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RESOURCE-EFFICIENT DOUBLE-GAS-SHIELDED WELDING OF ALLOY STEELS: EFFECT OF MODES ON STRUCTURE AND MECHANICAL PROPERTIES

D. Tomaszewicz[1], P. Chmielewski[1], D.B. Hlushkova[2], V.M. Volchuk[3], V.A. Bagrov[2], V.O. Saienko[2]
[1]International Academy of Applied Sciences in Łomża, Łomża, Poland;
[2]Kharkiv National Automobile and Highway University, Kharkiv, Ukraine;
[3]Prydniprovska State Academy of Civil Engineering and Architecture, Dnipro, Ukraine
E-mail: diana.borisovna@gmail.com

The study investigates the influence of welding parameters using a double-jet gas shielding technique on the microstructure and mechanical properties of welded joints made of 30KhGSA alloy steel, which is highly susceptible to hardening and cold cracking. The purpose of the work is to improve the welding process with a consumable electrode in a CO_2 environment by applying a controlled dual-jet gas flow that stabilizes the weld pool, reduces thermal inhomogeneity, and eliminates the need for preheating and post-weld heat treatment. The methodology included multi-pass welding of tubular joints using traditional shielding and the proposed double-jet configuration, followed by optical microscopy, microhardness testing, and comparative analysis of structural transformations within the weld metal and heat-affected zone. The results show that the double-jet shielding mode produces a finer and more stable ferrite-pearlite structure, ensures better mixing of the weld pool, and significantly reduces structural gradients across the joint. Welded samples obtained with the proposed technique exhibit higher tensile strength and microhardness values compared with the conventional method. The originality of the research lies in demonstrating that controlled dual-jet gas flow can effectively regulate heat transfer and chemical composition in the weld without additional thermal operations. The practical value is the development of an energy-efficient and resource-saving welding technology that improves the performance and reliability of welded alloy-steel structures.

INTRODUCTION

Medium carbon alloy steels have a high set of operational properties and are used for the production of critical welded structures [1–4]. They provide high structural strength while simultaneously reducing its metal consumption. However, under the influence of the thermal cycle of welding [5, 6], hardened structures are formed in the heat affected zone (HAZ) of welded joints, characterized by high hardness values at low viscosity [7, 8]. Therefore, the HAZ accounts for the largest share of cold cracks formed during the welding process [9].

To prevent the formation of cold cracks and increase the operational reliability of welded structures made of steels susceptible to hardening, as a rule, additional operations are used, which complicate the technological process and increase the cost of manufacturing welded structures [10–14]. In domestic and foreign practice, preheating and post-welding heat treatment are widely used for this purpose [15, 16]. This welding technology allows you to reduce the cooling rate of the weld metal and HAZ, increase the time for structural transformations in the welded joint [17–19]. The use of preheating and heat treatment is associated with additional costs of various resources [20, 21].

PURPOSE AND TASK STATEMENT

The aim of the work is to improve the welding process with a consumable electrode in a shielding gas environment and thereby investigate the structure and properties of non-separable joints.

To achieve the goal, the following tasks were defined:

1. Determine the degree of influence of the active shielding gas jet on the chemical composition and geometry of the weld metal.
2. To investigate the basic patterns of formation of the structure and properties of non-separable joints depending on the technological parameters of welding with a consumable electrode with double-jet gas protection, under which the stability of high operational properties is ensured.

MATERIALS AND METHODS OF THE STUDY

The study was conducted on medium-carbon alloy steel 30KhGSA, widely used in high-strength welded structures. The following materials were used:

Pipes with 90 mm diameter and 20 mm wall thickness; groove preparation – 8 mm slot; welding wire Sv-08G2S, Ø 1.2 mm.

Two welding technologies were compared:

Method I – Traditional – consumable-electrode arc welding in CO_2; preheating to 350 °C; post-weld heat treatment at 600 °C.

Method II – Developed arc welding in double-jet gas shielding; no preheating; no heat treatment.

Equipment: welding power source TDFZh-1000; automatic welding head A-1420; shielding gas – CO_2; metallographic microscope NEOPHOT-21; microhardness tester PMT-3.

In the developed method:

- the inner active gas jet increased melt stirring; the outer annular jet stabilized protection and reduced turbulence.

In both methods, mechanized multilayer welding of the pipe joint was performed.

The traditional method applied a full thermal cycle, while the developed method ensured accelerated cooling due to modified gas flow dynamics.

The following structural zones were analyzed: weld metal; fusion zone; incomplete fusion zone; overheating zone; normalization zone; base metal (Fig. 1).

