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# INFLUENCE OF THE CONDITIONS OF WELD POOL PROTECTION BY ARGON ON THE PROPERTIES OF WELDS IN TIG WELDING OF TITANIUM

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A procedure was developed that allows an experimental determination of a correlation between an increased oxygen content in welding torch argon, intensity of radiation of OI atomic oxygen lines in the arc and the corresponding change in the properties of welds in real time at welding of titanium. It was found that an increase in oxygen content in argon to 0.34 vol.% at violation of the weld protection leads to an increase in the tensile strength of weld metal by 30 % and at the same time reduction in ductility by 65 %. The proposed procedure can be used to create a database at development of systems for predicting the operational reliability of welded structures from titanium alloys by quantitative indices of changes in the characteristics of the weld metal during welding. 9 Ref., 4 Tables, 8 Figures.

*K e y w o r d s : argon arc (TIG) welding, VT1-0 titanium alloy, violation of argon protection, gas impurities, prediction of weld properties*

Tungsten electrode arc welding in inert gas (usually argon) is one of the most widely accepted fusion welding methods, which is used in industry for fabrication of critical structures from titanium alloys. In order to ensure high-quality protection of the welded joint by inert gas that prevents weld metal contamination by harmful impurities (oxygen and nitrogen), higher grade argon containing not less that 99.993 vol.% of the main substance was used, alongside design features of welding torches and shielding devices [1]. Transition of oxygen, nitrogen and hydrogen from argon into the wed metal was studied in a number of works [2–4]. It is shown that relative increase of the content of oxygen and nitrogen in the weld metal mainly depends on partial pressure of these gases in argon and duration of its contact with the weld pool liquid metal and cooling welded joint. Thus, accidental violation of argon protection during welding, just as an insufficient purity of argon, cause an increase of the concentration of interstitial impurities in the weld metal that lowers the welded joint mechanical properties to varying degrees.

Known nondestructive testing methods do not allow establishing in real time even the very fact of gas impurity transition from the shielding environment (argon) into the weld metal and, even less so, predicting the extent of the change of its properties as a result of this transition. The proposed diagnostic methods allow just registering the deviations of welding process parameters from the nominal values and revealing possible defects in the welded joints after welding [5, 6]. Therefore, one of the important technological tasks is development of the method that allows not only revealing violation of argon protection of the weld pool during welding, but also establishing the extent of the influence of such a violation on the mechanical properties of the weld. Its solution can be the base for development of diagnostic systems, and prediction of operational reliability of titanium alloy welded structures.

The objective of the work consisted in development of the procedure of forming an experimental database of the dependencies of weld metal properties in welding VT1-0 titanium on concentration of harmful impurities (oxygen and nitrogen) in the arc gap.

**Materials and methods**. Alongside the air admixture in argon, an additional source of penetration of harmful impurities-gas into the weld metal can be contamination of the edges of plates being welded and filler wire. To avoid the influence of these sources, welding was performed with through penetration of the plates without filler wire application. Welding was performed on sheets of 3 mm titanium alloy of VT1-0 grade. Welding mode was as follows: $I_w$ = 160 A; $U_a$ = = 10.5 V; $v_w$ = 12 m/h, arc gap length of 1.5 mm, tungsten electrode diameter of 3 mm, electrode sharpening angle of 30° electrode grade was SVI-1. Six concentrations of air were added to argon [1], fed to the torch

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**Table 1.** Content of air (oxygen and nitrogen) in welding torch argon

| Batch No. | Air content, vol.% | Oxygen content, vol.% | Nitrogen content, vol.% |
|---|---|---|---|
| 1 | 0.25 | 0.05 | 0.20 |
| 2 | 0.40 | 0.08 | 0.32 |
| 3 | 0.66 | 0.14 | 0.52 |
| 4 | 1.00 | 0.21 | 0.78 |
| 5 | 1.08 | 0.23 | 0.84 |
| 6 | 1.58 | 0.33 | 1.23 |

**Table 2.** Mechanical properties of base metal of VT1-0 alloy and weld metal

| $\sigma_{0.2}$, MPa | $\sigma_t$, MPa | $\delta$, % | $\psi$, % | $H_\mu$, MPa |
|---|---|---|---|---|
| 379.0 / 390.5 | 453.0 / 430.0 | 36.0 / 33.0 | 58.0 / 64.0 | 1580 / 1585 |

*Note*. Average values of the results of testing five samples are given. The numerator shows weld metal value, the denominator is base metal value.

