Increasing Strength and Operational Reliability of Fixed Joints of Tubes by MMA Welding

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Abstract. This paper presents peculiar properties of structure formation, phase and chemical composition while welding of low-alloy steel 09MnSi2-1 depending on the dynamic characteristics of power sources of different types. Proper selection of power sources enables to decrease burning of alloy elements in metal of weld (Mn by 14% and Si by 17% of the weight ratio), to obtain more homogenous structure of deposited metal, to reduce length of heat-affected zone by 50% and to improve impact strength by 4-9%.

1. Introduction

Providing the required physical-mechanical properties and uniform strength of jointing areas, preventing from cold cracks formation and formation of structures reducing joints resistance to delayed and brittle failure raise the question of increasing strength and operational reliability of weld joints of tubes made from low-alloy steel [1].

Results in issues related to efficiency enhancement of the process of manual arc welding by coated electrodes (MAW) are marked by appearing of modulated current welding (MCW). MCW contributes to improvement of mechanical properties of weld joint [2,3,4]. The main technical facilities of MCW methods implementation are modulators-adapters [2] and inverter-type welding converters. However, irrespective of technical facility structure, these methods do not find wide application [5].

For quality welding of fixed joints of pipelines in conditions of constantly changing space position of welding pool current source should have dynamic properties, provide rapid growth of stresses while transition from short circuit to arc burning, and provide optimal velocity of current change (to reduce sputtering connected with transition of melted electrode droplets into welding pool) as well as to meet other requirements [6].

Welding process stability while using power sources with different energy parameters can be evaluated by the ratio $\frac{I_{s.c.}}{I_2} \to 1$ [7] , where $I_{s.c.}$- short circuit current, A: I_2 – arc current, A, according to which the value of spatter of electrode metal can be characterized. Spatter of electrode metal depends on energy parameters of welding current supply having influence on rate of rise of short circuit current, and thereby influencing the values of: power of electric explosion at the time of droplet detachment after short circuit; amplitude value of current [8].

Works [9] study the impact of welding current magnitude upon the amount of electrode metal spatter when applying coated electrodes of various types but no such dependences were revealed when using different power supplies. Rectifier further diode rectifier and inverter power source were used as power supplies. The results of the completed studies are presented in Fig. 1.

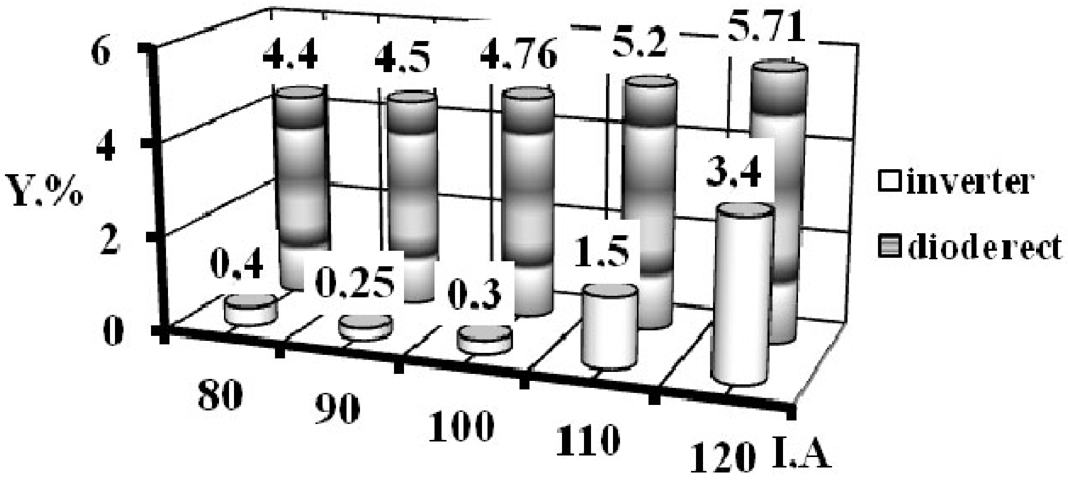


Figure 1. Impact of current magnitude upon the amount of electrode spatter under MAW with coated electrodes 3.2 mm in diameter – LB 52U (basic coating)

Performed studies [10] showed that while using inverter power source thermal impact of arc on the droplet of electrode metal is changing. Therefore use of inverter power source leads to alteration of kinetics of metallurgical process in droplet, and as a consequence to change of chemical composition of added metal [11].

The present work is devoted to comparative integrated study of chemical composition, microstructure and mechanical properties, including microhardness of welded joints from steel 09G2S made using inverter power source and diode rectifier.