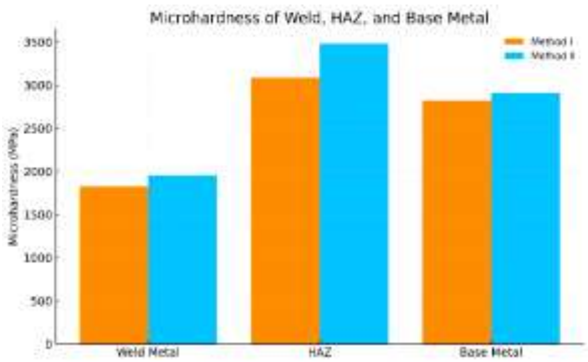


Fig. 1. Schematic representation of microstructural zones

Microhardness was measured 5 mm below the upper surface of the weld (Fig. 2). Measurement error: ±5…7%.

Fig. 2. Microhardness distribution across the weld

INFLUENCE OF TECHNOLOGICAL PARAMETERS OF FUSION WELDING IN JET GAS PROTECTION ON THE PROPERTIES OF WELDED JOINTS

Structural alloyed steels include steels alloyed with one or more elements with a total content of 2.5…10%. Modern alloyed steels are characterized by multicomponent complex alloying, which allows steels with high mechanical properties to be obtained. Alloyed steels used for welded structures mainly belong to the pearlitic class.

High mechanical properties of structural alloyed steels are achieved by alloying with elements that strengthen ferrite and increase the annealing of steel, and by proper heat treatment, after which the positive effect of alloying elements is manifested. Therefore, steels of this group are subjected to improvement by quenching with subsequent tempering. With high strength properties, alloyed steels after appropriate heat treatment are not inferior in plasticity and toughness, and in some cases even surpass such a plastic material as low-carbon steel.

Structural alloy steels are widely used to create lightweight high-strength welded structures. However, not all structural alloy steels weld well or satisfactorily. The more the steel is alloyed with chemical elements (including carbon), which contribute to the formation of a brittle martensite structure in the thermal cycle of welding, the worse the weldability of this steel under other conditions being equal (melting method, type of joint, thickness of the part being welded, etc.). A characteristic feature of structural medium-carbon alloy steels is the formation of hardening structures in the weld and HAZ, which create the risk of brittle fracture. The resistance of welded steel to the formation of cold cracks depends on many factors and is determined both by the features of the welding process and the properties of the base and filler metal. A typical representative of steels of this class is 30KhGSA steel. The influence of various welding methods and techniques on the performance properties of this steel is an interesting object of research in order to determine the best technological parameters and welding conditions that ensure high-quality uniform formation of welded joints, and to develop resource-saving welding technology.

Based on the results of a complex of conducted research, a method of multilayer welding of alloy steels with double-jet gas protection of the welding zone without heating and subsequent heat treatment was developed.

The developed welding method ensures the stability of the internal gas jet supplied, reliable protection of the welding zone, reduces gas turbulence in the near-seam zone. Control of the dynamic influence of the internal shielding gas jet on the processes in the welding zone, liquid metal drops of electrode metal and the weld pool leads to a change in the heat and mass transfer processes in the welding zone and intensive mixing of the molten electrode metal with the base in the weld pool. The gas exhaust rate increases and reduces the time the weld metal and HAZ stay in the high-temperature zone. The external annular jet blocks gas turbulence near the surface of the welded product and provides reliable protection of the welding zone from the harmful effects of air.

For a comparative assessment of the operational properties of welded joints made of 30KhGSA alloy steel, experimental studies were conducted using the following welding methods:

1. Basic (traditional) – stationary arc welding with preheating to a temperature of 3500 °C and subsequent heat treatment at a temperature of 6000 °C.

2. Developed – stationary arc welding with double-jet gas protection without preheating and heat treatment.

In each case, mechanized multi-pass welding of a rotary joint of a pipe with a diameter of 90 mm and a wall thickness of 20 mm was performed in a CO_2 environment in a slot processing with a width of 8 mm with a welding wire Sv-08G2S with a diameter of 1.2 mm. For welding the samples, a TDFZh-1000 power source and an A-1420 automatic welding head were used. The welding modes of the samples using the traditional method were determined based on the analysis of the dependence of the mechanical characteristics of multilayer welded joints of 30KhGSA steel on the parameters of the thermal cycle of welding (T_{pod} – preheating temperature; T_{to} – temperature of subsequent heat treatment; Izv – welding current strength) [3]. For welding samples by methods I and II, the following mode was selected: Izv = 180...185 A, Ud = 26...27, Vzv = 14...15 m/h, Qg = 10...11 l/min.