by the scheme given in Figure 1 (Table 1). Argon flow rate and air dosing were controlled by RS-3 and RS-3A rotameter, respectively. Argon flow rate in the torch was equal to 12 l/min, in the protective nozzle it was 27 l/min. Air content in the torch argon was varied in the range of 0.25–1.58 vol.%, here oxygen content changed in the ranges of 0.05–0.34 %. The criterion for assessment of the properties of the metal of welds, obtained at addition of dosed air concentrations to argon, was taken to be the value of the ratios of the characteristics of ultimate strength, relative elongation, reduction in area, metal hardness and gas content in these welds to the respective values for the metal of welds, produced in welding in argon without air addition. In keeping with the data of Table 2, the results of mechanical tests of welds produced in welding in argon without air addition show a certain correlation of their property values with the respective base metal property values. Practically all the values of the ratios of weld properties to the respective values for base metal are close to a unity (Table 3). The result of gas analysis of the metal of welds produced in welding in argon without air addition (Table 4) show that the content of oxygen, nitrogen and hydrogen in them remains practically on the level of their content in the base metal. Therefore, the obtained parameters of weld metal properties were taken as the base ones for comparison with the quality of metal of welds produced in welding with added concentrations of air to argon.

**Table 3.** Characteristics of mechanical properties of weld metal (conventional units)

| $\sigma_{0.2}$ | $\sigma_t$ | $d$ | $y$ | $H_\mu$ |
|---|---|---|---|---|
| 0.97 | 1.05 | 1.09 | 0.9 | 0.99 |

**Table 4.** Values from gas analysis of base metal of VT1-0 alloy and weld metal

| Gas content, wt.% | | |
|---|---|---|
| $O_2$ | $N_2$ | $H_2$ |
| 0.070 / 0.067 | 0.026 / 0.025 | 0.0027 / 0.0025 |

*Note*. Average values of the results of testing five samples are given. The numerator shows weld metal value, the denominator is base metal value.

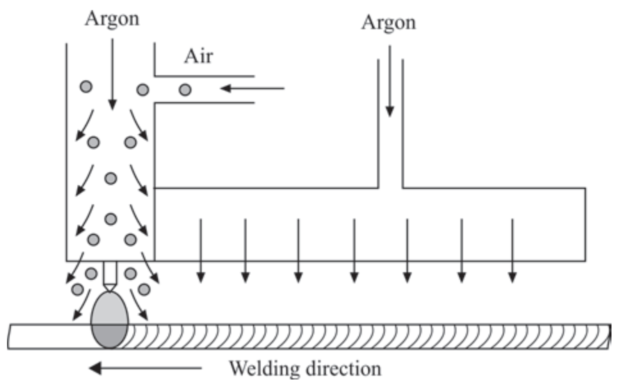


**Figure 1.** Schematic of air feeding into the torch

In order to select the spectral lines of nitrogen or oxygen, by which the radiation intensities should be registered, comparative analysis of the characteristics of NI and NII, OI and OII spectral lines in the visible range with the characteristics of ArI and ArII lines located nearby was performed. Analysis was performed by the spectral line tables [7], which showed that there are few intensive lines of nitrogen and oxygen in the visible spectrum range (400–700 nm). Comparison of the values of wave lines of radiation of nitrogen (NI, NII) and oxygen (OI, OII) atoms and ions with the values of wave lengths of argon (ArI, ArII) atoms and ions showed that these values are extremely close. Moreover, NI, NII and OI, OII radiation intensity is

