesenice catalogue, Jesenice, 2005.

[4] R.Jovicic, Cracks and integrity analysis in ferrite - austenite welding joints, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, 2007.