Influence of Protective Gas Content on Quality of Welded Joint While Welding With Impulse Supply of Electrode Wire

N V Pavlov [a], A V Kryukov, E A Zernin, V V Gritsenko

Yurga Institute of Technology (branch) of National Research Tomsk Polytechnic University
Leningradskaya 26, Yurga, Russian Federation, 652055

E-mail: pavlin123@rambler.ru

Abstract. Currently one of the advanced ways of obtaining quality welded joint while welding of medium alloy martensitic-bainitic steel is the one with impulse supply of electrode wire in gas mixture $Ar(70\%\pm3\%)+CO_2(30\%\pm3\%)$. Results of experimental studies proved that application of protective gas $Ar(70\%\pm3\%)+CO_2(30\%\pm3\%)$ in comparison with $CO_2(100\%)$ enables to increase strength properties of the welded joint by 10-15% and enlarge the transition coefficient of chemical elements.

1. Introduction

Medium alloy martensitic-bainitic steel is characterized by a large number of operational properties and is used for manufacture of critical structures [1,2]. By critical structures particularly meant are high-pressure vessels, heavy loaded mechanical products and other structures as they provide high strength of structure after the appropriate heat treatment, at the same time providing reduced metal consumption. Steels of that group are marked by carbon content up to 0,5% while integrated alloy addition in total 5...9 %. Steels with carbon content being that high due to high sensitivity to welding thermal cycle are prone to formation of hardening structures and cold cracks.

Obtaining reliable welded joints is also problematic due to high sensitivity to stress raisers under static loads and dynamic loads in particular. Larger alloy addition with carbon makes welded joints even more sensitive [2].

The required strength of steel together with keeping high ductility is reached by integrated alloy addition with different elements, the main of which being chrome, nickel, molybdenum, etc. The given elements strengthen ferrite and increase steel hardening capacity. Increase of alloy addition level while high carbon content increases austenite stability and almost at any cooling rate of weld-affected zone and welding modes providing satisfactory weld formation, austenite decomposition occurs in martensitic area [1].

Different process solutions also find broad application, such as use of heatsink, different kinds of forming base surfaces, two-stream gas protection, use of nanostructured powders-modifiers while welding [3,4].

Research direction connected with application of impulse-arc welding methods has been actively developing recently, realized by:

1) tools controlling electrode metal transition by means of pulsed supply of welding arc [5,6];

2) mechanical programming of droplet transition into welding pool by means of impulse supply of welding wire [7,8,9].

Variety of ways to realize the first direction gives an opportunity to obtain almost any algorithms of changing the energy characteristics of welding arc.

However there is a number of disadvantages:

- complexity of design solutions;
- higher cost in comparison with standard equipment;
- inability of use together with mass-produced power supply sources.

The second direction provides controlled transition of electrode metal into welding pool by means of using the mechanisms of impulse supply of electrode wire.

While realizing this research direction it is reasonable to use pulling-type mechanisms, as they provide not only system portability, but more importantly transfer the form of impulse more accurately [7,8,9].

Therefore welding with impulse supply of electrode wire with pulling-type mechanisms is a relevant objective. This process provides advantages of impulse-arc welding methods and also does not have any significant disadvantages.

The other factor influencing the quality of weld joint is protective gas medium.

