ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 11, Issue 2, February 2024

Grade of the Resistance of Weld Metal Against Brittle Failure During Arc Flux Welding

N.Z. Khudaykulov, M.M.Abralov

Associate Professor, Department of Technological machines and equipment, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan
Associate Professor, Doctor of Philosophy in Technical Sciences (PhD), Department of Technological machines and equipment, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan

ABSTRACT: During automatic submerged arc welding, an intense silicon reduction process begins to take place in the weld pool, and the oxygen content in the weld metal is even higher than when welding with wire with a silicon content of 0.2% - 0.3%. Even a slight reduction of silicon from the flux (0.25% - 0.35%) leads to a significant decrease in the resistance of the weld to brittle fracture. This work proposes an assessment of the susceptibility of a material to brittle fracture based on the value of the critical crack opening δ_c.

KEY WORDS: silicon reduction process, resistance to brittle fracture, submerged arc welding, oxide inclusions

I. INTRODUCTION

The influence of non-metallic oxide inclusions on the ductility and toughness of the weld metal is recognized by all researchers, but the main role is played not by the oxide inclusions themselves, but by the amount of reduced silicon and manganese obtained as a result of the corresponding redox processes. That is why, when striving for a minimum silicon content in the weld metal to increase its resistance to brittle fracture, the use of Св-08ГС and Св-12ГС wires is limited. Moreover, quite often silicon - free wires are used for automatic submerged arc welding. As a result of this process, an intense silicon reduction process begins to occur in the weld pool, and the oxygen content in the weld metal turns out to be even higher than when welding with wire with a silicon content of 0.2% - 0.3%.

II. LITERATURE SURVEY

Even a slight reduction of silicon from the flux (0.25 - 0.35%) leads to a significant decrease in the resistance of the weld to brittle fracture [2, 3, 4]. At the same time, alloying the weld with silicon through the welding wire up to 0.5% has virtually no effect on the ductility and toughness of ferrite [1]. Based on the above, the task was set to differentially assess the influence of silicon and oxygen in the form of non-metallic inclusions in the weld metal on its susceptibility to brittle fracture. The choice of the silicon reduction process was due to the fact that an increase of 0.1% Si in a weld produces approximately 2.5 times more oxygen than an increase of 0.1% Mn .

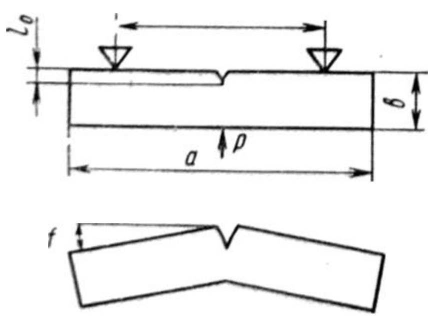

Fig. 1. Scheme of testing samples for critical crack opening

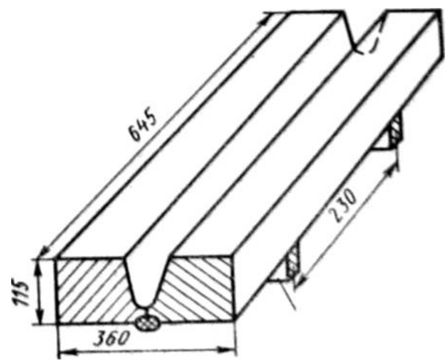

Fig. 2. Type and dimensions of experimental plates for multi-pass automatic welding

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 11, Issue 2, February 2024

The susceptibility of materials to brittle fracture is assessed by determining the stress intensity factor K_c on the contour of the crack. However, such tests are very labor-intensive, since the methodology for conducting them involves the use of large-sized samples [5]. At the same time, this work proposes an assessment of the susceptibility of a material to brittle fracture based on the value of the critical crack opening δ_c. It is proposed to use the possibility of determining it on small cross-section samples using the empirical formula

$$\delta_c = \frac{0,4 f_{pl}\ (b - l_0)}{\frac{L}{2}}$$

here f_{pl} - plastic component of the sample deflection at the moment of crack development ; b - is the height of the cross-section of the sample; l_0 - initial length of the crack; L is the distance between the supports for three-point concentrated bending of the sample.

III. METHODOLOGY

In accordance with the recommendations [5] for research, samples with a cross section of 12 mm^2 at L = 20 mm, l_0 = 2.4 mm were used in the work. An initial fatigue crack of the specified length was applied using a resonant vibrator. The test diagram to determine the susceptibility of the weld metal to brittle fracture is shown in Fig. 1.

