WELDED ELECTRIC CONTACTS OF DISSIMILAR CONDUCTORS

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High energy effectiveness of application of welded electric contacts of metals with different carbon materials and welded electric contacts of cathode units and burnt anodes developed at PWI is substituted. Designs of electric contact plugs (ECP) as well as arcotrons, i.e. nozzle-free torches using an oxide cathode, were developed. Examples of effective application of contact assemblies with ECP in synthesis and Acheson furnaces are given.

Keywords: *energy consumption, loss of energy, electric contact, transient electric resistance, oxide cathode, arcotron, wetting, metal to carbon material welding, electric contact plugs, welded contact assembly, electrolytic cell, Acheson furnace*

Cost of electricity constantly rises, according to the data of world market of electrical energy, and apparently such a tendency remains for a long time unless forever. Therefore, prime task of the industrial engineers should lie in searching of new ways of minimization of energy consumption in the technological processes and constant control of energy loss. What is a level of effectiveness of this task solving in production?

Let us show by example of aluminum production how prodigally electricity is consumed in this sub-branch of non-ferrous metallurgy.

Transfer of electricity from a power station to aluminum plant depends on distance and loss can make up to 13 %, therefore, the powerman make a number of efforts for energy-saving, increasing, for example, voltage in the electric main. But after electricity has been supplied to the plant attitude to it changes. One of the authors saw how welding of the main aluminum bus bars was carried out by open carbon arc of large power without any gas or slag shielding in a shop of magnesium production at one of Ural industrial enterprises. Such an operation performance was only used in N.N. Benardos time when the arc welding in Russia began and steel but not aluminum was welded in such a way. Strictly speaking this technological process is difficult to be termed welding. At the moment we can just imagine a number of oxide films being involved in a weld at that and amount of electricity that was lost then on this joint.

Recently, complex «aluminum plant–electric power station» is considered as a whole in designing of new aluminum plants, and all necessary measures for energy saving are to be taken.

It is known from statistical data, obtained as far back as soviet time, that an aluminum industry was the most energy consuming among all consumers of electricity in the national economy of the Soviet Union. Considering the next example we can imagine an amount of electricity necessary for a current aluminum production. Production of 36 mln t of aluminum (recently obtained annual production of metal all over the world) requires the amount of electricity that can be generated in two and a half year period by such a giant as Krasnoyarsk hydropower plant.

Such a huge consumption of energy during aluminum production by high-temperature electrolysis is explained, first of all, by strong bond between aluminum and oxygen in Al_2O_3 alumina, i.e. a raw for this metal production. Around 7000 kW·h counting on each tone of obtained metal are necessary, on different data, for breaking a bond between elements in the compaund with the purpose of aluminum release. At the same time, specific consumption of electricity in the industry makes at average 14000 kW·h. The rest 7000 kW·h is the loss. So, only half of all electricity being supplied to the electrolytic cell is used effectively. This is too prodigally, isn't it?

Yu.V. Bajmakov, serious and conscientious scientist, standing at the beginnings of aluminum metallurgy of USSR, thoroughly analyzed energy consumption in the production of light metals back in prewar years and wrote small but very important book [1] during the Leningrad blockade. He showed that the clamping electric contacts between steel contact jaws and electrodes from graphitized carbon material are the most wasteful elements in the structure of aluminum electrolytic cell if they are produced using cast iron pouring. Only these contacts lose up to 30 % from the whole being observed in multiple electric contacts of the electrolytic cell. This is the Moloch consuming electricity so difficultly obtained by humanity. Followers of Yu.V. Bajmakov scorned his advices and even invented the title to these parasitic contact resistances, i.e. «heating resistances». Thus, they have rehabilitated these losses, adjusted to them and, therefore, the same structure of contacts that have been used more than hundred years ago in first industrial devices is preserved today even in the electrolytic cells of the XXI century.