2. Materials, research and results

The following samples were manufactured to conduct integrated study: weld joint of tubes Ø159 ×6 made from steel 09G2S by electrodes: root - LB-52U (d=2.6 mm), welding current I = 50-60 A, filling - LB-52U (d=3.2 mm), welding current I = 80 – 90 A from different power supplies (diode rectifier VD-306 and inverter Nebula-315).

Analysis of weld chemical composition (Table 1) showed that while using inverter power supply alloy burning of Si decreases by 14% and Mn by 17%. It is conditioned by the fact that energy parameters of inverter power supply provide less rate of rise of arc welding current and that in its turn confines the value of short-circuit current [9]. This statement is indirectly proved by the data in [12].

Table 1. Average chemical composition of metal of weld, made from tube Ø159×6 (steel 09MnSi2-1) welded with LB 52U electrodes

Power supply	Chemical composition, %							
	C	Si	Mn	S	P	Cr	Ni	Cu
diode rectifier	0.10± 0.012	0.52± 0.03	1.03±0.05	0.010	0.014	0.03±0.01	0.05±0.01	0.03
inverter	0.09± 0.005	0.60± 0.03	1.23±0.05	0.010	0.014	0.03±0.01	0.06±0.01	0.03

Macro- and microstructural studies were carried out by means of optical metallography on sections, made from weld joints (Fig. 2). Optical microscope Olympus GX-71 was used. For manufacturing of sections abrasing machining was applied, mechanical polishing with diamond paste ASM 10/7 NVL and chemical milling in 4% solution of nitric acid. Microhardness testing in added metal was carried on these sections, in thermal impact zone and in the basic metal using microhardness tester DURAMIN 5. Vickers hardness was defined while loading 50 g and soaking time 10 s.

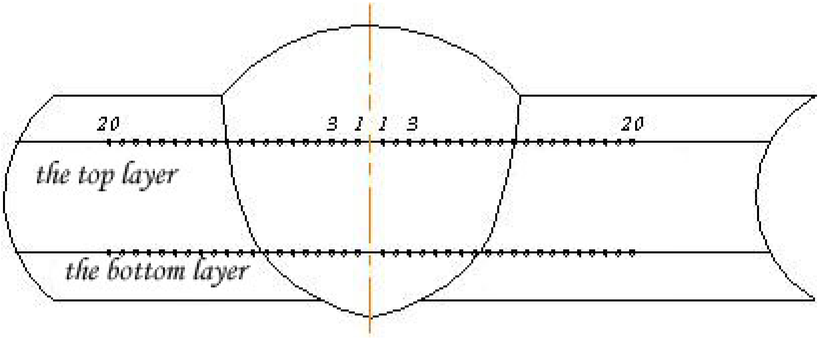
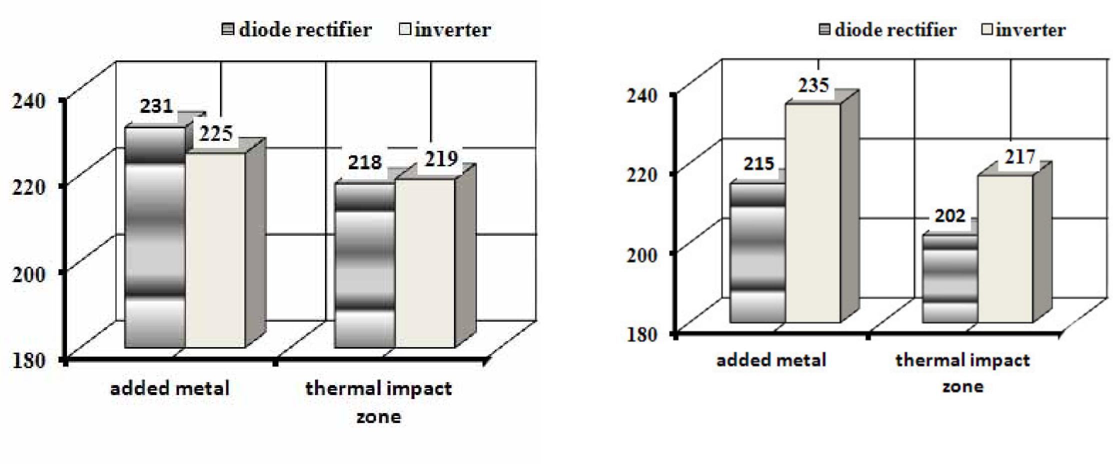


Figure 2. Schematic plan of microstructural studies and measuring microhardness (step between points – 0.5 mm)

Figure 3 demonstrate microhardness of weld joints from steel 09G2S (according to scheme given in Fig. 2).