Having analyzed the existing and applied protective gases and mixtures on their basis, it was proved to be rational to use the mixture $Ar+CO_2$ [10]. This mixture is actively applied in the process of manufacturing, has a positive effect on processing properties of welding arc (increased stability of its combustion), splashes size decreases and spatter losses reduce, weld reinforcement decreases with sharp transition to the base metal (Figure 1) [11].
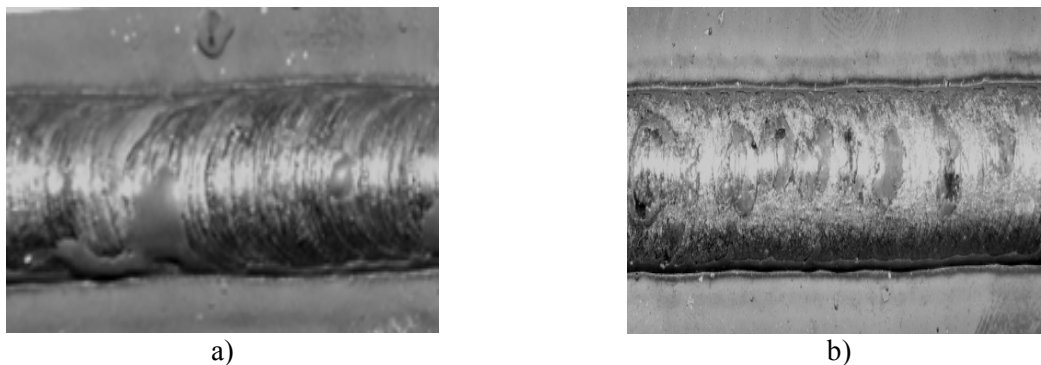

a)   b)

Figure 1. Layout of welds obtained by welding with impulse supply of electrode wire in CO_2 (a) and by welding with impulse supply of electrode wire in gas mixture $Ar+CO_2$ (b).

Following the conducted experiments it was established that application of mixture $Ar(70\%\pm3\%)+CO_2(30\%\pm3\%)$ while steel welding of standard quality (structural carbon steel of regular quality) reduces the value of electrode metal losses by burning and spattering up to 2% [12] (Figure 2).
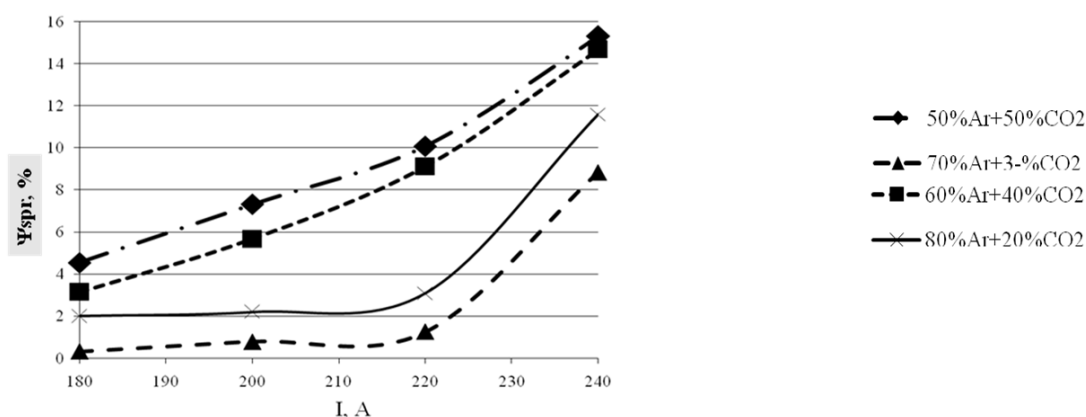
Figure 2. Dependency diagram of value of electrode metal losses by burning and spattering (ψspat.) of the value of arc welding current (I).

Based on the data described in work of Novozhilov N.M. [13] the obtained ratio is determined by the fact that addition of carbon to argon up to 70 % Ar + 30 % CO2 is accompanied by decrease in size of electrode droplets and corresponding increase of their number. Increasing of carbon content in argon beyond this limit at some conditions is accompanied by sharp decrease of the number of droplets, and by other conditions is accompanied by gradual decrease of the number of droplets formed per unit time.

However the issues of applicability of welding mode with impulse supply of electrode wire in gas mixture Ar(70%±3%)+CO2(30%±3%) while welding of medium alloy martensitic-bainitic steel are still not well studied.

Resulting from that the objective was set to increase strength properties of welded joint made of medium alloy martensitic-bainitic steel by means of using a mixture of protective gases in the ratio 70 % Ar + 30 % CO2 while welding with impulse supply of electrode wire.

