

Physical Nature of the Processes in Forming Structures, Phase and Chemical Compositions of Medium-Carbon Steel Welds

D P Il'yaschenko^{1,a}, D A Chinakhov^{1,b}, V I Danilov^{1,2}, G V Schlyakhova^{2,3},
Yu M Gotovshchik¹

¹Yurga Institute of Technology National Research Tomsk Polytechnic University
Leningradskaya 26, Yurga, Russian Federation, 652055

²Institute of Strength Physics and Materials Science, Siberian Branch of Russian
Academy of Sciences

Akademicheskyy, 2/4, Tomsk, Russian Federation, 634055

³Seversk Institute of Technology, National Research Nuclear University MEPHI
Kommunisticheskyy, 65, Seversk, Russian Federation, 636036

e-mail: ^a mita8@rambler.ru, ^b chinakhov@tpu.ru

Abstract. This work presents peculiarities of forming a structure, phase and chemical composition while welding medium-carbon steels (Steel 45) depending on a heat content of molten electrode metal droplets when using welding power sources having different power parameters. It was experimentally established that the power inverter provides the decreased heat input into droplets of electrode metal during the welding process. This stimulates obtaining a fine-grained structure of the deposited metal and heat affected zone, reduces the extent of the HAZ that enhances working properties of welded joints.

1. Introduction

Soundness of welds in steel fabrications used in all industries has a significant influence on the safety and economic efficiency of production, therefore it is of supreme concern to both manufacturers and scientific communities.

Welding is a continuous process that is required to result in uniform strength through base metal, weld metal and a heat-affected zone (HAZ), and to provide the complete transfer of alloying elements from an electrode to a molten weld pool. These requirements are met by using modern materials and applying advanced welding techniques, namely:

- Materials used for welding include nanoscale components (coated electrodes, flux cored wire);
- New inverter power sources fitted with controls providing a variety of energy supply schemes and parameters for welding processes.

Welding consumables having nanocomponents stimulate the refinement of weld metal structures [1, 2], improve mechanical properties of weld metals and increase a value of alloy transfer efficiency [3]. However, their use may have a negative impact on a welder's health [4, 5], and the health effects as a constraining factor keep these welding materials from the widespread use.

At present time, a number of Russia's and foreign manufacturers of welding equipment offer a wide range of power sources for manual arc welding requiring coated wire electrodes, for example, such companies as Fronius (Austria), Lincoln Electric (USA), ESAB (Sweden), Tekhnotron, (Russia),



ZAO NPF ITS (Russia), etc. This means that almost all the world leaders in the field of welding equipment are mainly focused on the development and production of inverter welding power sources [6, 7]. However, welding diode rectifiers are still widely employed by industrial enterprises. And whereas the new welding equipment is available, but at the moment there is no complex methodology enabling the objective assessment of changes in heat input in terms of weldments from various types of equipment for MMA welding.

The authors of the work in reference [8] proved the positive effect of energy characteristics of an inverter power source on the transfer of alloying elements from an electrode to the weld metal in the case of welding steel 12Cr18Ni10Ti. At the same time, such medium carbon steels as Steel 45 (Russia), S45C, LS (Japan), 1.0503, DIN (Germany) and 1.0503, EN (European Union) find wider use in manufacturing welded fabrications because of their higher sensibility to a thermal cycle.

This work gives the results obtained in the comparative study to analyze the welded joints made of steel 45 using both an inverter and diode rectifier relative to chemical composition, microstructure and mechanical properties, including microhardness.

2. Materials, research procedures and results

Plates having a 10 mm thickness were welded taking 4 layers (see Fig. 1) and using the following electrodes: the UONI 13/55 electrode ($d = 3$ mm) with a welding current of $I = 80-90$ A for root welding and UONI 13/55 electrode ($d = 4$ mm) with a welding current of $I = 120-130$ A for filling. The parts were preheating to 300oC and then slowly cooled (by covering with insulator and asbestos fiber till full cooling down).

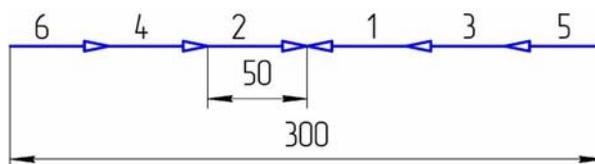


Figure 1. Schematic Welding Sequence

Analyzing the chemical composition of the welded joint in Fig. 1 showed that energetic parameters of the power supplies made an effect on chemical composition of the welded joint. When using the inverter as a power source, the workpiece is less overheated due to the decreased heat content in molten droplets of the electrode metal [9], this results in minor burning out of alloying elements, in particular manganese. This fact is indirectly confirmed by the work of the author in reference [10].