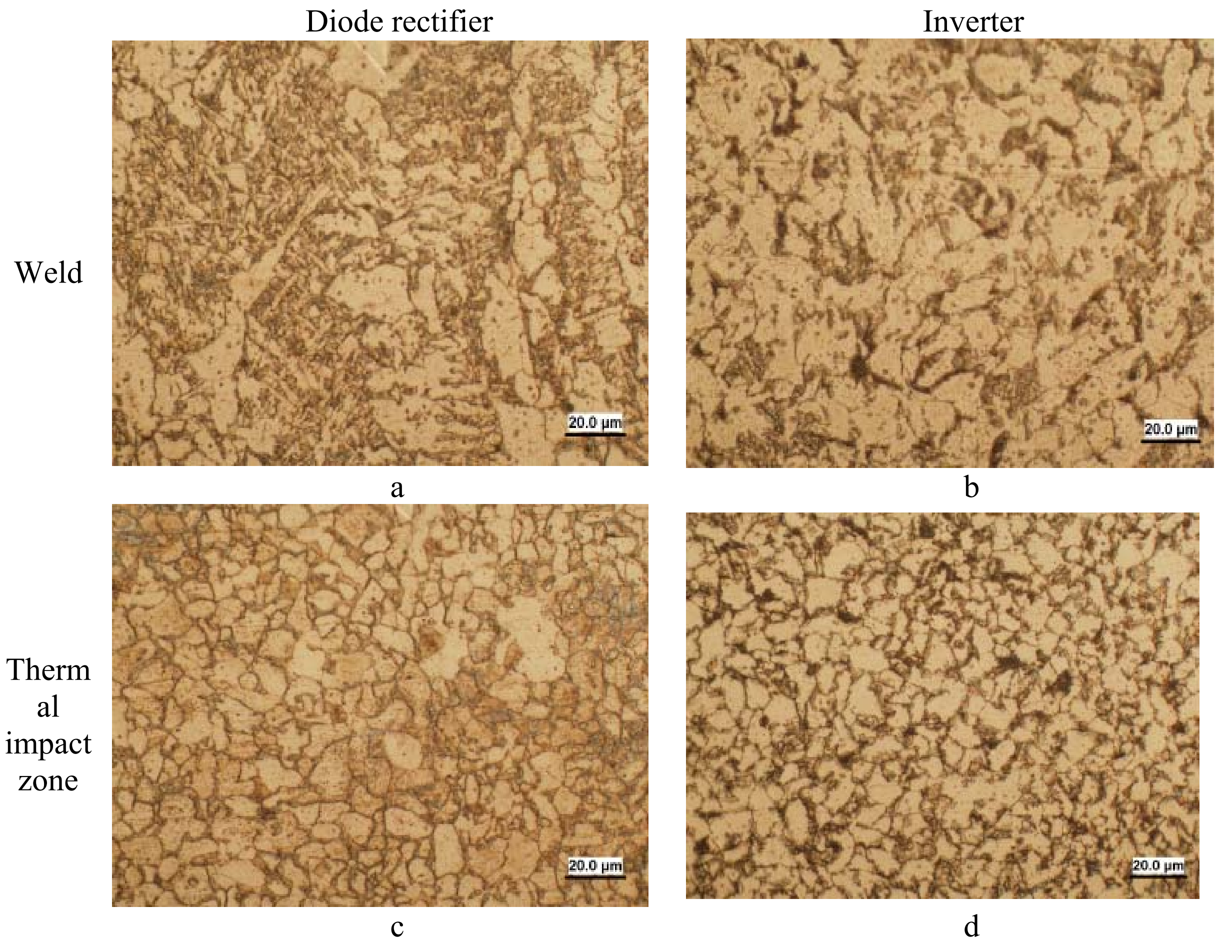
a b

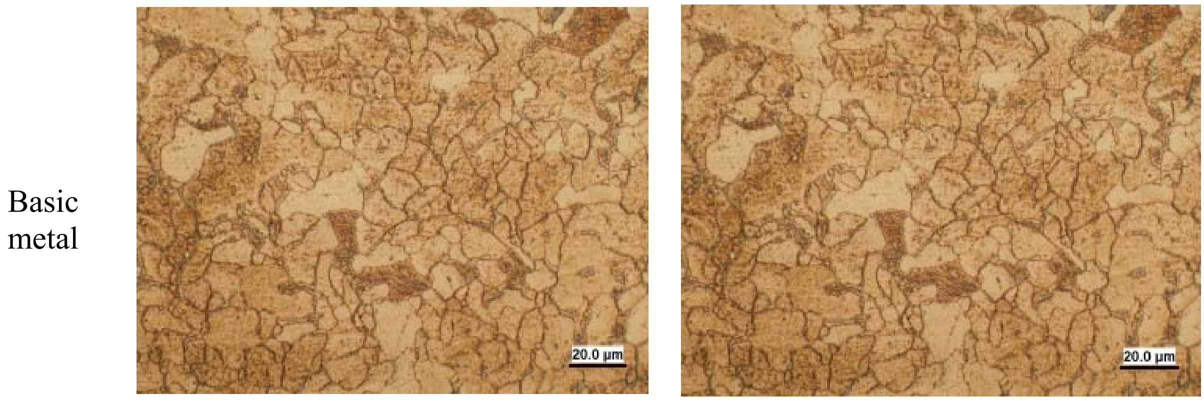
Figure 3. Average distribution bar charts of microhardness (MPa) in cross-section of weld joints made by different power supply sources: a – the top layer on Fig. 2; b – the bottom layer on Fig. 2

It can be seen that in weld joint when welding with diode rectifier, added metal has maximum hardness (Fig. 3a). During transition from added metal to the thermal impact zone microhardness decreases. In the bottom layer (Fig. 3b) difference of microhardness of added metal and thermal impact zone is insignificant, but in the top layer (Fig. 3b) it is statistically significant. Distribution pattern of microhardness along zones in weld joint obtained when welding with inverter source is qualitatively the same. Added metal also has maximum microhardness, again the difference in bottom layer between thermal impact zone and added metal is insignificant while it is significant in the top layer (Fig. 3). However the values of microhardness in the respective zones of weld joint made when using inverter source is higher. It is most noticeable for top layer (Fig. 3a). It should be noted that statically insignificant difference of microhardness of basic metal both in top and bottom layers in both joints is fairly expected (Fig. 3).

The noted patterns conform to structural conditions of the studied weld joints. Microphotographs (Fig. 4) demonstrate structure of added metal, thermal impact zones and basic metal.

