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MICRO ALLOYED STEEL WELDABILITY AND SENSIBILITY TESTING ON THE LAMELLAR CRACKS APPEARANCE

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Preliminary Note – Prethodno priopćenje

In this work are given the testing results of mechanical properties welded joints and microstructure of micro alloyed steel as well as its sensitivity to lamellar cracks appearance. The obtained results show that steel has good resistance to lamellar cracks appearance and with an appropriate wire choice for welding, a good combination of mechanical properties could be obtained at room (ambience) temperatures as well as at low temperatures.

Key words: micro alloyed steel welding, mechanical properties, microstructure, lamellar cracks

Ispitivanje zavarljivosti i osjetljivosti mikrolegiranog čelika na pojavu lamelarnih pukotina. U radu su dani rezultati ispitivanja mehaničkih svojstava i mikrostrukture zavarenih spojeva mikrolegiranog čelika, kao i njegove osjetljivosti prema pojavi lamelarnih pukotina. Dobiveni rezultati ukazuju da čelik ima dobru otpornost prema pojavi lamelarnih pukotina i da se, izborom adekvatnih elektroda za zavarivanje, može dobiti dobra kombinacija mehaničkih svojstava, kako na sobnoj, tako i na niskim temperaturama.

Ključne riječi: zavarivanje mikrolegiranog čelika, mehanička svojstva, mikrostruktura, lamelarne pukotine

INTRODUCTION

High efficiency of welded constructions, necessary quality and safety during the exploatation are enabled using new kinds of steel. Micro alloyed steels with greater toughness, due to their usability properties, are one of new and perspective materials. The existing domestic and foreign standards are defining set of demands, that they must fulfil in order to be used for manufacturing accountable constructions. One of data, normatively not prescribed by standards, is the value of plasticity of steel in thickness direction of rolled steel products, and that's average relative thickness limitation Ψ_z.

The practice of producing and assembly of welded steel constructions strenghtened with nitrides, tells us that in certain cases technological cracks can appear, with characteristic look, caused by stretching tensions in the direction of thickness of sheet, that lead to breaking of steel sheets without deformation. Cracks are named lamellar, because of their cascade spreading.

It's still arguable should lamellar cracks be related to welding exclusively, even if they occur predominamtly under the welded seam in the basic metal. It's hard to negate the relations between welding process and occurence of cracks, however, it's certain that the conditions of welding aren't the only cause of this type of cracks. Welded seam, while contracting and cooling, weighs the base metal in the direction of thickness and, in that way, emphasizes weak points in sheet. Contraction in the direction of thickness depends on the method of steel producing, contents and distribution of sulfur and other non-metal inclusions in rolled steel sheets.

Therefore, we can conclude that welding isn't the basic cause for lamellar cracks occurence, but just a starter for flaws showing, that are present in steel since its production. So, the problem of lamellar cracks should be considered as a question of metallurgical quality of steel.

The aim of this work is that – based on processing and studying of theoretical knowledge about lamellar cracks occurence, as well based on welding of experimental samples and determining the mechanical-technological characteristics of welded joints, to define the technology of welding the selected steel quality.

OCCURENCE OF LAMELLAR CRACKS

Lamellar cracks are a consequence of tensions in the direction of the thickness of welded joint, that occur during thermic cycle of welding and, by rule, are parallel with the surface of base metal. Lamellar cracks occur most often in L, T and X joints of greater thickness, near the amalgamation zone (Figure 1). These cracks occur at relatively low temperatures, and are significantly influenced by presence of the inclusions of MnS type, silicates, and other impurities, that lower the plasticity of material in the direction of thickness, as well bad constructional solution for welded joint, (Figure 1) [1].