2. Methods investigations
Experimental testing was held to study influence of protective gas media composition on structure and operational properties of welded joints made from medium alloy martensitic-bainitic steel:

1) traditional method – welding with impulse supply of electrode wire in CO2(100%);

2) suggested method – welding with impulse supply of electrode wire in gas mixture Ar(70%±3%)+CO2(30%±3%).

In both cases the experimental facility included: automatic welding head, equipped with impulse supply of electrode wire [14], Power supply welding rectifier (rated current – 300A), mixing equipment including three flow meters and mixing chamber. Welding was held from sheets made of steel (0.3% - C; up to 1 percent – Cr, Mn, Si) thickness 10mm, in X-shaped splicing by welding wire ER70S-6 (diameter 1,2 mm).

Welding methods of samples are given in Table 1.

Table 1. Welding methods of samples.

Welding method	I, A	U, B	Vw, mm/s	f, Hz
traditional method	200-210	23-24	3.6	64
suggested method	220-230	24-25	3.7	64

Difference in value of energy parameters is connected with the fact that in order to reach the same geometrical parameters it is necessary to increase welding modes with impulse supply of electrode

wire in gas mixture Ar+CO2 to 5-10% in comparison with impulse supply of electrode wire in CO2, as addition of argon leads to its reduction [12].

Evaluation of chemical compound of weld was carried out using consequent x-ray fluorescent spectrometer LabCenter XRF-1800.

Experimental samples were taken in two points in the basic metal and in weld metal (Figure 3). Point diameter is 3mm.
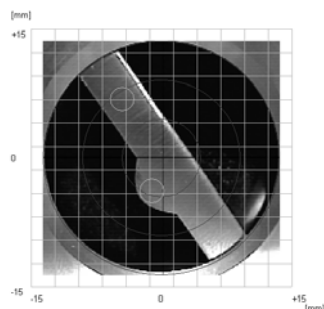

Figure 3. Points of measurement to study chemical compound.

Mechanical properties of welded joints were defined in accordance with common methods, given in Russian State Standard (GOST) No.6996-66 "Welded joints. Ways to define mechanical properties".

Microstructure of weld metal was studied and observed by means of microscope ES METAM RV (Russian State Standard (GOST) 15150-69) complete with digital camera Fuji Film Fine Pix S6500fd, providing recording of data from microscope.

3. Results and discussion

Experimental studies implied exposing of the obtained welded samples to quantitative estimation of chemical compound, mechanical testing and structural analysis of welded joint (Tables 2, 3 and Figure 4).

Table 2. Chemical compound of weld metal.

Welding method	Chemical elements				
	C, %	Si, %	Mn, %	S, %	P, %
traditional method	0.24-0.26	0.72-0.74	0.61-0.63	0.013	0.017
suggested method	0.22-0.23	0.78-0.8	0.66-0.68	0.011	0.015

Table 3. Results of mechanical testing of welded samples.

Welding method	Impact strength, KCU, J/sm2		
	T=0ºC	T=20ºC	T=-20ºC
traditional method	62…66	72…76	52..56
suggested method	71…75	82…86	60…64

As seen in Table 2 while welding in gas mixture transition coefficient of chemical elements-deoxidizing agents (silicon and manganese) into welding pool increases by 4-6%. Such change occurs due to change in the value of specific speed of metal oxidation ω_{spec}.

Based on the methodology described in N.M. Novozhilov's work specific speed of metal oxidation is calculated according to the formula below [13]:

$$\omega_{spec} = \frac{\sum O_w}{100 t_{av}} \, g / gmet \cdot s, \qquad (1)$$

where tav – average time of metal being in liquid state in seconds;
ΣOw – specific oxidation of metal, g/100 g met.

Due to short term of electrode droplets this value is accepted as time of metal being in liquid state equal to metal being in welding pool [13]:

$$t_{av} = \frac{G_w}{g} \, sec, \qquad (2)$$

where Gw – amount of molten metal in welding pool, g;
g – amount of metal, melted by arc in 1 s. in g/s.