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All aluminum engineers know that the electric contacts in a hearth of electrolytic cell are manufactured by means of liquid cast iron pouring in a technological gap formed between steel current jaw and channel in carbon hearth block. The liquid cast iron gives good wetting to solid steel, therefore, a good electric contact is provided. At the same time the liquid cast iron makes no wetting to carbon material of the hearth block, thus, transfer of electric charges through this interface is provided with large energy loss and the interface itself is available for penetration of different fusible materials in it. Separate elements of electrolyte pool leak out on this surface through a cathode unit and, in particular, along the seams between the blocks in a process of electrolytic cell running. In time this interface loses significant part of still small electrical conductance. This is one more reason of heavy losses of electricity and example of that how large electricity losses are tolerated then in the process of five-four years operation of the electrolytic cell for the sake of simplicity of technology for assembly of the cathode units.

Further, the analysis shows that the most electric contacts in electrometallurgy units operate under elevated temperatures up to 250–300 °C as well as 850–900 °C (hearth blocks). But, electric heavy-current contacts are still manufacture as clamping ones regardless heavy operating conditions that promotes great electricity loss due to high transient electric resistance, increasing during unit operation that is in particular important. For example, each microohm of resistance in the current electrolytic cell for 175 kA leads to $1\cdot10^{-6}(175)^2\cdot10^6\cdot24\cdot365 = 268000$ kW·h annual loss that can illustrate amount of loss of electricity on the heavy-current contacts. Note that this is only for one contact!

A lot of electrolytic cells with self-baking anodes (Soderberg anodes) are still used in the aluminum industry. Electricity to them is fed from main bus bar of the shop with the help of aluminum-copper-steel chutes. Workers often have to dress contact surfaces manually under uncomfortable operating conditions (temperature up to 150–200 °C) if clamping contacts are used in them. In our opinion it is violent to ask workers to perform these tasks at heights and under such temperatures. Apparently, industrial engineers at aluminum plants forgot that the task of engineers according to the history of technologies development was facilitation of labor of workers, mechanization of their work, development of such structures which would save workers from activity under difficult conditions.

We gave these two examples for showing that the aluminum engineers use out-of-date structures of powerful contact assemblies in the electrolytic cells, regardless that advanced welding technologies have existed already for more than 20 years.

Method for production of the welded electric contacts of metals with different carbon materials [2] was developed and thoroughly examined under industrial conditions by the E.O. Paton Electric Welding Institute of the NAS of Ukraine back in 1980s due to creation of the oxide cathodes of welding arcs [2, 3].

The E.O. Paton Electric Welding Institute developed technologies of assembly using welded electric contacts of cathode units and burnt anodes. Energy-saving contact having not need in dressing of contact surfaces during the whole life time of the electrolytic cell was designed in the Institute based on new welding technology with respect to «aluminum–copper» hanging contact. This contact was termed «PWI hanger» since being located in the hanged condition.

Formerly all electric contacts in the aluminum shops were clamping ones, but after the Great Patriotic War all the plants were obliged to change them in the welded electric contacts by order of Ministry of Non-Ferrous Metals of USSR. Methods of welding of dissimilar materials were unknown at that time and transfer to the welded contacts allowed saving 7 % of electricity, consumed by «Soyuzalyuminprom», only in metal conductors. This had obvious economic effect along the country on the whole.

Today the developments of the E.O. Paton Electric Welding Institute in area of welding of dissimilar current-conducting materials are well-known but the aluminum plants avoid them for some reasons. They, wasting large amount of electricity, include these losses in a cost price of the metal and do not want to turn to new methods of assembly of the electric contacts. Thus, electricity makes a half of the cost price of aluminum. No ministry could make the plants to master new welding technology! Obviously, that a decision of the government is necessary in this case, since electricity loss, for example, in Russia producing 5–6 mln t of aluminum per year, is evaluated on a national scale. In our opinion, the government should not agree with requests from aluminum engineers for reduction of rate of electricity, generated by state electric power station. They have own internal reserves which allow them reducing specific consumption of electricity and, thus, decreasing metal cost price that will raise competitiveness of aluminum in the external market.

