Algorithm of realization of the problem of double-arc welding with coated electrodes of different types

S.N. Pivnev[1], D.P. Sidorov [1], S.V. Pivneva[2]

[1]Togliatti State University, Belorusskia st. 14, Togliatty, Russia, 445020
[2]Russian State Social University, Wilhelm Pieck str. 4, Moscow, Russia, 129226

Abstract. In the article the algorithm of realization of a problem of two-arc welding by the covered electrodes of different types is considered. When burning two welding arcs from electrodes of different composition into one welding bath, we change the chemical composition of the deposited metal. Thus, without creating new electrodes, we obtain the required chemical composition of the weld metal and weld. The study of the possibility of obtaining samples for the analysis of the chemical composition of the deposited metal, an arc of indirect action. This method can reduce the cost of welding materials in the process of obtaining samples, as well as reduce the complexity and energy intensity of the work.

1. Introduction

At the moment in Russia, the largest volume of welding operations is necessary in manual arc welding with covered electrode (GSPE). In the most developed industrial countries, the share of manual welding is much lower, but also quite high.

The disadvantages of RDSPE include low productivity, low stability of the quality of welded joints, high requirements for the qualification of personnel, but it also has a number of advantages over other methods of arc welding. These include [1]:

1. Possibility of welding in all spatial positions.
2. Possibility of welding in hard-to-reach places.
3. Relative cheapness of the equipment.
4. Low costs for welding of short seams and small series of welded units and structures.
5. In most cases, high quality of the deposited metal is ensured.

Due to the demand for manual arc welding with coated electrodes in Russia, special attention should be paid to their verification for compliance of its properties with the requirements of GOST 9466-75 «Metal coated Electrodes for manual arc welding of steels and surfacing. Classification and General specifications» [2], as well as GOST 9467-75, GOST 10051-75 and GOST 10052-75 for electrodes for different purposes [3 - 5].

The relevance of the work lies in the fact that in our country the main method of welding is manual arc welding with a covered electrode. In the market of welding materials a large number of manufacturers and suppliers of welding consumables, including imported, but the quality of products does not always meet the standards. Therefore it is necessary to carry out control of welding electrodes before the beginning of works.

Of great importance is the control of the chemical composition of the deposited metal coated with electrodes. The chemical composition of the weld is usually different from the composition of the base

metal and the weld metal. But the quality of the weld is largely determined by the chemical composition of the deposited metal. The composition of the base metal, we can not affect, as it relates to the original data. The weld is obtained as a mixture of the base metal with the weld.
The exact chemical composition of the weld metal must be known for the following reasons:

1. To determine whether the actual composition of the deposited metal meets the requirements of the technical conditions for the electrodes.
2. To calculate the chemical composition of the weld resulting from mixing in the design of welding technology.
3. In the preparation of manufacturers of certificates for electrodes, which include data on the chemical composition of the deposited metal.

Known standard methods for obtaining samples of the deposited metal [6] require its high cost, time-consuming and energy-consuming. They were developed a long time ago, when mainly chemical composition determination using chemical analysis was used, and spectral analysis equipment was available only to large enterprises. Currently, the equipment for determining the chemical composition by spectral analysis has become much cheaper and more affordable, it can have both small enterprises and installation organizations. Samples for spectral analysis may be small in size. The main task of obtaining samples is to ensure identical conditions with welding conditions, the absence of mixing of the weld metal with other materials and the similar behavior of the protective atmosphere of the arc. It seems that this can be achieved by welding with an arc not direct, but indirect action.
The purpose of this work is to study the possibility of obtaining samples for the analysis of the chemical composition of the deposited metal, an arc of indirect action. This method can reduce the cost of welding materials in the process of obtaining samples, as well as reduce the complexity and energy intensity of the work.