Obviously added metal (Fig. 4a) while welding using diode rectifier has inhomogeneous structure of rodlike dendrite, distinctive of cast-condition. Ferrite plate reaches 1 mm in length and 20 µm in width. Inter-plate space is occupied with dendrites of smaller size. By larger scaling it was established that ferrite plates consist of polyhedral grains, about 12µm in size. Other phases and structural components except for ferrite are not observed, this corresponds with the composition of electrode core LB 52U.





e f

Figure 4. Results of microstructural analysis: a, b – microstructure of weld; c, d – microstructure of thermal affected zone of weld joint; e, f – microstructure of basic metal

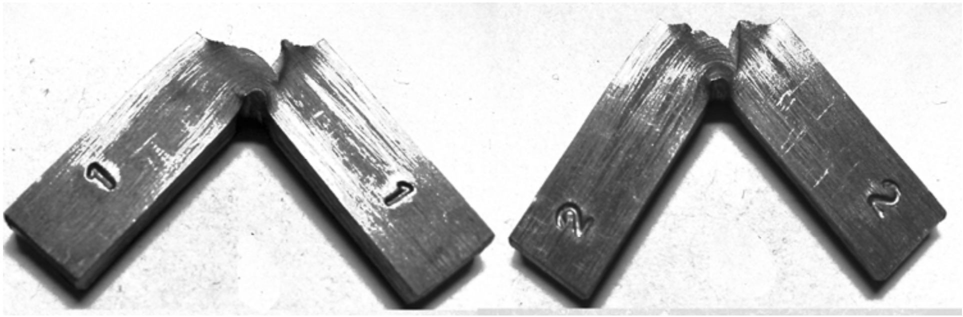
Structure of added metal in weld made using inverter source (Fig. 4b) is significantly more homogeneous. Columnar behavior is faintly observed. Length of ferrite plates does not exceed 50 µm, while thickness reaches 20 µm as in the previous case. The average size of ferrite grains that dendrites are made of is 14.5 µm.

Transition from added metal to the thermal impact zone and afterwards to the structure of basic metal occurs gradually, without sharp changes both in case of using source VD-306 (Fig. 4c) and source Nebula-315 (Fig. 4d). In both cases thermal impact zone is presented by polyhedral ferrite grains.

In thermal impact zone of weld joint obtained when welding using diode source (Fig. 4c) size of ferrite grain is insignificantly larger and reaches 10.3 µm. Pearlite is found in the structure, in the amount corresponding to basic metal (steel 09G2S). Total width of thermal zone impact reaches 2 mm.