Metallographic studies of samples welded by method I showed that the weld metal (Fig. 3,a) has a coarse-grained ferrite -pearlite structure. In the fusion zone (Fig. 3,b) the transition from the weld metal to the base metal (incomplete melting area) is clearly visible. The incomplete melting area (Fig. 3,c) is a Widmanstädt structure [9]. The boundary of the former austenite grains is clearly visible. The structure of the overheating area (Fig. 3,d) is a tempered bainite structure with ferrite grains.

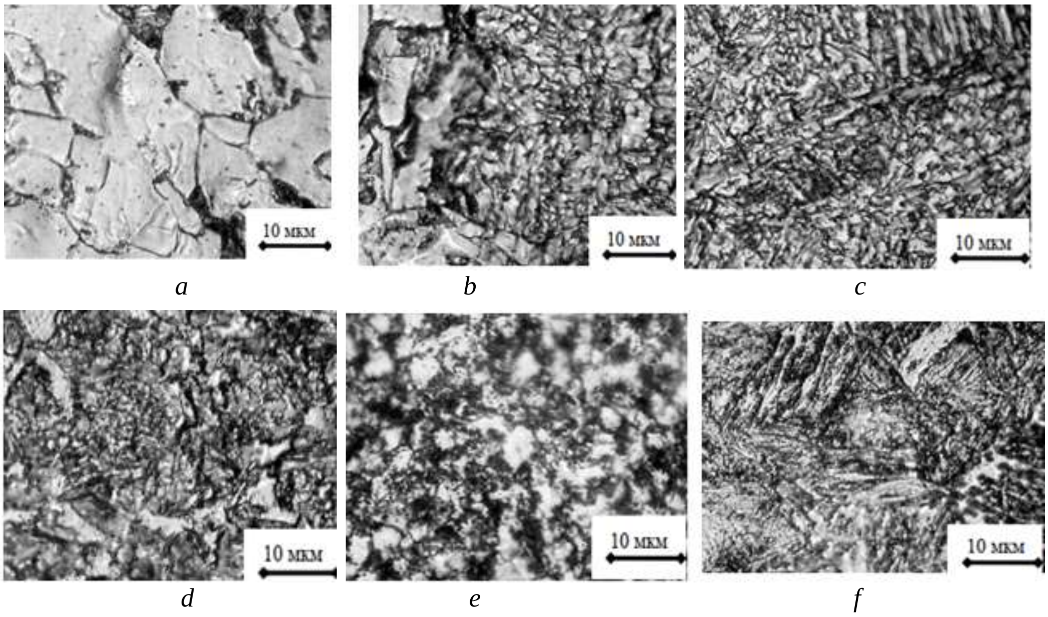


Fig. 3. Microstructure of a welded joint made of 30KhGSA steel obtained by the first method: a – weld metal; b – fusion zone; c – incomplete fusion zone; d – overheating zone; e – normalization zone; f – base metal

The enlarged structure of the normalization area (Fig. 3,e) indicates significant heat input (heat treatment). The microstructure of the base metal (see Fig. 3,e) is represented by acicular grains of ferrite and pearlite. Fig. 4 shows the microstructure of a sample welded by the II method.

