Influence of refractory nanosized particles of tungsten carbide and titanium on the structure and properties of the weld metal

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Abstract. The paper considers the influence of nanosized particles of tungsten and titanium carbides on the structure and properties of the weld metal of welded joints made by automatic submerged-arc automatic arc welding. To add them into the weld pool, an alloying composition was used in the form of composite granules based on nickel powder (PNE-1 as per GOST 9722). The prospects of using nanosized tungsten carbide particles for modifying the weld metal with the aim to increase the values of impact strength were shown. However, titanium carbide in the same conditions leads to a decrease in the average value of impact strength, despite the modifying effect of its use.

1. Introduction

Submerged arc welding has found wide application in the welding industry, at the same time in order to increase productivity, two or more electronic wires can be used, at the torches of which independent arcs are burning (multi-arc submerged-arc welding). In particular, multi-arc processes have proven themselves in the production of main pipelines, and two-arc welding can be used to weld annular joints of pipelines during their installation [1, 2]. However, in this case, due to the greater heat input, a coarse structure can be formed of both the weld metal and the heat-affected zone, which leads to a decrease in the impact strength in these zones. Traditionally, to solve this problem, it is necessary to optimize the scheme of alloying of the weld metal through welding materials, as well as apply various process methods (for example, the use of additional filler wire). An alternative way of influencing the mechanical characteristics of the weld metal is its modification, which allows grinding the grain of the weld metal and, thus, improving the mechanical properties (in particular, increasing the impact strength values) [3,4,5].

An analytical review [3], conducted by the authors earlier, showed that recently there was an interest in using nanoscale particles for modifying the structure of the weld metal and built up metal of functional coatings. Therefore, the article is devoted to the study of the influence of nanoscale particles on the structure and properties of the weld metal during the implementation of two-arc welding under flux. For the addition of nanosized particles the filler material in the form of alloying composition was used, which was tested in [4]. In addition, the analogue of such a material in the form of a metal chemical additive (MHP) has a widely used analog in bridge construction [5–7].

The alloying composition represents composite granules obtained by mixing in a high-energy planetary mill powders of metals and their alloys and powders of nanoscale refractory compounds.
2. Research methodology
Experimental studies were carried out when welding plates 300x100x10 mm (LxWxT), made of St3sp as per GOST 380. The welded joint is of C-19 type according to GOST 8713 (with the remaining lining). The applied cutting allows to weld in one pass, the presence of blunting allows to control the dosage of the added alloying composition, and the steel lining will keep it from spilling out and does not require special measures to prevent burn-through and the formation of the back side of the seam. The combination of electrode wire and welding flux is selected for reasons of making the welded joint in one pass, ensuring a chemical composition of the weld metal of 0.08% C; 1.7% Mn and 0.9% Si. The alloying composition was prepared by mixing nickel powders (PNE-1 as per GOST 9722) with an average size of not less than 50 microns and nanoscale particles in a proportion of 30 wt% of nanoparticles and 70 wt% of nickel. Tungsten carbide (WC) and titanium carbide (TiC) particles were used as refractory particles. Nanoscale carbide particles were obtained by plasma-chemical synthesis in thermal plasma using electric arc plasma torch [8,9]. Powders consist of individual, non-porous particles of equiaxial form. The average particle size of titanium carbide is 50 nm, tungsten carbide is 70 nm. The powders are characterized by a particle size distribution close to log-normal [10] and single-phase. The experiments were carried out according to the scheme of submerged arc welding with two wire electrodes (two-arc welding). The alloying composition is pre-laid into the groove before welding and then melted by an arc [11]. This scheme of the process allows avoiding the welding arc direct impact on particles and shields them at the expense of the liquid layer. In this case, the second arc creates an additional metal flow in welding pool, which intensively mixes it and allows you to get uniform distribution of particles by volume of the pool. To perform the experiments, the parameters of the mode were selected that ensure the formation of a weld in one pass that meets the requirements of GOST 8713 (Table 1).

| Item Number | Parameter                              | Value range                         |
|-------------|----------------------------------------|-------------------------------------|
| 1           | Type of current                         | DC+\(^4\)                           |
| 2           | Welding current per arc (A)             | 650 ± 20 AC\(^5\)                   |
| 3           | Arc voltage (V)                         | 27 ± 1 32 ± 1                        |
| 4           | Welding speed (m/h)                     | 45 45                                |
| 5           | Electrode stickout distance (mm)        | 30 40                                |
| 6           | Distance between electrodes (mm)        | 27 27                                |
| 7           | Electrode Tilt Angle                    | 90° 60° (forward angle)             |
| 8           | Balance\(^6\) (%)                      | 100 25                               |

\(^4\) DC+ - direct current of reverse polarity  
\(^5\) AC - alternating current  
\(^6\) Balance - the ratio of the arc burning time in reverse polarity to the duration of the arc burning period

The alloying composition was pre-laid in the groove while controlling the height of the filling. Two variants of the filling height were tested: 2 and 3 mm. As a result, joints characterized by the number of nanosized particles added in accordance with Table 2 were obtained. Also, to establish the degree of influence of nanoscale particles on the weld metal, experiments on welding with nickel powder filling (PNE-1 as per GOST 9722) were performed, as well as a variant without additional additives, the so-called “Basic”.