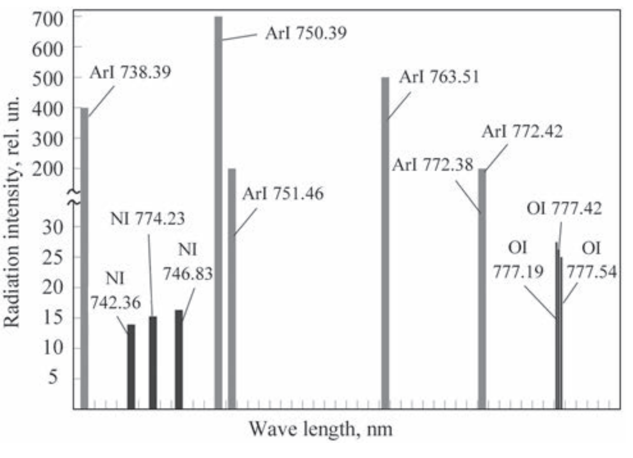


**Figure 2.** Scheme of near infrared region of the spectrum (700–800 nm)

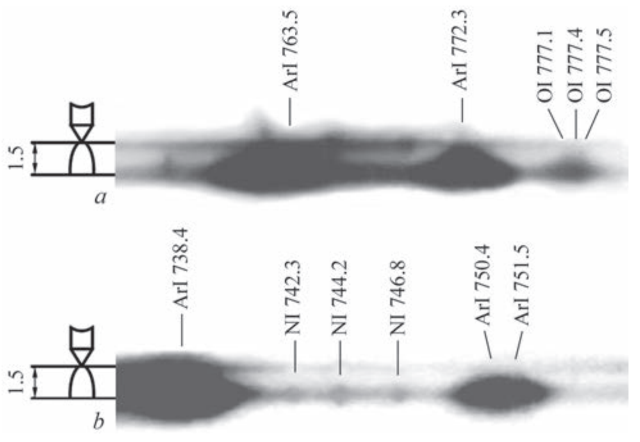


**Figure 3.** Longitudinal spectra of the arc (Ar + 0.25 vol.%): *a* — radiation spectrum of OI oxygen atoms; *b* — Radiation spectrum of NI nitrogen atoms

very low, compared to argon line intensity. Thus, application of nitrogen and oxygen lines for registration in this range against the background of strong radiation of argon ions is not rational. From the data of analysis of the spectrum of near-range infrared region (700–800 nm) one can see that it contains spectral lines of radiation of nitrogen (NI) and oxygen (OI) atoms with lower excitation energy than in the visible spectrum. Figure 2 illustrates that a sufficiently great difference between the wave lengths of radiation of nitrogen and oxygen atoms and closest lines of argon atoms can reduce the influence of argon atom radiation on nitrogen and oxygen atom radiation. Therefore, the intensity of their glow in the studied spectra can be much higher, than in the visible spectrum. For greater decrease of the influence of radiation of ArI argon atoms and outlining the spectral region, in which NI nitrogen and OI oxygen atoms radiate, it is desirable to use narrowband filters.

The change of radiation intensity of oxygen and nitrogen atomic lines in the arc gap, depending on air concentration in argon of the welding torch was registered with STE-1 spectrograph, which can register the spectral lines in the range of 220–900 nm. The spectral lines were registered on photographic plates of Infra-780 type. Then average values of intensity were calculated for each experiment. Thus, values of radiation intensity of atomic lines of oxygen OI and nitrogen NI in the arc gap were obtained at addition of six air concentrations to argon of the welding torch. It allowed establishing such correlation dependencies: change of oxygen and nitrogen concentration in argon of the welding torch – radiation intensity of OI and NI atomic lines in the arc; change of radiation intensity of OI atomic lines in the arc – weld metal properties.

**Experimental results.** The method of photographing the spectrum with the removed spectrograph slot was used to check the assumption about the radiation intensity of NI nitrogen lines and three OI lines that merged into one [8]. This method enables observing the full monochromatic image of the arc in the glow of the corresponding wave length. The thus obtained through narrowband filters images of the spectrograms at addition of minimum air concentration (0.25 vol.%) to the torch argon are presented in Figure 3. The density of spectrogram images allows assessment of radiation intensity of the singled out lines of NI nitrogen and OI oxygen atoms over the entire volume of the arc gap. As one can see, the density of the image of each nitrogen line (Figure 3, *a*) is much weaker, than the total image density of oxygen lines, visible as one line (Figure 3, *b*). To obtain additional information on the distributions of radiation intensity of nitrogen and oxygen atomic lines along the arc