2. Method of analysis of chemical composition of samples

In the course of the research 2 methods for determining the chemical composition of samples were used:

- Atomic-emission spectral analysis
- X-ray fluorescence spectral analysis

These methods make it possible to determine the content of chemical elements in a wide range.
The principle of atomic emission spectral analysis is based on the measurement of radiation intensity at a certain wavelength of the emission spectrum of atoms of the analyzed elements. The radiation is excited by a spark discharge between the auxiliary electrode and the analyzed metal sample. During the analysis, argon flows around the object, making it more visible for study. Emission spectrometer records the intensity of the radiation and on the basis of received data analyzes the composition of the metal. The content of elements in the sample is determined by the calibration dependences between the intensity of emission radiation and the content of the element in the sample [7].
The principal difference between x-ray fluorescence spectral analysis is that it uses x-rays to excite the spectrum. During irradiation, the atoms in the sample emit fluorescent radiation. In each element, atoms have their own characteristic radiation, which is strictly determined by the wavelength and energy.
The main advantages of these methods are:

- Wide range of chemical elements to be determined
- Short-term analysis
- Conduct both basic quantitative analysis
- Obtaining results in digital form

A number of these advantages indicate the prospects of these methods in determining the chemical composition of the metal.

3. Description of the context of the studies

A number of methods of indirect arc welding were considered. One of them is surfacing in graphite masonry.

Under the graphite block is meant contact insert (Figure 1) for sliding current collector and intended for urban electric transport. The product is made in the form of a plate length 87 mm thick 28 mm, with the working part in the form of a chute corresponding to the form of a contact wire with symmetrical bells at the ends. At 70-80% of the total mass, the insert consists of an electrode graphite, it also includes phenol-formaldehyde resin, urotropin. A metal powder with a particle size of not more than 150 mkm can be added to the composition [8].

Figure 1. Graphite contact insert.

For the experiment the paste was vysvetlilas hole size 25x10x8 mm to give the resulting alloy teardrop shape. Electrodes of CRATON J422 grade with a diameter of 2.5 mm were used, which according to the chemical composition (Table 1) the deposited metal is close to UONI – 13/45 and Mr-3. The power source was the welding inverter Blueweld Starmig 200. The polarity of the arc is straight-recommended specifications for the electrodes. In this case, the block served as the anode of the arc and the maximum power is allocated on it, as on a non-consumable electrode.

Table 1. Chemical composition of the deposited metal, declared by the manufacturer.

Element	C	Mn	Si	S	P
Material, %	No more than 0,12	0,3-0,6	No more than 0,25	No more than 0,035	No more than 0,04

The study used three welding currents: 100A, 80A and 60A. During the experiment, about 6 samples were obtained at the cost of one electrode per 3 samples. Further one test (Figure 2) was sent for spectral analysis. The size of the smallest sample in diameter was 9.1 mm, the largest 15.6 mm.
Spectral analysis was carried out on the basis of Togliatti State University on optical emission spectrometer Q4 TASMAN [9].The results of determining the chemical composition are shown in the Table 2. The sample after atomic emission spectral analysis is shown in Figure 3.

Table 2. Chemical composition of the deposited metal obtained during spectral analysis.

Element	C	Mn	Si	S	P
Material, %	0,235	0,085	0,037	0,0071	0,02

Figure 2. Fused samples.

As a result of the analysis, it was found that only for harmful impurities sulfur and phosphorus, the data obtained meet the requirements for the deposited metal. Apparently, in the process of surfacing there is a chemical interaction of carbon pads with air and other elements.

Also, during the study of the method of indirect arc welding, the method of melting the electrode onto an aluminum plate was considered (Figure 4) as a welding material, the electrodes of the TSL 11 brand with a diameter of 2.5 mm were used, which are used for welding corrosion-resistant and chromium-Nickel steels. As a power source for welding was used welding rectifier VDM-1202S. The chemical composition of the deposited metal declared by the manufacturer is presented in the table 3.

Figure 3. Sample after atomic-emission spectral analysis.

Table 3. Chemical composition of the deposited metal, declared by the manufacturer.