It should be recognized that performance of erection works using cathode units and burnt anodes, certainly, more laborious process than pouring of the blocks by liquid cast iron. However, transfer to new technology allows the plant saving electricity, the price of which overlaps the costs for wages of more qualified workers-welders than pourers of liquid cast iron. It should be remembered that the plant makes contribution to solution of one of the social tasks paying larger salaries to the workers. Besides, the plant removes the cupola-furnaces being the sources of harmful gases, dust and slag, unusual for aluminum production, and, thus, improving ecological conditions on the plant.

Now examine the contact again. It is known from the theory of contacts of the solid bodies [5] that no matter how thoroughly the surface of metal contacts is prepared, it, however, remains rough and real contact of two contact jaws is performed only over the micropeaks on this surface and not along the whole visible area. For example, an actual area on copper-aluminum contacts makes only 5 % of the visible area. In this connection the contact surfaces are pressed to each other with force trying to deform micropeaks and, thus, increasing the actual area of clamping contact. However, increase of the area of real indicated contact more than to 30 % is physically impossible.

Hyperbolic dependence of contact electric resistance on pressing force of the contacting pair explains this effect. Initial pressing forces are highly effective, and, further forces vice versa have very small effect on resistance of contact.

The same character of dependence between contact electric resistance and, as it may be strange at first sight, current intensity is observed at normal (room) temperature in «carbon material–cast iron» contact: the higher intensity of current, passing through the contact, the lower is its resistance. This effect (fitting effect) is explained by electric breakdown of a narrow air gap between contacting materials. At that, so-called additional microbridges from cast iron are formed in the area of large currents and current is passing along them. It should be noted that this effect is observed only at normal temperature. If elevation of temperature and oxidation of cast iron surface are made at that, then the fitting effect, unfortunately, is not observed.

In contrast, the actual contact surface equals observable surface in the welded contacts. This is the main advantage of welded metal electric contacts. It is natural that contact eclectic resistance of the welded contacts is significantly lower than that of the clamping ones and has no increase during contact operation, what is very important.

Welded electric contacts of metals with carbon materials take separate position at that. The matter is that all hard carbon materials are porous. Total porosity varies from 20 to 30 %. There are special graphitized materials with 50 % porosity.

Materials specified have pores of two types: closed, isolated and channel, transporting pores. It should be noted that the latter makes 3/4 of total volume of pores.

This their peculiarity is used in welding of metals with carbon materials. Liquid copper or aluminum provides no wetting of carbon materials under normal conditions. If intensive carbide-forming elements, the best of which are silicon and manganese in this case, are added to them, then an angle of wetting of carbon materials decreases up to 5–15°, and liquid overheated alloy penetrates to 10–15 mm deep inside the graphitized materials through their transporting pores. At that, the area of actual contact tens and even hundred times exceeds observable area. This is an unprecedented case in the practice of electric contacts and man should use this gift of the nature. Carbon materials are wetted by liquid iron, however, some carbide-forming chemical elements are also added to electric iron-based contacts.

Structural element of different welded contact assemblies is so-called electric contact plug (ECP). Three variants of structure of this plug are shown in Figure 1. ECP is a plug of 30 mm diameter and not more than 40 mm depth, welded in a body of carbon block whenever this is cathode unit of the electrolytic cell or its burnt anode. The ECP is a common element for all three variants of electric contact assemblies. They differ by method of electric contact joint with flat metal contact jaw. Variant *A* is recommended for the use in contact assemblies if distance between end plugs does not exceed 200 mm, and variant *B* is applied at distances depending on diameter of a tip-compensator up to 500 mm. Finally, variant *C* can be used without inter-plug distance limitations. Figure shows that the compensator, whether it being single bar or bunch of bars, is welded to current jaw using manual or semiautomatic welding.