Welding of samples (Fig. 2) was carried out with wire Св –10ХГНМА composition: 0.1% C; 0.16% Si; 0.98% Mn; 1.75% Cr; 1.35% Ni; 0.68% Mo; 0.006% S and 0.01% P. After welding, the metal was subjected to double tempering at temperatures of 620 and 620°C and a holding time of 5 and 10 hours, respectively.
For welding multilayer seams, two series of fluxes were used: the first - seven fused fluxes with varying silica concentration, which made it possible to change the silicon content in the seams from 0.2% to 1.0% and, accordingly, oxygen from 0.015 % to 0.08%, and the second - five ceramic fluxes with different ferrosilicon content.

The slag system was used as the basis for ceramic fluxes: CaF_2 - Al_2O_3 - MgO (55%, 40%, 5%, respectively). All components of ceramic fluxes are taken in the form of pure chemical compounds. The introduction of ferrosilicon additives was carried out by reducing the amount of CaF_2. To minimize all redox processes in the melting zone, sodium aluminate was used as a binder for ceramic fluxes in an amount of 40% by weight of the dry charge. The use of this series of fluxes made it possible to obtain a similar increase in silicon in the deposited metal at a constant oxygen content of 0.025% - 0.035%.

The results of analyzes of the chemical composition, gas concentrations and δ_c values in the deposited metal during submerged arc welding with different chemical reactivity are given in Table. 1.

Table 1.

flux	Chemical composition of weld metal, %						Δ, [Si], %	Content gas,%		δ_c , at	
	C	Si	Mn	Cr	Ni	Mo		[O]	[N]	20°C	350°C
fused	0.071	0.2	0.78	1.68	1.28	0.57	0.04	0.015	0.019	0.432	0.386
	0.069	0.28	0.87	1.72	1.30	0.59	0.12	0.02	0.016	0.495	0.465
	0.065	0.38	0.90	1.7	1.35	0.56	0.22	0.032	0.017	0.784	0.581
	0.067	0.5	0.98	1.67	1.32	0.59	0.34	0.049	0.014	0.712	0.495
	0.063	0.61	0.96	1.64	1.28	0.59	0.45	0.058	0.016	0.562	0.348
	0.072	0.85	0.09	1.59	1.29	0.60	0.69	0.072	0.016	0.282	0.215
	0.068	0.96	0.76	1.58	1.28	0.57	0.80	0.08	0.018	0.185	0.139
ceramic	0.073	0.2	0.75	1.7	1.48	0.57	0.04	0.035	0.018	0.827	0.641
	0.076	0.35	0.68	1.68	1.48	0.54	0.19	0.032	0.021	0.81	0.605
	0.075	0.45	0.75	1.75	1.55	0.58	0.29	0.03	0.02	0.805	0.593
	0.079	0.73	0.76	1.7	1.5	0.56	0.57	0.028	0.019	0.695	0.585
	0.077	0.97	0.82	1.62	1.3	0.54	0.81	0.024	0.017	0.534	0.310

The dependence of the critical crack opening δc on the silicon content in the deposited metal is shown in Fig. 3.
As can be seen from the data obtained, an increase in the silicon content in the weld metal during submerged arc welding with increasing chemical activity of silica (curves 1, Fig. 3) leads to a large decrease in the value of the critical crack

opening than in the second case. This is due to the fact that the silicon reduction process in the case under consideration was accompanied by an increase in the total oxygen concentration , while in the second case a relatively constant oxygen concentration was ensured. The difference between the ordinate values of dependences *1* and *2* (see Fig. 3) at the same Si content can be conditionally attributed to the negative influence of non-metallic inclusions (Fig.4).

At the same time, the analysis of the presented data indicates that when welding under relatively passive fluxes (see Table 1), when a minimum oxygen content is observed in the weld metal and, accordingly, the reduction of silicon from the flux-slag, a decrease in the value of δ_c is observed (see Fig. 3). It is not possible to explain this by the minimum silicon content in the weld, because a similar concentration when welding under ceramic fluxes does not lead to this phenomenon. Therefore, it remains to be assumed that the decrease in the value of δ_c is associated with a relatively low amount of oxygen in the weld metal - 0.02%.