Table 1. The Statistically Average Chemical Composition of Welds in Steel 45 Using Electrodes UONI 13/55

Source of Power	Chemical Analysis, %						
	C	Si	Mn	P	Cr	Ni	Cu
Diode rectifier	0.12	0.30	0.92	0.019	0.06	0.05	0.09
Inverter	0.12	0.31	1.00	0.02	0.06	0.06	0.10

Macro- and microstructural studies based on optical metallography were performed to analyze cross-sections taken from the weld samples (Fig. 2). The Neophot-21 microscope and Genius Vileacam digital camera were used. The metallographic specimens were prepared using the following processes: mechanical grinding, mechanical polishing with diamond paste ASM 10/7 NVL and chemical etching in nitrohydrochloric acid (40% HCl + 40% HNO₃ +

10% C₂H₅OH). The DURAMIN 5 tester was used to measure microhardness in the weld metal, heat affected zone and base metal with the same metallographic specimens. The microhardness value was determined according to the Vickers test method, with a load of 50 g at a holding time of 10 s.

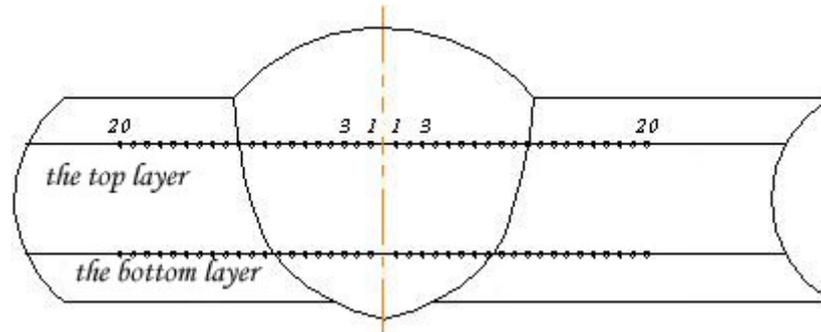


Figure 2. Diagram for micro structure studies and microhardness measuring (0,5 mm spot - to-spot interval)

Figure 3 shows how the microhardness values detected on welds are distributed. The test procedure is according to the diagram in Fig. 2.

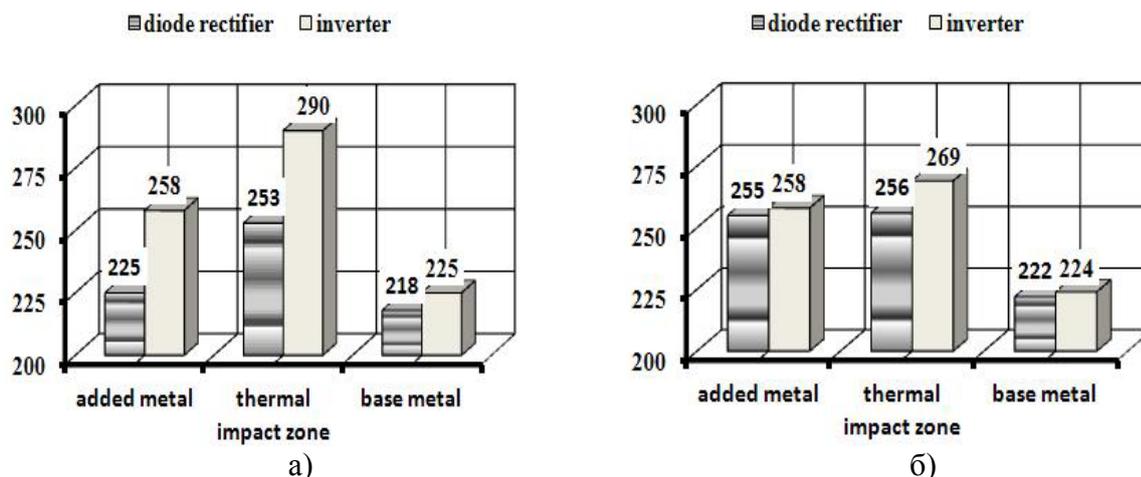


Figure 3. Microhardness (MPa) distribution over weld cross-sections when utilizing different power supplies:

a - the top layer in Fig. 2; b – the bottom layer in Fig. 2

It is obvious that in the case of the welded joints with a diode rectifier being utilized as a power source, the microhardness is maximal within the heat-affected zone. The microhardness increases in going from the weld metal to the HAZ and then decreases again in going to the base metal. Considering the bottom layer (Fig. 3, b), the difference in microhardness between the weld metal and HAZ is little, but with the top layer (Fig. 3, a) it is statistically significant. A pattern of microhardness distribution over the zones in the welded joint made using the inverter power source is qualitatively the same. The heat affected zone also has the maximum microhardness; the same seen in the bottom layer where the difference between the HAZ and weld metal is insignificant, but it is essential for the top layer (Figure 3). However, the values of microhardness are higher in the same areas of welds made using the inverter. This is particularly visible referring to the top layer (Fig. 3, a). We point out that the statistically insignificant difference in terms of the base metal microhardness detected in the top and bottom layers (Fig. 3) of both weld types is reasonably predictable.