Element	C	Mn	Si	Ni	Cr	Nb	P	S
Material no more than,%	0,10	1,8	0,53	9,8	20,8	0,99	0,02	0,011

The essence of this method is obtaining a sample due to spattering of the electrode metal on an aluminum circle with a diameter of 750 mm. To improve the spray current was increased about 2 times compared to the recommendations of the manufacturer and was equal to 107 A.

Later in the study it was found that the determination of the chemical composition of the sample using an optical emission spectrometer is impossible because of the small sample size.

A portable x-ray fluorescence analyzer X-MET 5000 was used for the analysis [10]. The results of the chemical composition determination are given in the summary table 4.

Table 4. The chemical composition of the sample obtained during the melting of the electrode metal.

Element	C	Mn	Si	Ni	Cr	Nb	P	S
Material,%	-----	1,3	0,93	7,9	22,0	1,0	0,01	-----
On standard no more than,%	0,10	1,8	0,53	9,8	20,8	0,99	0,02	0,011

This method can be considered promising, since 3 of the 8 elements are within the range of permissible content and one element exceeds this range by only 0.01%, but it is technically impossible to determine the chemical composition by another method because of the small size of the samples.

The result of the study of samples from the melting of the electrode by an arc of indirect action on the aluminum circle can not be considered sufficient. In the future, it is proposed to replace aluminum with copper and conduct the process of melting the electrode in the form of surfacing.

A copper plate with a thickness of 20 mm and a length of 110 mm was selected.as welding materials, coated electrodes of the tml-1U brand with a diameter of 3 mm were taken. These electrodes are intended for welding of alloyed heat-resistant steels. The chemical composition of the deposited metal declared by the manufacturer is shown in table 5. According to the passport, the electrodes were pierced at a temperature of 370°.

Table 5. Chemical composition of the deposited metal, declared by the manufacturer.

Element	C	Mn	Si	Cr	Mo	S	P
Material,%	0,06-0,12	0,5-0,9	0,15-0,40	0,8-1,2	0,4-0,7	no more than 0,025	0,020
Average value	0,08	0,7	0,275	1,0	0,55		

Welding was performed using welding inverter FORSAZH – 315 AD. An additional electrode holder was used for indirect arc surfacing. For surfacing taken two calcined electrodes and to facilitate the ignition of the arc end of the electrode is trimmed from the cover by 1-2 mm. power of the arc current I = 100 A. due to the lack of possibility of welding with alternating current, it was carried out at a constant current. When using an indirect arc, connecting the electrodes to (-) or (+) affects the melting rate of the electrodes. So the electrode to which the connected plus source melted faster than the second electrode. During the measurements after surfacing, the length of the lights was 110 mm when connected to the plus and 130 mm when connected to the minus. In the course of the welding was obtained, the sample (Figure 4). The length of the sample is 31 mm and the width is about 12 mm.

Figure 4. The deposited sample.

The quality of surfacing in this way directly depends on the qualification of the welder, since the electrodes should be melted with a short arc, with a slight extension of the arc it goes out. Re-ignition of the arc is difficult because of the melting of the ends of the electrodes.
The resulting sample was sanded to a metallic luster. In some cases, samples of small sizes it is more expedient to flatten with the help of press machines.
The result of x-ray fluorescence analysis is shown in Table 6.

Table 6. Chemical composition of metal deposited by indirect arc.

Element	C	Mn	Si	Cr	Mo	S	P	Ca	Cu	Ni	Fe
Material, %	------	0,708	------	1,101	0,445	0,036	-----	0,534	0,324	0,082	96,77
Average value On standard	0,08	0,7	0,275	1,0	0,55	0,025	-----	------	------	--------	--------

It is impossible to determine C,P,Si in small quantities on the EDX-8000 x-ray fluorescence spectrometer without additional equipment [11].