Indeed, the effect of oxygen on impact strength is interrelated with the effect of other impurities [3, 6, 7]. A number of studies have established that as the oxygen content in the weld metal decreases, its impact strength increases. At the same time, it is known that reducing the amount of impurities delays the transformation, thereby promoting the formation of low temperature nonequilibrium structures [6]. Analysis of the microstructures of the metal of multilayer welds of almost identical composition, but with different oxygen contents shows that the ferrite matrix at an oxygen concentration of 0.02% has a needle-like structure. An increase in the amount of oxygen in the weld metal promotes the formation of more equilibrium structures (Fig. 5).

In a number of works [3, 6, 7], an increase in the susceptibility of weld metal to brittle fracture with a decrease in oxygen concentration is associated with the nature and shape of the resulting sulfur inclusions and low-melting eutectics, consisting of sulfides and oxysulfides. For example, the presence of suspended particles of oxides and carbides in the weld pool metal promotes earlier release of sulfur from the melt with the formation of complex oxy or carbosulfide inclusions [3, 6, 7]. In their absence, the release of sulfur from the melt occurs at a later stage of crystallization, when, as a result of the segregation of sulfur, a supersaturation of the mother liquid with it is created. In this case, films or chains of ferromanganese sulfides are formed. In this case, not only the total oxygen content is important, but also the amount of iron - manganese oxides, in which sulfur is most soluble [7].

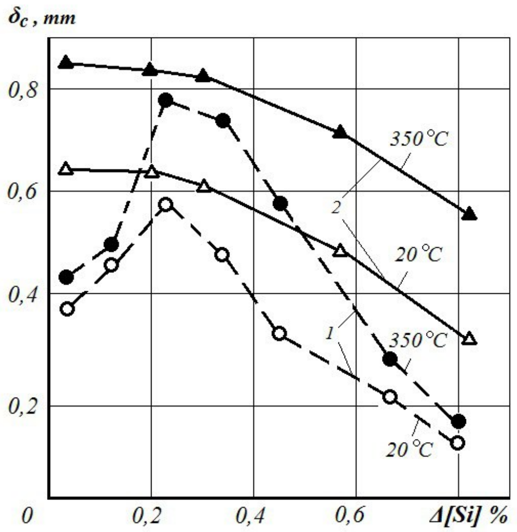

Fig. 3. Critical crack opening δ_c depending on the - silicon content in the weld metal: 1 - when welding under fused flux; *2* - when welding under ceramic flux.

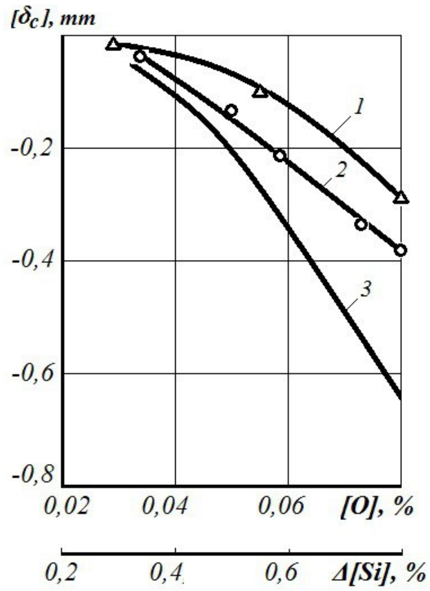

Fig. 4. Scheme of the differentiated influence of silicon and oxygen concentrations on reducing the critical crack opening of the weld metal when welding 15X2HMΦA steel: 1 – $\Delta\ \delta_c = f\ (\Delta\ [Si])$; 2 - $\Delta\ \delta_c = f\ [O]$; 3 - $\Sigma\delta_s = f\ ([O],\ \Delta\ [Si])$.

In our opinion, it is difficult to give preference to any one of these hypotheses. Everything depends on the specific welding

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 11, Issue 2, February 2024

conditions, the composition and purity of the welding materials, the alloying system of the weld metal, etc. The listed specific conditions will determine the specific weight of each factor in the mechanism of embrittlement of the weld metal at low concentrations of oxide inclusions in it.

An excessive increase in the purity of weld metal due to non-metallic inclusions when welding low-alloy steels may not only not recoup the associated costs, but also cause additional difficulties. The studies carried out during this work made it possible to establish the permissible limits for the oxygen content in the weld metal - 0.02 % - 0.035%, which in terms of non-metallic inclusions is approximately 0.045% - 0.065%.