The observed patterns are consistent with structural conditions of the welded joints under study. The weld metal in the welding process using a diode rectifier (Fig. 4, b) does not reflect a dendritic structure typical for the molten condition. Ferrite grains are polyhedral and almost equiaxial. The average size of ferrite grains is ≈ 12 microns. At a high magnification it is seen there are conglomerates of very small (less than one micrometer) ferrite grains in the intergranular spaces. Other phases and structural constituents, except for ferrites, can not be detected, corresponding to the composition of rod electrodes UONI 13/55 (0.07%).

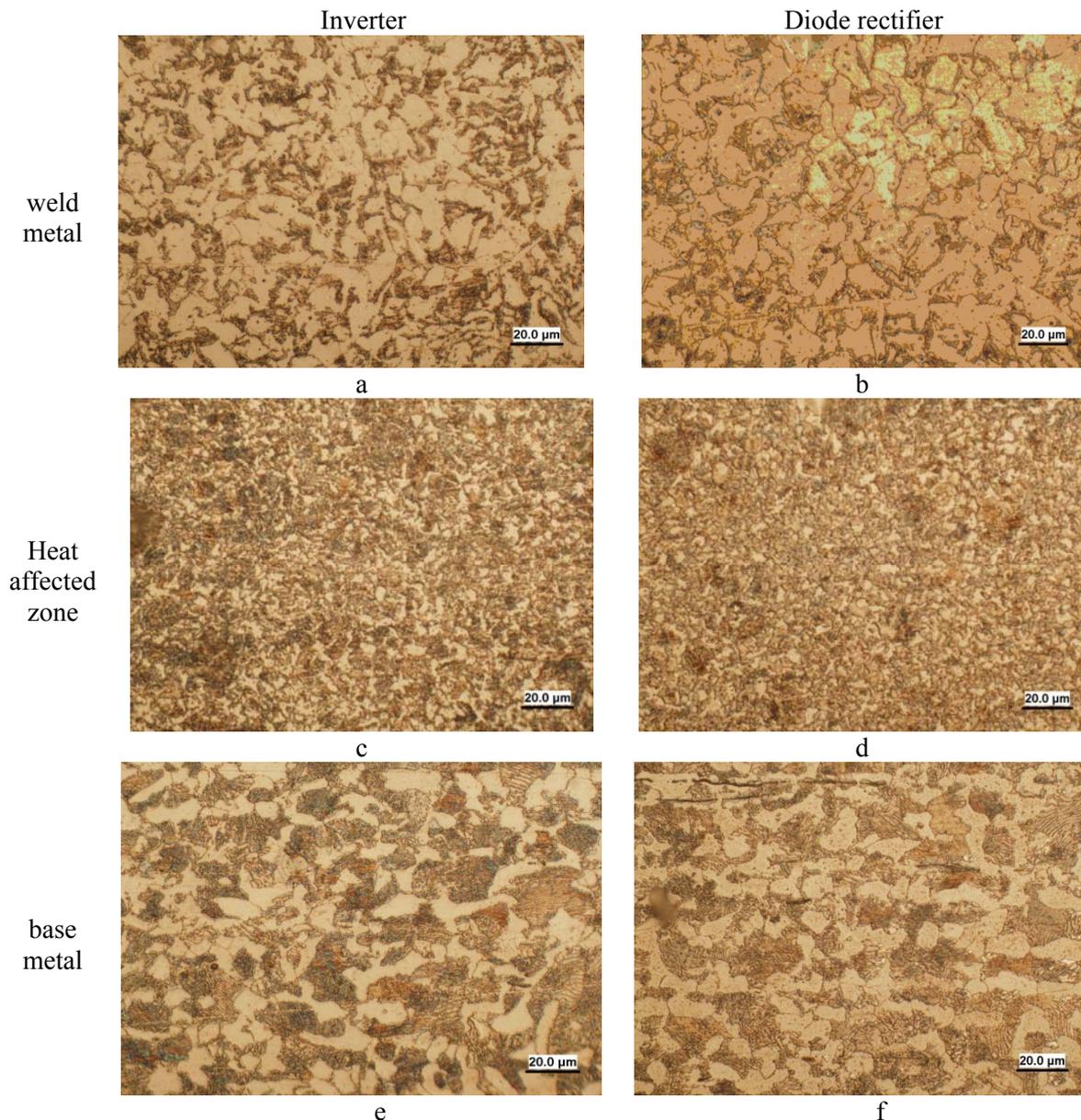


Figure 4. The results of micro structure analysis:

a, b – weld microstructure, c, d – HAZ microstructure of the welded joint; e, f - base metal microstructure