After the welds were completed, samples were cut from them to prepare thin sections to study the structure of the weld metal. Also, samples of type X as per GOST 6996 were prepared for testing the impact strength of the weld metal at a temperature of “minus” 20°C. After testing, the fracture surface was subjected to fractographic analysis.
3. Results of research
The macrostructure of the weld metal has a pronounced column structure and is a ferritic-pearlitic mixture (Figure 1). Inside the columnar crystals, ferritic-pearlitic areas are observed, while at the periphery the ferritic component of different dispersion dominated. The use of nanoscale particles does not change the morphology of the structural components.
However, with the addition of nanoscale particles of tungsten carbide grain size decrease is observed: the average width of the primary crystals decreases by at least 2 times (Table 2). At the same time, the structure becomes more uniform (Figure 3), which should have a positive impact on the plastic characteristics. With the addition of titanium carbide, a decrease in the average width of the primary crystals is also observed, however, it does not exceed 30% (Table 2). Moreover, the addition of nanoscale particles of titanium carbide, making part of the alloying composition, leads to a variation of the widths of the primary crystals, which can adversely affect the stability of mechanical properties.
Analysis of the results obtained after tests for impact strength showed that the addition of a total of 1.10-1.56 wt% of nickel powder into the molten weld pool leads to a slight increase in the average impact strength of the weld metal: by 13 and 7%, respectively, compared to the base case (Figure 2, Table 2). At the same time, there is a decrease in the stability of its values. The insignificant effect of nickel on the impact strength of the weld metal is explained by the high manganese content in the weld metal, which is consistent with the paper [12].
Figure 1. Structure of the weld metal of welded joints obtained without the use of the alloying compositions (a, x50), as well as with the use of the alloying compositions (x100) L / Ni (b, c), L / Ni-WC (d, e) and L/Ni-TiC (f, g). b, d, f - $K_{kg} = 0.03$ vol%, b, d, f - $K_{kg} = 0.04$ vol%
Figure 2. Results of impact strength tests at a temperature of “minus” 20°C:
- minimum impact strength value, J/cm²;
- variation of impact strength values

The use of the alloying composition which included nanoscale particles of tungsten carbide leads to an increase in the average impact strength of the weld metal by 26% and 36% compared to the base case, and by 12% and 26% compared to the use of the nickel powder-based alloying composition, respectively (Figure 4, Table 2). It should be noted that with the addition of a smaller amount of the alloying composition with tungsten carbide, the spread of values decreases by 39% relative to the base case.

Thus, the addition of tungsten carbide through the alloying composition allows to modify the structure of the weld metal and increase the impact strength by 26-36% while reducing scatter values, which is explained by its influence on the structure.

The impact strength of the weld metal made using the L/Ni-WC alloying composition turned out to be lower (by 12 ... 13% depending on the amount of the additive added) average values of the base case (Figure 4). At the same time, there is an increase in the spread of the impact strength. Also, nanoscale particles of titanium carbide level the positive effects of nickel on the impact strength of the weld metal.

The research has shown that the addition of nanosized particles of titanium carbide into the weld pool together with the alloying composition is not promising.

The fractographic analysis of fractures included the analysis of the ratio of the fragile and viscous component (Table 2) according to GOST 30456 and GOST R ISO 148. Analysis of the results indicates an increase in the proportion of the viscous component when using the L/Ni-WC alloying composition. On the contrary, the use of the L/Ni-TiC alloying composition leads to an increase in the fraction of the brittle component in the fracture.

4. Conclusions

1. The prospects of modifying the weld metal of welded joints by nanoscale tungsten carbide particles are shown.
2. The addition of nanoscale particles of tungsten carbide, being the part of the alloying composition, in the weld pool melt leads to an increase in the impact strength values of the weld metal. At the same time, this indicator stabilizes, which is associated with a decrease in the width of the primary crystal of the weld metal and an increase in the uniformity of dimensions. Thus, adding 0.29 wt% and 0.34 wt% of particles to the weld pool melt leads to an increase in the average impact strength of the weld metal at a test temperature of minus 20°C by 26% and 36%, respectively.

3. The addition of titanium carbide as part of the alloying composition into the weld pool melt leads to a decrease in the average impact strength values of the weld metal: by 12% when adding 0.05 wt% of the compound and by 13% when adding 0.16 wt% thereof. However, an increase in the impact strength values is observed. At the same time, the addition of titanium carbide contributes to the modification of the structure of the weld metal: the average width of the primary crystals is reduced by at least 30%.

Acknowledgments
The paper has been prepared thank to the financial support of applied researches by the Ministry of Education and Science of the Russian Federation (Agreement No. 14.578.21.0216 on the provision of a grant dated September 28, 2016, the unique identifier PNER RFMEFI57816X0216).

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