Accordingly, lamellar cracks can be avoided with good constructional solution of joints, (Figure 2) and us-

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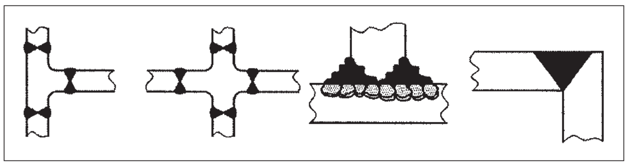

Figure 1 Examples of lamellar cracks caused by bad constructional solution [1]

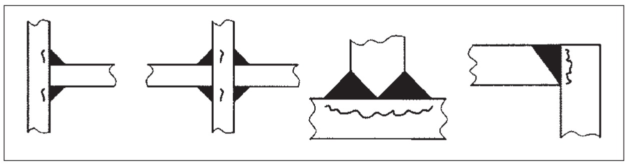

Figure 2 Examples of preventig the occurence of lamellar cracks using good constructional solutions [1]

ing the basic metal with low contents of impurities and high plasticity on the direction of thickness (e.g. steel with less than 0,007 % S and with the elongation A_5 at least 25 %), also pre-heating can be useful.

Even if lamellar cracks are typical for welded joints, that are more rigid than others (angular, T and X cross - shaped), they still occur even in frontal joints of great thickness, for example C-Mn steel welded by MPP method, mainly because of ribbon-like structure of thick rolled steel sheets with high concentration of MnS contents in individual plains.

The main reason for disintegration of material by separation of neighbour layers, is directly connected to non-metal contents and layered formation of non-metal presence – sulfide, silicate, oxide and others.

Non-metal contents, in the process of steel rolling, deform in the form of plates – lamellae or they elongate linearly, so layered structure is formed in the direction of steel sheet thickness. The consequence of quantity, shape and distribution of this contents is anisotropy of material in the direction of thickness, relative to longitudinal and lateral direction. Therefore, mechanical properties, during the tension testing, in direction of thickness are lower. That distinct drop of plasticity in the direction of thickness doesn't have the ability to transfer the active stresses, so breaking happens. Lamellar cracks that precede breaking, occur in various parts of steel sheet parallel to the surface of rolling, and are separated by metal layers. They spread from surface towards inside the steel sheet in cascade shape, that connect lamellae and hence the name lamellar cracks – lamellar tearing.

Data suggest that the occurence of lamellar tearing is characteristical for welding thicker steel sheets (thickness greater than 10mm), but it also occurs on steel sheets produced from high toughness steel, or impure steel with thickness lower than 10 mm [2-6].

For a long time it has been believed that the occurence of lamellar cracks is connected with carbon and low alloyed steels, however, today we know that this type of crack can occur on austenite steel sheets, if it's impured by oxide, sulfide or carbide contents.

Lamellar cracks occur during the process of cooling of welded joints in relatively low temperatures. There is various published data about this temperature interval (100 – 250 °C; 100 – 600 °C; 400 – 550 °C); however, they are discovered even after welding (to be honest, substantially rarely).

Based on numerous systematized literature data, possible causes of lamellar cracks are: metallurgical and constructional-tension influences, as well the conditions of welding process [1, 5, 7].

Metallurgical influences that include lower plasticity, or dispersion of plasticity in the direction of thickness of rolled steel sheet, as a consequence of presence of non-metal inclusions. It has been determined that mechanical characteristics of steel sheet in the direction of thickness depend on type, size, quantity, shape, composition and distribution of non-metal inclusions, as of texture present, plasticity reserve and sensitivity to the cut of selected steel type [5, 8, 9].

Preventive measures during designing:

- To assure with design of construction that tensions of steel sheet in Z-axis direction (direction of thickness) are minimal.
- To use materials resistant to lamellar tearing on critical places on construction.
- To choose the method of welding and to prescribe a plan for welding, that minimizes deformations caused by stiffening, with welding performance, that gives minimal volume of additional material with good mechanical-technological characteristics, using dried wires.
- To obey the criteria for choosing the base material recommended by Japanese welding society (Table 1).

WELDING OF EXPERIMENTAL SAMPLES OF MICROALLOYED STEEL

Upgrowth of knowledge related to improving the quality of fine-grained steels has been directed, on one side, towards optimization of mechanical-technological properties, and on another, to lower the degradation of properties of basic material, obtained by manufacturing, with shaping technologies and installing in adequate constructions. Weldability and manufacturing of welded constructions had to get deserved attention, because it's well known that obtaining the complex of mechanical-technological properties in basic metal and welded joint is very different, especially in seam metal, that consists of specific foundry structure.