4. Comparative analysis

By comparing the tables (table 6) and (table 7) it can be seen that the analysis recorded a number of elements that are not declared by the manufacturer. I was able to get into the weld from the copper plate. The remaining elements could have been melted due to poor atmospheric protection, a poorly cleaned copper plate, or during sample preparation for analysis.
Unfortunately, at the investigated electrodes had no certificate on the part from the manufacturer. Nevertheless, table 7 shows that the values obtained for the three elements are close to the average

values set by the standard. This evidence in favor of the fact that the method of collecting samples welding arc indirect actions is very promising.

Also, according to GOST 9466-75 were produced 3 surfacing: one, two and five layers. The results of x-ray fluorescence analysis of the deposited metal are shown in Table 8.

Table 8. The chemical composition of the weld.

Element	Surfacing in 1 layer, %	Surfacing in 2 layer, %	Surfacing in 5 layer, %
Fe	96,909	97,108	97,088
Cr	0.836	0.985	1.030
	0,8- 1,0		
	+17,8 %		+4,6%
Mn	0.642	0.755	0.792
	0,5-0,7		
	+17,6%		+4,9%
Ca	0.656	0.316	0.394
	-51,8%		+19,8
Mo	0.351	0.417	0.430
	0,4-0,55		
	+18,8%		+3,1%
Cu	0.252	0.244	0.237
	-3,2%		+2,9
Ni	0.096	----------------------	----------------------
S	0.017	0.276	0.03
Si	0.242	----------------------	----------------------
C	----------------------	----------------------	----------------------

The most important elements for these electrodes, providing heat resistance of welds, are chromium and molybdenum.

It can be noted that the content of all elements, which was determined in all surfacing, changes with increasing layers. The table shows the analysis of such changes in interest rates. Double-layer surfacing with respect to single-layer and five-layer with respect to two-layer. It is interesting that for chromium, molybdenum and manganese, the percentage change in the seam coincides with high accuracy. The change in the composition of the five-layer surfacing in relation to the two-layer 6-7 times less than the two-layer relative to the single-layer. Each of the surfacing shows that its content is within the range of permissible changes specified by the standard.

Let us analyze the composition of the table. 3.7 for each of the main elements. In table. 3.7. the data on the minimum and average content of elements are given.

Chrome. In all three seams, the actual content exceeds the minimum specified by the standard. Surfacing in 5 layers practically coincides with the average value of the standard.

Manganese. In all three seams, the actual content exceeds the minimum specified by the standard. Surfacing in 2 and 5 layers exceeds the average value of the standard.

Molybdenum. The only one of the three elements for which the value in the single-layer cladding is less than the minimum specified by the standard. Values in 2-and 5 –layer surfacing exceed the minimum, but are below the average.

Hence, it can be concluded that the chemical composition of the deposited metal by spectral method can be determined by a two-layer surfacing. At the same time, compliance with the requirements of the standard or certificate for the main alloying elements will be clearly determined.

Surfacing with an arc of indirect action provides a more accurate value of the content of elements in the deposited metal than in the 5-layer surfacing.

5. Algorithm of realization of the problem of double-arc welding with coated electrodes of different types

Consider the use of two-arc welding coated electrodes of different types [10]. These are different electrodes. According to Russian standards, there are about 100 types of electrodes, which regulate the chemical composition of the deposited metal. When two-arc welding in a common weld pool (melting space), it is possible to combine different types of electrodes and obtain new chemical compositions of the deposited metal. This means that the number of electrode types seems to increase a hundred times without creating new types. This creates new opportunities, for example, for the repair of critical structures [11].

The idea of the work is that when two welding arcs are burning from electrodes of different composition, the chemical composition of the deposited metal can be changed into one welding bath. It is possible, without creating new electrodes, to obtain the required chemical composition of the weld metal and weld.

To simplify the task, we take two electrodes for welding heat-resistant steels. The most important variable is the type of electrodes. It defines the requirements for the chemical composition. The specific design is characterized by a brand that can only change the technological properties of the electrodes-this is the second variable. It defines the diameters of the electrodes and the range of possible arc currents for each diameter. Diameter is the third variable. The fourth variable is the two arc currents, which we must choose the minimum and maximum for a given diameter. If we have nine types of electrodes, it is possible about 80 of their combinations of 2. For two randomly selected types of electrodes have one or more brands.