The structure of the deposited metal in the welded joint made using the inverter power supply (Fig. 4, a) is also purely ferritic and more homogeneous. The average size of ferrite grains is slightly finer and is $\approx 9,2$ μm . There is an inconsiderable amount of fine powder fractions as well.

The transition from the deposited metal to the heat-affected zone and then to the base metal is smooth without sharp changes when using either a diode rectifier (Fig. 4, d) or an inverter (Figure 4, c). In both cases the heat affected zone is a polycrystalline aggregate of ferrite grains and pearlite colonies. A pearlite content increases gradually with respect to the distance from the deposited metal to the base metal and reaches $\approx 50\%$ in terms of volume.

When using the diode source supply (Fig. 4, d), the average ferrite grain size is 4 microns. The average grain size in pearlite colonies is the same. The heat affected zone width reaches 8 mm.

In the heat affected zone of the welded joint made using the inverter power supply (Fig. 4, c), the ferrite grain size is almost the same and makes 4.4 micron. The total width of the heat affected zone is visibly smaller (≤ 6 mm). This indicates a lower heat input and the weldable product is overheated.

The base metal is of a ferrite and pearlite structure (Fig. 4, e, f). The volume fraction of pearlite is 55% that corresponds to the chemical composition of Steel 45. Ferrite grains are polyhedral with well-defined and clean boundaries. The average size in both cases as expected is the same $\approx 12,5 \mu\text{m}$. It is important to emphasize that forming welded joints causes significant (almost three times) refinement in the HAZ structure.

Thus, the application of an inverter insures the weldment with the uniform and fine grain structure in the deposited metal and narrower gradient heat affected zone.

Referring to the differences identified during the microstructure analysis, we assume mechanical properties vary as to the welded joints made using various power supplies.

Toughness tests on the notched weld metal test specimens were performed for impact properties according to the standard testing procedure. The test results are shown in Figure 5.

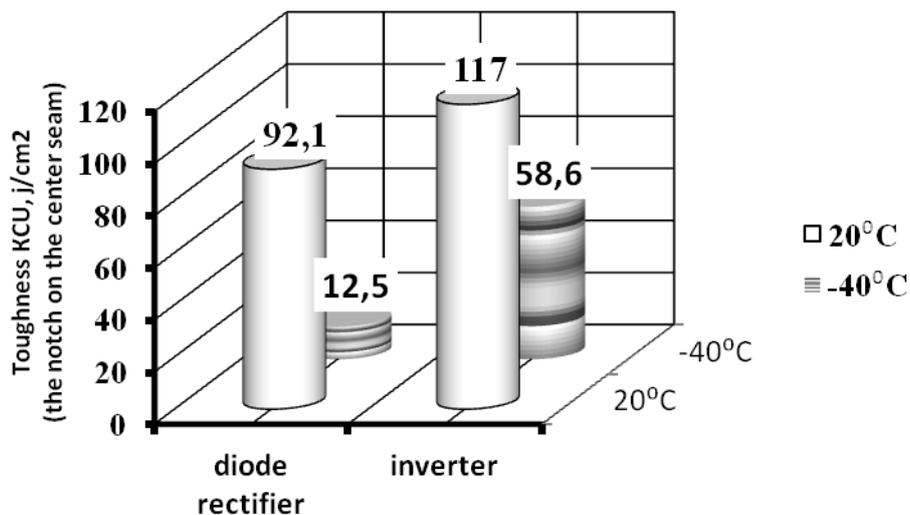


Figure 5. Influence of energy characteristics of power sources on toughness (KSU) of welded joints made of steel 45 using the UONI 13/55 electrodes

Analyzing the results of mechanical tests performed on weld specimens (Fig. 5) indicates that the decrease in heat content and overheating of electrode metal droplets while welding from the inverter power source enhance the toughness, particularly at sub-zero temperatures. This is essential for weldments designed for the use at low temperatures.

3 Conclusion

The results of the comprehensive research revealed that, when using inverters as a welding power supply, a drop of molten electrode metal has a less heat content, resulting in the decreased heat input and overheating of weldments. This insures the reduction in manganese

burning out, improvement of microstructure in all weld zones and enhanced impact properties of welded joints at negative temperatures.

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