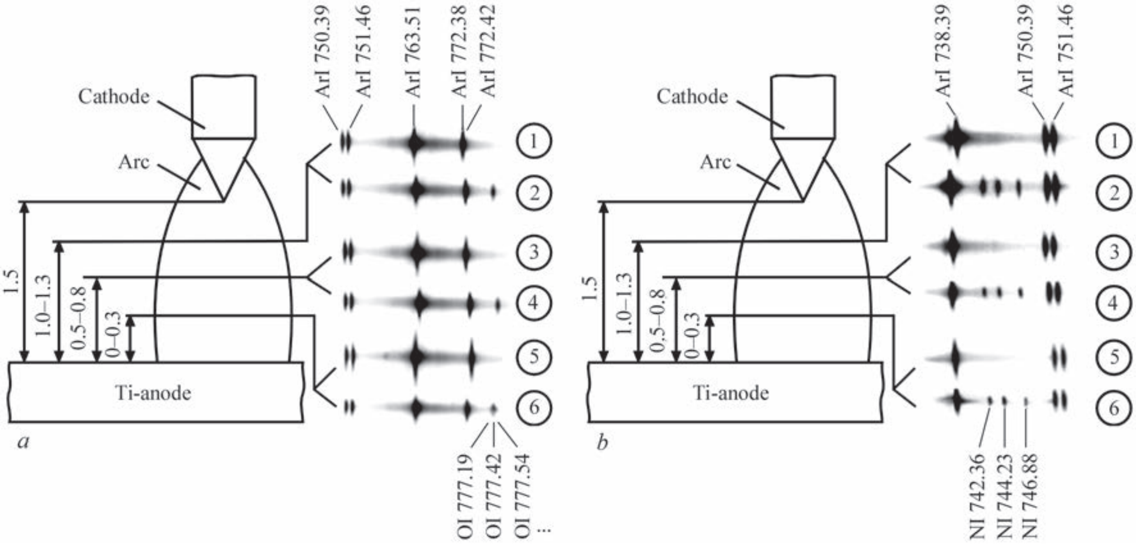


**Figure 4.** Transverse spectra of the arc: *a* — radiation spectrum of OI oxygen atoms; *b* — radiation spectrum of NI nitrogen atoms (1, 3, 5 — Ar 100 %; 2, 4, 6 — Ar + (0.25 vol.% air)

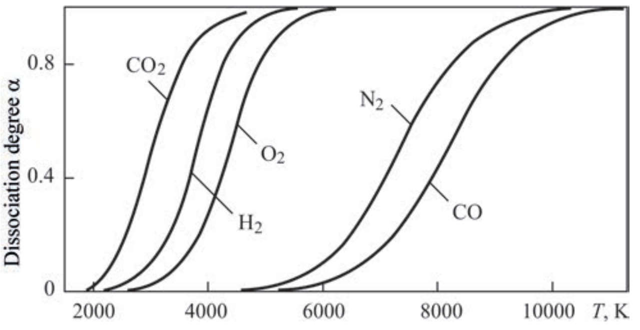


**Figure 5.** Degree of dissociation *a* of diatomic gases, depending on temperature at pressure $p$ = 760 mm Hg

gap length, transverse spectra of the arc were studied, which were photographed at different distances from the anode (Figure 4). The presented data show that the radiation intensity of nitrogen atoms in the direction from the cathode to the anode decreases, whereas the radiation intensity of oxygen atoms is quite evenly distributed over the entire arc gap. Thus, a conclusion was made that a stronger radiation signal can be obtained at registration of the total intensity of radiation spectrum of OI oxygen atoms in the arc and application of quantitative characteristic of the condition of argon protection of the weld pool as the main one.

It should be noted that the weak intensity of nitrogen atom radiation is related, most probably, to a relatively low temperature of plasma near the anode and, thus, insufficient condition for nitrogen molecule dissociation (Figure 5) [9]. Experiments show that at increase of oxygen content in argon of the welding torch in the range of 0.05–0.34 vol.% the intensity of glowing of oxygen lines grows linearly (Figure 6). A certain data scatter observed in the graph is attributable to an uncontrolled phenomenon of air admixture fluctuation and its flow rate at the outlet from the torch nozzle. Here, a certain part of oxygen molecules can penetrate into the low-temperature regions of the arc, where the degree of their dissociation becomes lower. That is why the total intensity of glowing of OI oxygen lines also decreases. After passing through the high-temperature zone of the arc, the flow of argon and air mixture descends to the weld pool, where the impurities (oxygen and nitrogen) are absorbed by the molten metal. This is confirmed by the results of gas analysis of the weld metal (Figure 7). As one can see from the above data, nitrogen and oxygen content in