Amount of molten metal in welding pool is defined by approximate formula based on allowance that volume of welded pool equals half of the ellipsoid volume [13]:

$$G_w = 0{,}523 K_f LBh \gamma_t, gmet, \qquad (3)$$

where Kf – filling coefficient of welding pool with molten metal, accepted as 0,8-0,9;
L – length of welding pool, accepted as equal to crater length, mm;
B, h – width of weld and depth of weld penetration of the base metal, mm;
γt – density of molten metal in welding pool;

Amount of metal melted by arc in 1 second, is defined by formula [13]:

$$g = F v \gamma, gmet / sec, \qquad (4)$$

where F – cross section area of weld, mm2;
v – welding velocity, mm/s;
γ – density of molten metal.

Calculations performed by this method (Table 4) showed increase in specific velocity of metal oxidation by 5-6% and reduction of specific amount of oxidized metal up to 10%.

Table 4. Evaluation of intensity of metal oxidation.

Welding method	g, gmet/sec	Gw gmet	tav, s	Wspec
traditional method	0.262	0.327	1.248	0.03
Suggested method	0.279	0.327	1.172	0.028

Reduction of heat input value into droplet of electrode metal contributes to keeping elements-deoxidizing agents in welded joint, as heating capacity of welding arc is different due to value of effective heating.

Combination of these factors enables silicon dissolving in ferrite to increase yield limit and decrease tendency to cold brittleness, manganese forms solid solution with iron, increases hardness and strength insignificantly that contributes to increase in the value of impact strength by 10-15% (Table 3) compared to welding in CO_2.

Conducted metallographic studies of two methods demonstrated similarity of the obtained results (Figure 4).

a)   b)

c)   d)
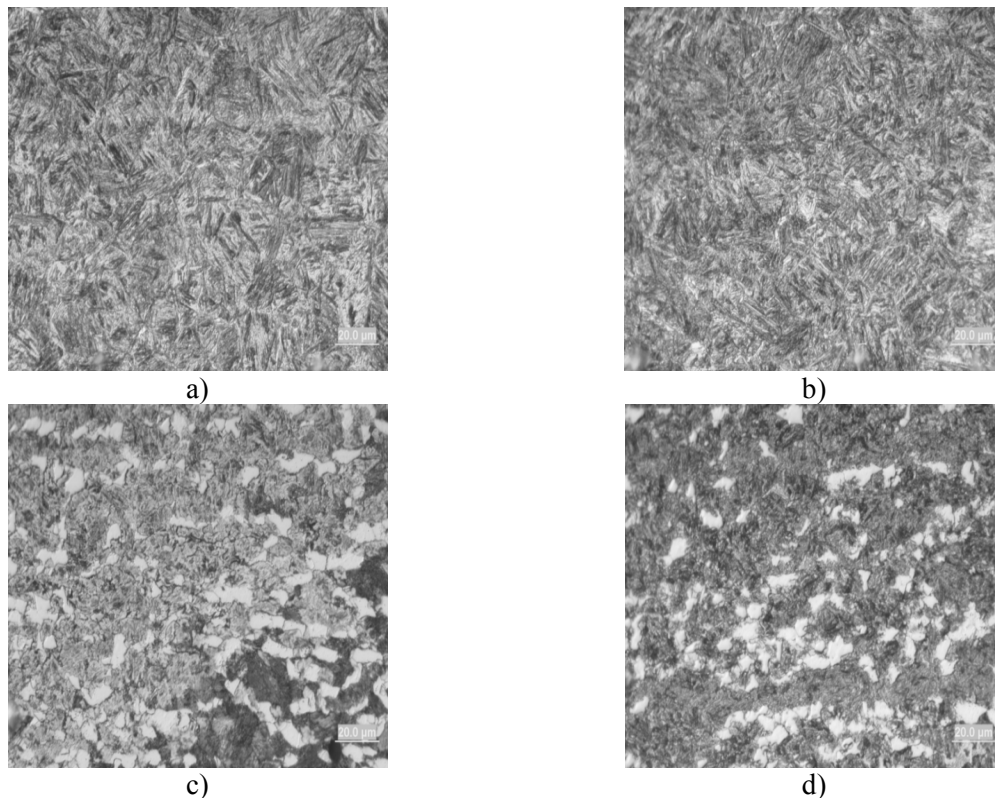
Figure 4. Microstructure (increase 20.0 μm) a) area in the center of weld metal while welding by traditional method; b) area in the center of weld metal while welding by the suggested method; c) area of thermal cycle boundary zone while welding by traditional method; d) area of thermal cycle boundary zone while welding by the suggested method.