Stamp sets is also an important parameter is the deposition rate. The brand has one or three diameters and two currents for each diameter. The data are calculated by the mixing formula [12]. Next, there are options for creating a cycle in which all possible combinations of electrode types are drawn.

We present the calculation algorithm:

1. Two types of electrodes are randomly selected. This means that their chemical composition is known.
2. Select a brand and is determined by the deposition rate for each of the types.
3. The electrode diameters for each grade are selected.
4. Current is selected for each diameter (minimum or maximum).
5. The deposition rate for each diameter and current is calculated.
6. According to the mixing formula, the chemical composition of the deposited metal is calculated by two arcs simultaneously.
7. The specified efficiency criterion is calculated.
8. Go back to item 4 and perform calculations for three more combinations of currents.
9. Go back to item 3, change one of the diameters and repeat for all possible currents. So we pass all possible combination of diameters.
10. Go back to paragraph 2 and change one of the brands.

On the basis of the algorithm, a program is written in Kotlin language to summarize data on welding electrodes, their brands and calculate the required chemical composition during combustion of two welding pipes.

6. Conclusion

In the course of the study, possible options for obtaining samples for indirect arc surfacing were tested. Their advantages and disadvantages are revealed.

The advantages include:

- Reducing the complexity of the sample production.
- Reduction of costs for electricity and welding materials.
- Improve performance certification of covered electrodes.

The disadvantages include:

- Obtaining an incomplete list of chemical elements due to the lack of additional equipment.
- Unstable burning of the arc, including possible breakages of the arc during the weld test.

- Inclusion in the deposited metal of chemical elements, data on which are not available in the documentation for the electrodes.

7. References

[1] Akulov, A.I. Technology and equipment for fusion welding and thermal cutting /A.I. Akulov, V.P. Alehin, S.I. Ermakov. – M.: Mashinostroenie, 2003. – 560 p.
[2] GOST 9466-75. Metallic coated electrodes for manual arc welding and surfacing. Classification and general requirements. Rosstadart. – M., 1992.
[3] GOST 9467-75. Electrodes coated for manual welding of structural and heat-resistant steels. M.: IPK Publishing Standards, 2005. – 6 p.
[4] GOST 10051-75. Metallic coated electrodes for manual arc surfacing of surface layers with special properties. – M.: Publishing house of standards, 1993. – 12 p.
[5] GOST 10052-75. Metallic coated electrodes for manual arc welding of high-alloy steels with special properties. – M.: Publishing house of standards, 1993. – 12 p.
[6] Optiko-emissionnij spektralnij analiz metallov [Electronic resource]. – Access mode: https://studfiles.net/preview/4001631 (29.11.2018).
[7] Ivin, K.V. Current removal of urban land transport / K.V. Ivin, A.N. Trifimov, G.G. Engels. – M.: Publishing house of literature on construction, 1965. – 262 p.
[8] Rentgenofluorescentnij X-MET-5000 [Electronic resource]. – Access mode: http://xrs-ndt.ru/index.php?option=com_content&view=article&id=41&Itemid=164 (29.11.2018).
[9] Rentgenofluorescentnij EDX-8000 [Electronic resource]. – Access mode: https://www.shimadzu.ru/sites/default/files/edx-7000-8000-c142e037a_rus.pdf (29.11.2018).
[10] Sidorov, V.P. Calculation of the weld cross-section when welding under fluosomes of double-sided butt joints / Collection of materials of the international scientific and technical conference. – 2018. - P. 190-199.
[11] Sidorov, V.P. Analysis of welding modes under fluosome of double-sided butt joints without edge cutting / Innovations in the fuel and energy complex and mechanical engineering, 2017. – P. 159-163.
[12] Pivneva, S.V. Simulation of discrete optimization problems / S.V. Pivneva, M.A. Trifonov // Science vector Togliatti State University. – 2010. – № 3. – P. 28-30.