In Table 2 chemical composition and mechanical properties of base material samples are shown (hot rolled steel sheet), marked J55, that is meant for manufacturing of welded tubings.

The tendency of metal tendency towards lamellar tearing is determined by experimental testing, that include methods with and without sample destruction.

For testing the sensitivity towards lamellar tearing occurence of steel J-55, Window method, with sample destruction has been chosen.

Testing using Window method is based on provoking the lamellar cracks occurence under the influence of stress in Z-axis direction. Basic goal of experimental welding of J-55 steel samples is determining of mechanical-technological properties of welded joints, as well the determining of its lamellar cracks occurence tendency. For realising the set goal, were prepared standard dimensions plates, of the mentioned basic material quality. For welding the micro-alloyed steel J-55 two qualities of wires were chosen (Table 3): PIVA 255BMo wire and an wire with the same label but with changed chemical composition, Ni=4,43 % (new) respectively.

The conditions of welding process treatment are given in Table 4.

Ultimate tensile strength testing of welded joints was done on test tubes made by JUS C.T3054 standard Charpy impact energy testing was done by JUS C.T3051 standard. The results of ultimate tensile strength and Charpy impact energy are given in Table 5.

Metallographic tests of welded joints of the mentioned steel were also done, for which the frontal joint was made in 3 passes (layers). The look of microstructure of seams and on joint line, obtained by welding using PIVA 255BMo wire (magnification 500 x) is given on Figure 3. The look of seam microstructure and on the joint line, obtained by welding with PIVA 255BMo (new), wire, magnified 400 x, is given on Figures 4 and 5.

RESULTS ANALYSES AND DISCUSION

Based on obtained values for ultimate tensile strength and impact tenacity we can conclude that a very good combination of mechanical properties has been achieved, while welding with classic PIVA BMo wire (Table 5, sample F), especially at 20 °C.

Table 1 **Criteria for choosing the base material [6]**

Class of steel	*S* Content /%	Contraction Ψ_Z /%	Applicable for joints:
A	≤0,007	≥25	High Z-axis tensions
B	≤0,010	≥ 15	Usual demands for Z-axis properties
C	≤0,020	≤8	Negligible Z-axis tensions

Table 2 **Chemical composition and mechanical properties of steel label J-55**

Chemical composition /*wt*.%									Mechanical properties		
C	*Si*	*Mn*	*P*	*S*	*Ti*	*Nb*	*Cu*	*Al*	R_p /MPa	R_m /MPa	A_5 /% min.
0,053	0,264	1,182	0,020	0,006	0,011	0,027	0,018	0,031	490 do 500	555 do 560	32

Table 3 **Chemical composition and mechanical properties of pure weld of used electrode**

No	Label on wire	Chemical composition /wt.%					Mechanical properties		
		C	*Mn*	*Si*	*Ni*	*Mo*	R_p /MPa	R_m /MPa	A_5 /%
1.	PIVA 255 BMo	0,08	0,95	0,5	2,5	0,35	550 ÷ 640	650÷750	22÷26
2.	PIVA 255 BMo (new)	0,11	1,45	0,58	4,43	0,28	-	-	-

Table 4 **Experimental welding of steel J-55 with PIVA 255BMo wires using E-method**

No	Sample label	Wire diameter / mm	Energy parameters			Pass	Linear energy / kJ/cm
1.			*U* / *V*	*I* /A	*V* /cm/min		
1.	X	ϕ 3,25	22-24	115 - 120	1,7 - 16	3	17,6 -1 8,4
2.	T	ϕ 4,0	24	110 -120	7 - 36	5	5,8 - 15
3.	E	ϕ 4,0	24	115 - 120	5 - 17,1	3	9,6 - 11,5

Table 5 **Mechanical properties and Charpy impact energy of J-55 steel welded joints**

No	Base material	Additional material	Sample	Ultimate tensile strength *Rm* / MPa	Charpy impact energy *KV* /J	*T* / °C
					Average	
1.	J-55	PIVA 255BMo	X F	593 614	97 14 82 8	+20 -80 +20 -80
2.	J-55	PIVA 255BMo (Nova)	T T	568 607	58 21	+20 -80
			E E	569 612	53 19	+20 -80