In the center of weld metal dark-brown sheets of bainit in lighter martensite matrix are seen (Figure 4 a,b), the structure is homogeneous and has echinulate martensite composition. In the structure of heat-affected zone of steel (0.3% - C; up to 1 percent – Cr, Mn, Si) areas of hardening structures are also observed, however deformation texture is not well observed in Figure 4,c. While removing from weld area the amount of martensite decreases, intensive grain refining occurs and recrystallized zone is formed (Figure 4,d). Recrystalized zone has fine grain and structure close to equilibrium state (Figure 4,d). While welding by traditional method recrystallized zone is characterized by better marked transition to the base metal (Figure 4,c).

It should be noted that welded joints did not undergo heat treatment. Elimination of heating and after-welding heat treatment from welding procedure of (0.3% - C; up to 1 percent – Cr, Mn, Si) steel and reduction of time for stripping of product will enable to increase labor efficiency in comparison with traditional method by 5-10%.

The obtained changes are connected with different temperature increment on the surface of product (Figure 5).
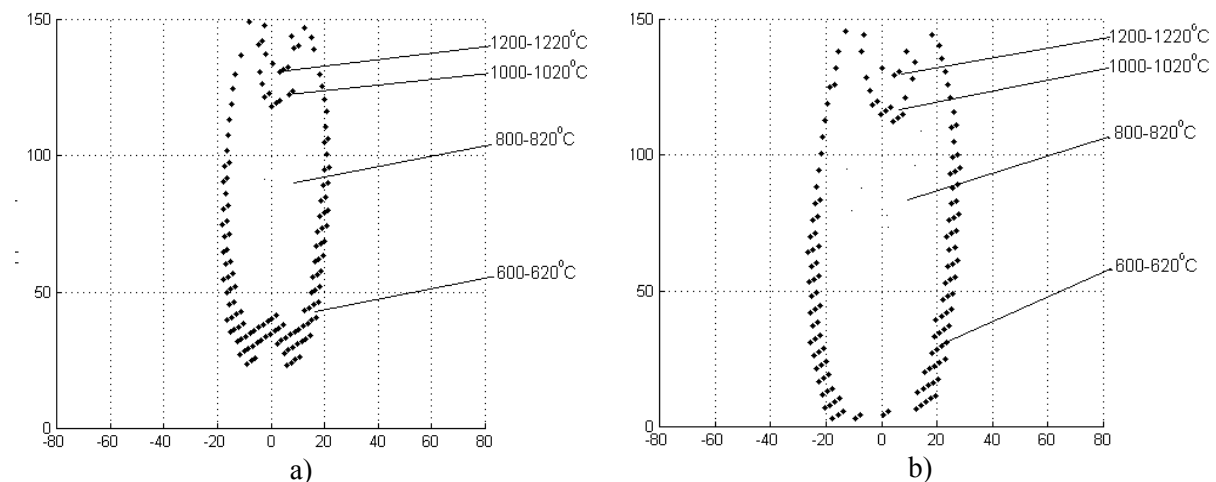
Figure 5. Experimental thermograms obtained after treatment: a) isotherm of temperature increment on the surface of weld while welding by traditional method; b) isotherm of temperature increment on the surface of weld while welded by the suggested method

During welding by the suggested method isotherm (Fig. 5,b) has more oblong form along weld (by 40%) while keeping weld width that proves more homogeneous distribution of temperature fields on the surface of product.

4. Conclusion
Resulting from experimental studies it was established that application of gas media Ar(70%±3%)+CO2(30%±3%) compared to CO2(100%) enables to increase strength properties of welded joint by 10-15% and increase transmission coefficient of chemical elements.

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