In case of inverter using (Fig. 4d) the average grain value is 8.5 µm. There are almost no signs of pearlite inclusions. The reason might be carbon diffusion in decarbonized added metal. Width of thermal zone impact is insignificant and does not exceed 1 mm.

The structure of basic metal is ferrite-pearlite (Fig. 4, e, f). Volume ratio of pearlite is 10-12%, corresponding to the chemical composition of steel 09G2S. Ferrite grains are polyhedral with well defined clear boundaries. Thus application of inverter source enables obtaining weld joint with more homogeneous and fine grained structure of added metal. Differences of microstructures of weld joint obtained in the conducted study can be explained by less heat content of droplet of melted electrode metal while welding using inverter and therefore less burning of Si and Mn (Table 1). Microstructural differences define different mechanical properties of weld joints as well, given in Table 2.



a) b)

Figure 5. Photographs of samples after testing KCU (+20 °C): a – inverter; b – diode rectifier

Weld joints (Fig. 5) in both cases have high viscosity and less probability of crack formation, which is the necessary condition for production of pipelines which will be used in conditions of low temperatures.

Table 2. Mechanical properties of weld joints made from tube Ø159×6 (steel 09MnS2-1) by LB 52U electrodes

Power supply	Limit of ultimate tensile resistance σB, MPa	Bend angle outward, inward and edgeway, deg.	Impact strength KCU, J/sm2 (cut along center of the weld)			
			+20 °C	0 °C	-20 °C	-40 °C
diode rectifier	541-543 542	120-120 120	201-220 210	212-223 216	200-233 219	143-230 182
inverter	550-560 556	120-120 120	208-226 217	215-254 235	224-250 237	150-258 193

Data analysis of Table 2 shows increase of impact strength of weld joints made when welding using inverter source in comparison to samples obtained by diode rectifier by 4-9% while different temperature of operation. This can be explained by difference of microstructure in weld joints, decrease of length of ferrite plates by 50% and thickness by 24% and reduction of length of thermal impact zone by 50%.

3. Conclusion

Proper selection of power supply enables to:
1. Reduce burning of alloy elements in metal of weld: Mn by 14% and Si by 17% of the weight ratio;
2. Obtain more homogenous structure of deposited metal;
3. Reduce length of thermal impact zone by 50%;
4. Increase impact strength by 4–9% under different operation temperature.

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References

[1] Saraev Y N Sleptsov O I, Bezborodov V P, Nikonova I V and Tyutev AV 2005 Ohysical Mesomechanics Influence of impulse welding on structure and properties of weld joints of tubes from high-strength steel 8 pp 141-144.

[2] Knyazkov V L and Knyazkov A F 2008 Enhancing effectiveness of manual arc welding of pipelines (Kemerovo: Publishing Office of Kuzbass State Technical University) 2008 pp 104.

[3] Krampit A G 2012 Welding International Welding with double modulation of the main welding 26 pp 867-869.

[4] Krampit N Y and Krampit A G 2011 Welding International Mechanical properties of welded joints in welding with continuous and pulsed arcs 25 pp 626-628.

[5] Dementsev K I 2010 Enhancing effectiveness of inverter-type welding converters by means of welding current modulation, PhD thesis: 05.02.10 Tomsk pp 16.

[6] Mustafin F M, Blekherova G M, Kvyatkovskii O P et al 2002 Nedra-Business Center LLC Welding of pipelines (Study book Moscow).

[7] Fedko V T 1998 Theory, technology and means of reducing spatter and labor input when welding in carbon dioxide (Tomsk, Tomsk State University) pp 156.

[8] Fedko V T, Brunov O G, Solodsky S A, Krukov A V and Sokolov P.D Engineering technology 2005 The methods of spatter reduction when welding in CO2 5 pp 24 – 30.

[9] Il’yashchenko D P, Chinakhov D A and Gotovshchik Yu M 2015 Applied Mechanics and Materials Influence of Power Supply Energy Characteristics upon the Stability of MMA Process 756 pp 97-100.

[10] Il’yashchenko D P, Chinakhov D A and Gotovshchik Yu M Applied Mechanics and Materials Calculation of the Heat Content of the Electrode Metal Droplet When Applying Power Supplies for Manual Arc Welding With Different Volt-Ampere Characteristic. 756 pp 101-104.

[11] Livshits L S 1979 Metallurgy for welders (welding of steel) (Moscow^ Machine Engineering Publishing Office pp 235.

[12] Ignatova A M 2013 Nauchno Tekhnicheskij Vestnik Povolzhja Mineral formation in particles of solid component in welding fumes at high temperatures and short pyrogenic welding processes 5 pp 166-173. (in Russian).