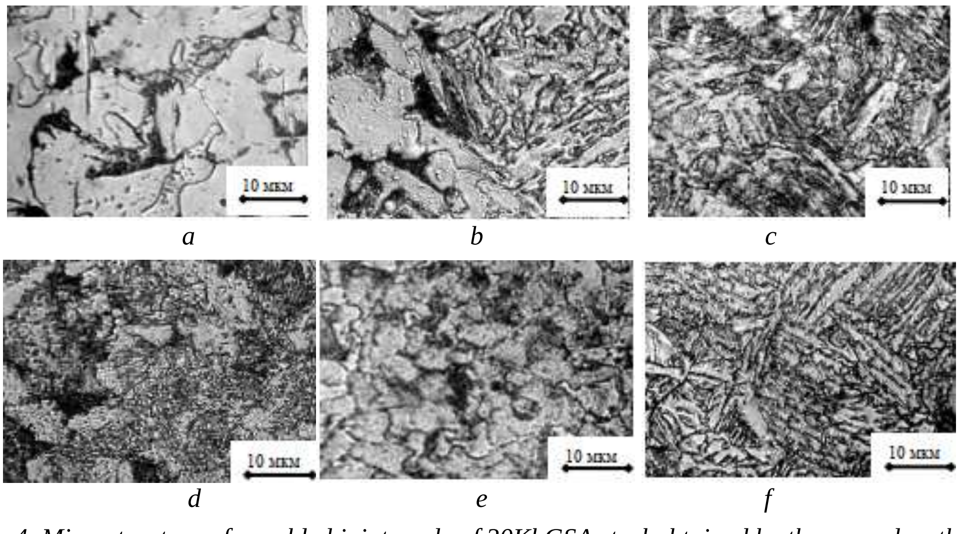


Fig. 4. Microstructure of a welded joint made of 30KhGSA steel obtained by the second method: a – weld metal; b – fusion zone; c – incomplete fusion area; d – overheating area; e – normalization area; f – base metal

The structure of the weld metal is a mixture of grains of ferrite and pearlite (see Fig. 4,a). The transition from the deposited metal to the base in the fusion zone (see Fig. 4,b) indicates good mixing of the molten metal in the weld pool. This ensures high performance of the welded joints. In the area of incomplete fusion (see Fig. 4,c), ferrite grains of an elongated shape are found. The structure of the overheating area is shown in Fig. 4,d, and is most likely characteristic of a bainite structure with ferrite layers.

The structure of the normalization area (see Fig. 4,e) is characterized by small equiaxed grains of ferrite. The base metal (see Fig. 4,f) has needle-shaped grains of ferrite and pearlite.

Fig. 5 shows a graph of the change in microhardness in the cross section of the welded joint obtained by method I. The measurement was carried out at a distance of 5 mm from the upper surface of the welded joint. The graph shows that the microhardness in the HAZ has an increased value compared to other areas [4].

The average values of the microhardness of the weld metal, heat-affected zone, and base metal are 1824, 3091, and 2823 MPa, respectively.

Fig. 6 shows the change in microhardness in the cross section of a welded joint obtained by welding with double-jet gas protection. The measurements were carried out at a distance of 5 mm from the upper surface of the welded joint.

Fig. 6 shows that the microhardness in the HAZ also increases compared to other areas, for example, in relation to the base metal it increased by approximately 19%, taking into account the measurement error. The average values of the microhardness of the weld metal, the heat affected zone and the base metal are respectively: 1952, 3481, 2913 MPa. The relative error is ±7%.

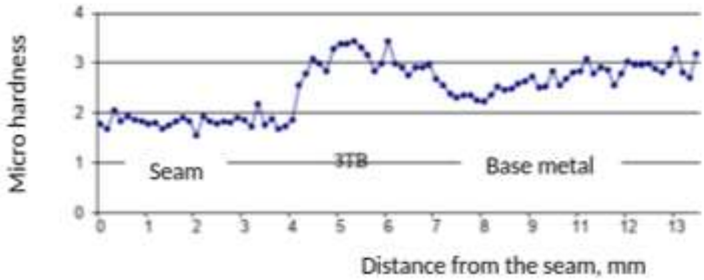


Fig. 5. Change in microhardness in the cross section of a welded joint made by method I

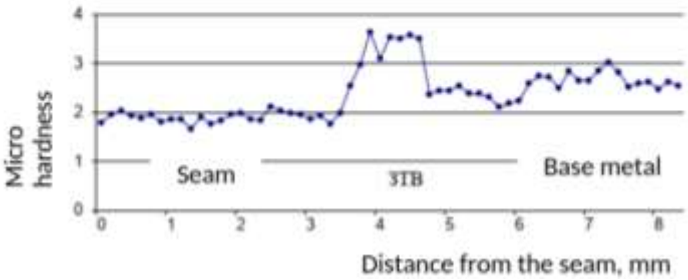
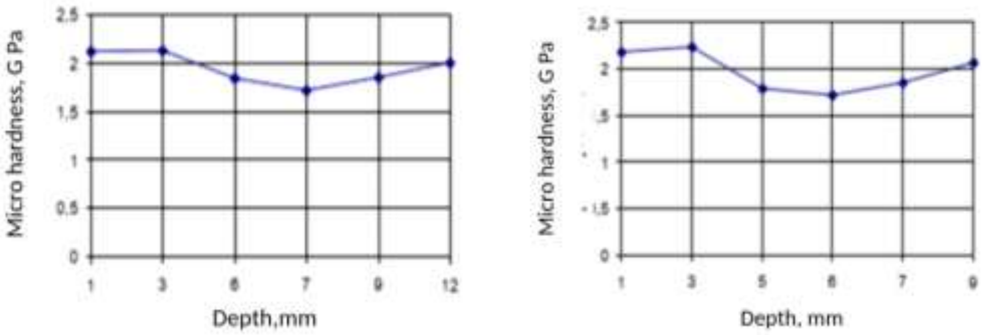