IV. EXPERIMENTAL RESULTS

The conclusions obtained in the work about the more noticeable negative effect of oxide inclusions on the weld metal can be illustrated by the example of multilayer welding of 22K steel using two metallurgical options: Св-08ГА wire in combination with high-manganese flux - silicate АН-348А and Св-08ГС wire in combination with low-active flux ФЦ-16 (Table 2). A slightly lower concentration of silicon in the weld metal made under the АН-348А flux (Table 3) would seem to contribute to the fact that in this case the ductility and impact strength will be higher. But the data presented show the opposite, and the reason for this is the increased content of oxygen, formed in the first case as a result of the intensive occurrence of the silicon and manganese reduction process (see Table 3).

Table 2.

Brand of wire and flux	Mechanical properties of weld metal					
	Tensile strength, kg/mm^2	Yield strength, kg/mm^2	Relative narrowing, %	Relative extension, %	Impact strength, $kg*m/cm^2$, at temperature, °C	
					+20	-20
Flux ФЦ-16, wire Св-08ГС	48.9	31.0	73.0	37.6	11.3	5.8
Flux АН-348А, wire Св-08ГА	45.4	30.5	66.5	27.2	6.5	2.2

The following welding mode was used: welding current 400 A, arc voltage 28-30 V, welding speed 26 m/h

Table 3.

Brand of wire and flux	Chemical composition, %					Oxygen content in the weld metal, %
	C	Si	Mn	S	P	
Flux ФЦ-16, wire Св-08ГС	0.07	0.75	1.51	0.023	0.022	0.032
Flux АН-348А, wire Св-08ГА	0.10	0.58	1.62	0.028	0.028	0.122

V. CONCLUSION

A differentiated assessment of the consequences of the silicon reduction process when welding pearlite-ferritic steels was carried out, which showed that the resistance of the weld metal against brittle fracture depends to a much greater extent on the total oxygen content than on the increase in silicon in the weld.
The permissible limits for the total oxygen content in the weld metal during submerged arc welding of low- alloy steels have been established - 0.02% - 0.035%. Welds with a high oxygen content , just like those with a lower content, have worse resistance to brittle fracture.

It has been established that the use of high-silicon wire Св-08ГС for automatic submerged arc welding provides a fairly high level of ductility and impact toughness of the weld metal with a relatively low content of oxide inclusions in it.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 11, Issue 2, February 2024

ACKNOWLEDGMENT

This work was carried out within the framework of a business agreement with the Tashkent Pipe Plant named after V.L. Galperin No. 1/2022 on the topic: "Research and development of the composition of ceramic fluxes for automatic arc welding of low-carbon and low-alloy steels".

REFERENCES

[1]. Wegman E. F., Bocharov L. N., Matyukhin B. P. Machines and instruments for testing materials – Moscow, Metallurgy, 1971. - 120 p
[2] Yu. N. Rabotnikov. New methods for assessing the resistance of metals to brittle fracture - Moscow, Mir, 1972. - 120 p.
[3]Podgaetsky V.V. On the shape of sulfide inclusions in welds.// Welding production. 1970, № 12.
[4]. Method for quantitative assessment of the resistance of flux granules anti-abrasion// First International Conference on the problem "Welding" - 1984. – Issue 25. pp. 76–77.
[5]. Ito Uoshinory, Naceishi Mutsuo. Study on charpy impect proporties of metal weld with submerged arc welding. — Sumitomo Search, 1976, № 15
[6]. Nurilla K., Muzaffar A. On the question of use of agglomered welding flux in the formation of weld metal during arc welding of low-alloyed high-strength steels //Universum: технические науки. – 2023. – №. 3-4 (108). – pp. 47-50.
[7]. Khudaykulov N.Z. Development of composition and production technology alloying ceramic flux// II-International Scientific and Scientific-Technical Conference on Innovative techniques and technologies agriculture ─ in the food network problems and prospects. April 2022. pp. 140-142.

AUTHOR'S BIOGRAPHY

	**Khudaykulov Nurulla Zikirillayevich**. Associate Professor, was born June 3, 1972 year in Tashkent city, Republic of Uzbekistan. Has more than 35 published scientific works in the form of articles, journals, theses and tutorials. Currently works at the department of "Technological machines and equipment" in Tashkent State Technical University.
	**Abralov Muzaffar Makhmudovich**, Associate Professor, Doctor of Philosophy in Technical Sciences (PhD), was born March 4, 1978 year in Tashkent city, Republic of Uzbekistan. Has more than 50 published scientific works in the form of articles, journals, theses and tutorials. Currently works at the department of "Technological machines and equipment" in Tashkent State Technical University.