Figure 3 Structure on the joint line

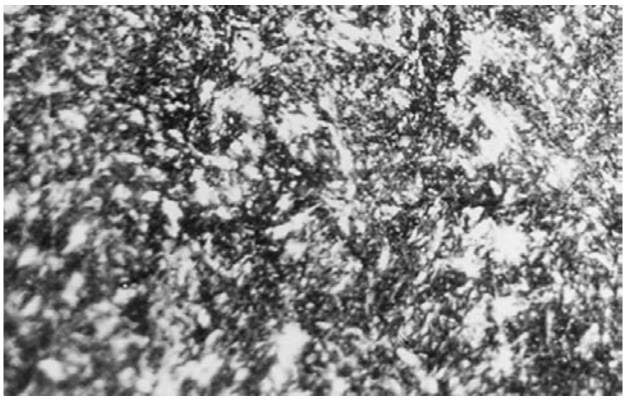

Figure 4 Seam structure, primary crystals zone

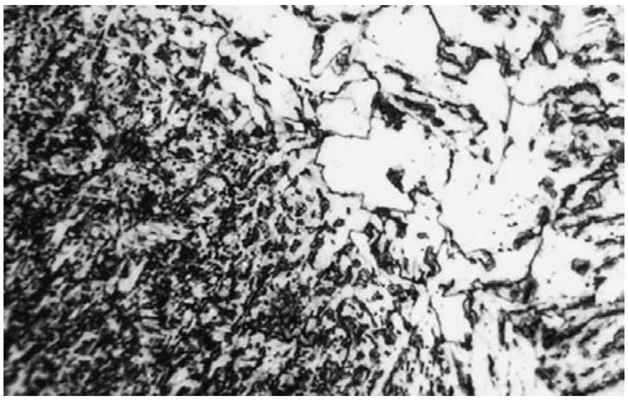

Figure 5 Seam structure on the joint line

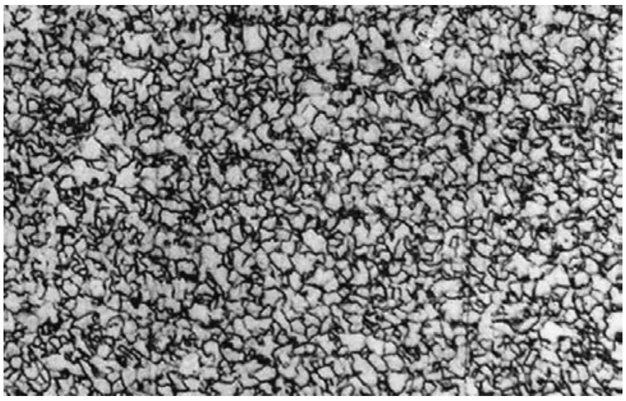

Figure 6 Structure of J-55 steel (basic)

On the other side, while welding steel with new PIVA wire a better combination of mechanical properties has been achieved, during the testing at low temperatures (-80 °C), Table 5, samples T and E.

We should, also, accentuate that the results of sensitivity to lamellar crack occurence of steel J-55 tests show its excellent tenability, which is in correlation with very low contents of sulfur and phosphorus (Table 2).

Based on analysis of pictures of microstructure, we can see that base (steel J-55) contains homogenous fine grain ferrite (Figure 6), while the seam structure (Figure 4) and structure on the joint line (Figure 3) show changes in grain size, or rather significant grain growth along the joint line (Figure 5). It's assumed that, on greater increase of size, it could be possible even to identify certain differences in ferrite structure, while using different welding wires.

CONCLUSION

Based on set research goal, realised tests and obtained results, we can conclude:

1. Microalloyed low carbon steel J-55, after sensitivity to cracks occurence testing, especially lamellar, has shown very good resistance.
2. Using the classic PIVA BMo wire for welding J-55 steel we get a good combination of ultimate tensile strength and impact tenacity, especialle at 20 °C.
3. With welding of J-55 steel with new PIVA wire a better combination of tested mechanical characteristics has been obtained at – 80 °C.

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