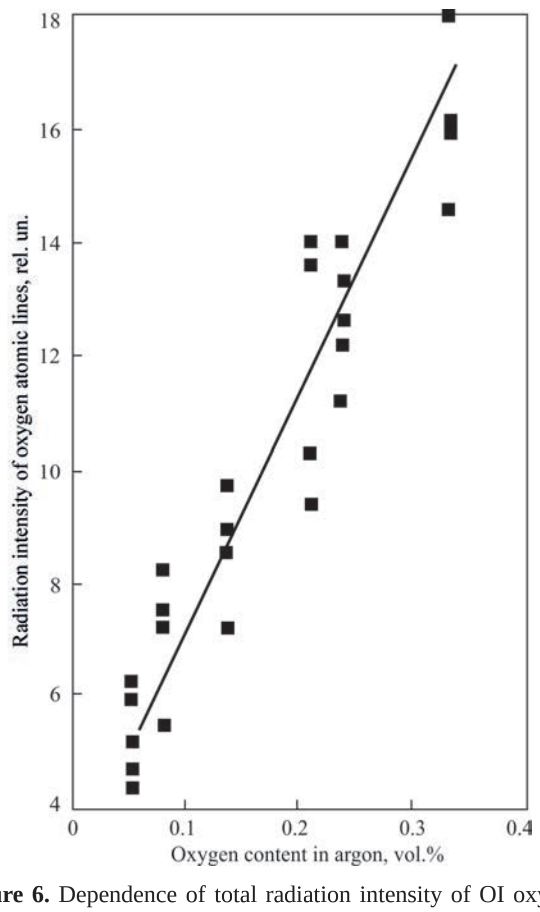


**Figure 6.** Dependence of total radiation intensity of OI oxygen atomic lines 777.19, 777.42, 777.54 nm in the arc on its content in welding torch argon

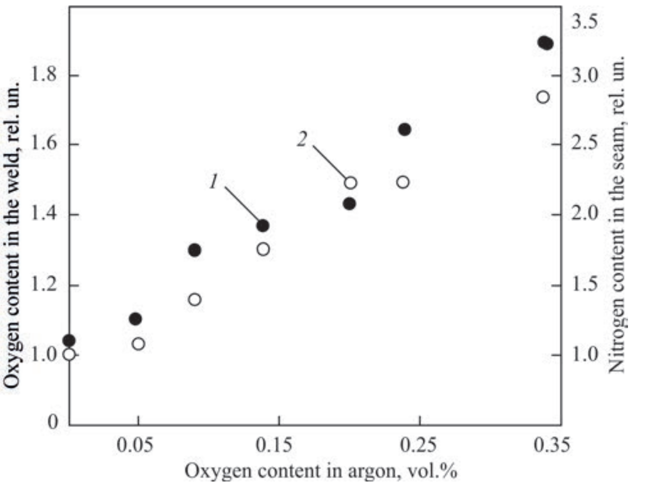


**Figure 7.** Dependence of relative content of oxygen (*1*) and nitrogen (*2*) in weld metal on oxygen content in welding torch argon

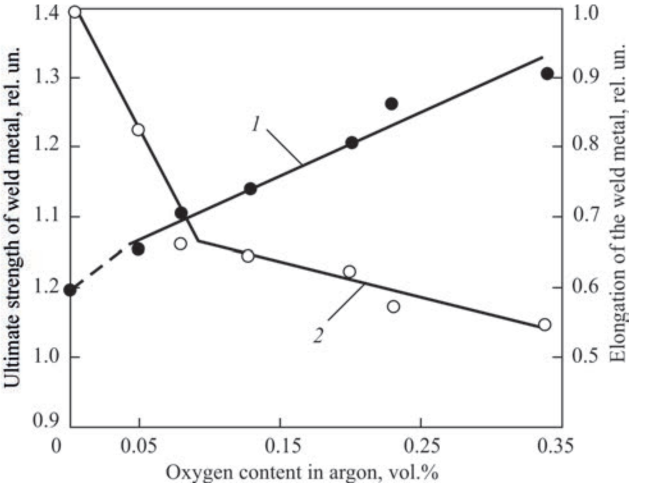


**Figure 8.** Relative change of ultimate strength (*1*) and elongation (*2*) of weld metal, depending on oxygen content in welding torch argon

the metal of welds increases in proportion to increase of oxygen content in argon.

Figure 8 gives the dependencies of the change of relative values of ultimate strength and elongation of weld metal on oxygen content in argon of the welding torch. As one can see, increase of oxygen in the arc gap up to 0.34 vol.% (and of nitrogen, respectively) leads to increase of ultimate strength of the welds by 30 %, while relative elongation decreases by 65 %. These results agree quite well with the data of work [2].

Obtained data lead to the conclusion that a direct correlation was experimentally established between the change of radiation intensity of OI oxygen atomic lines in the arc and change of weld metal properties. The proposed procedure can be used at development of systems of diagnostics of welded joint quality with prediction of quantitative characteristics of weld metal during welding.

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