Fig. 6. Change in microhardness in the cross section of the welded joint obtained by method II

Fig. 7 shows the change in microhardness in multilayer joints along the axis of the weld metal depending on its depth. Increased values of microhardness of facing layers and its decrease in the middle layers of welded joints are associated with the effect of autoheat treatment in multilayer joints. The high value of microhardness in the root weld is due to a significant proportion of base metal.



a *b*

Fig. 7. Distribution of microhardness along the axis of the weld depending on the depth of the weld: a – method I; b – method II

Analysis of the obtained dependencies showed that with increasing shielding gas consumption, the yield strength and impact toughness of welded samples decrease, and the manganese content in the weld metal decreases. An increase in welding speed leads to an increase in the impact toughness KCV at +200 °C and to its decrease at -400 °C, an increase in the manganese content and a decrease in chromium in the weld metal. An increase in welding current in the selected range increases the temporary resistance to rupture of welded samples, the content of silicon and manganese in the weld metal. For all mechanical properties of welded samples, the joint effect of current and welding speed is significant. The carbon content in the weld metal of multilayer welded joints made of 30KhGSA steel does not depend on the controlled parameters of the welding mode.

CONCLUSIONS

1. It has been established that the use of double-gas-shielded welding in a CO_2 environment ensures the formation of a stable ferrite-pearlite structure in the weld metal with a smaller grain size compared to the traditional welding method involving preheating and post-weld heat treatment.

2. Welded joints produced using the double-gas-shielding technology demonstrate higher mechanical properties – static strength, microhardness of the weld metal and heat-affected zones – indicating improved strengthening and reduced tendency to form brittle structures.

3. The proposed welding technology is resource- and energy-efficient, as it eliminates the need for preheating and post-weld heat treatment while maintaining high quality and performance of welded joints.

4. Variation of welding parameters (current, welding speed, gas flow rate) in double-gas-shielded welding enables targeted control of the weld metal chemistry, bead geometry, and mechanical properties, ensuring their stability and predictability.

5. The developed welding method for 30KhGSA alloy steel minimizes the formation of hardened structures in the heat-affected zone, reduces the risk of cold cracking, and enhances the reliability of critical welded components.

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РЕСУРСОЗБЕРІГАЛЬНЕ ЗВАРЮВАННЯ ЛЕГОВАНИХ СТАЛЕЙ З ПОДВІЙНИМ ГАЗОВИМ ЗАХИСТОМ: ВПЛИВ РЕЖИМІВ НА СТРУКТУРУ ТА МЕХАНІЧНІ ВЛАСТИВОСТІ

Д. Томашевич, П. Хмелевський, Д.Б. Глушкова, В.М. Волчук, В.А. Багров, В.О. Саєнко

Досліджено вплив технологічних параметрів зварювання із застосуванням двоструменевого газового захисту на мікроструктуру та механічні властивості зварних з’єднань зі сталі 30ХГСА, яка характеризується високою схильністю до загартування та утворення холодних тріщин. Метою дослідження є удосконалення процесу зварювання плавким електродом у середовищі CO_2 шляхом використання керованого двоструменевого газового потоку, що стабілізує зварювальну ванну, зменшує теплову нерівномірність і дає змогу відмовитися від попереднього підігріву та післязварювальної термообробки. Методика передбачала виконання багатошарового стикового зварювання труб із використанням традиційного та запропонованого режимів газового захисту, подальше металографічне дослідження, вимірювання мікротвердості та аналіз структурних перетворень у металі шва і зоні термічного впливу. Результати показали, що двоструменевий газовий захист забезпечує формування дрібнозернистої стабільної феритоперлітної структури, покращує перемішування розплавленого металу та суттєво знижує структурні градієнти по перерізу з’єднання. Зразки, які виготовлені за запропонованою технологією, характеризуються підвищеною міцністю та мікротвердістю, як порівняти з традиційним методом. Наукова новизна роботи полягає у доведенні можливості ефективного керування тепломасообміном і хімічним складом металу шва внаслідок контрольованого двоструменевого газового потоку без додаткових термічних операцій. Практична цінність полягає у розробленні енерго- та ресурсозберігаючої технології зварювання, що підвищує надійність та працездатність зварних конструкцій з легованих сталей.