Basis of electric contact alloy of the plug and material of the compensators must be the same as a metal of contact jaw. The compensators are necessary for smoothing a great difference in the values of thermal coefficient of linear expansion (TCLE) of carbon material ($4 \cdot 10^{-6}$ K^{-1}) and, for example, aluminum ($28 \cdot 10^{-6}$ K^{-1}). If compensators are abandoned then the welded joint can failure under effect of thermal stresses during temperature change. ECP contact resistance, measured at room temperature, varies from 50–70 for copper electric contact alloy to

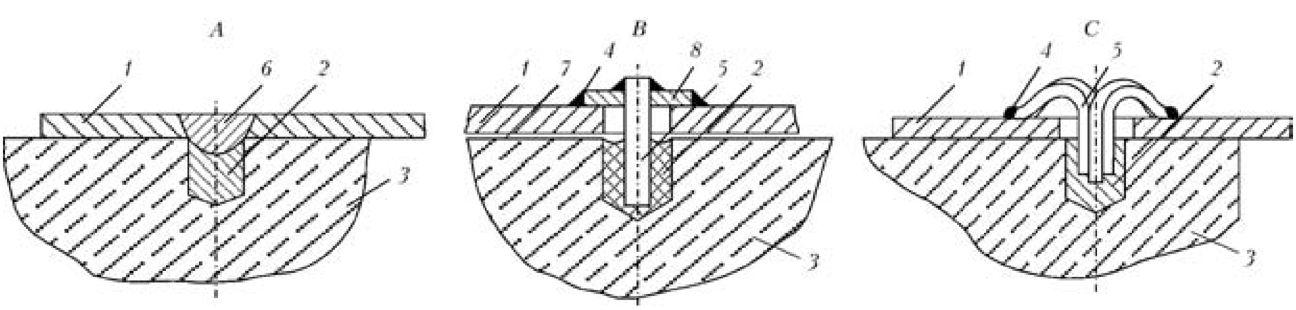

Figure 1. Scheme of the metal to carbon material welded joints of different variants *A*–*C*: *1* — metal plate; *2* — ECP; *3* — carbon block; *4* — weld; *5* — compensator; *6* — plug weld; *7* — gap between plate and carbon block; *8* — washer

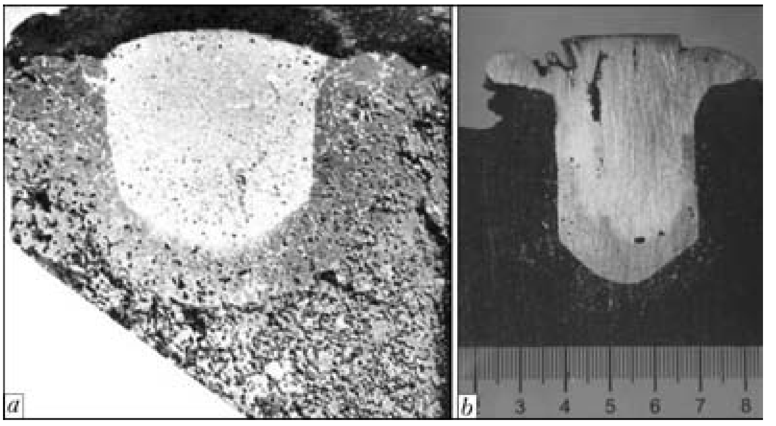

Figure 2. Macrosections of ECP welded in carbon material: *a*, *b* — iron- and aluminum-based alloy, respectively

100–120 μOhm for iron alloy depending on alloy material. Limit value of the current load of ECP varies from 400 (for iron alloy) to 750 A (for aluminum and copper alloys).

Development of ECP was a complex task. Dimensions of the plug are determined by comparison of the adhesion forces of alloy to carbon material with forces caused by casting shrinkage of ECP liquid alloy at its solidification and thermal shrinkage of metal at its further cooling.

Constant values of contact resistance of the plug in a course of long-term operation are specific and very important property. Note that its resistance reduces on 20–30 % at ECP heating.

It is strange from point of view of metallurgy that content of oxygen, for example in the metal of iron-based alloy, does not exceed 0.005 % after welding on open air. The same content of oxygen is observed in a simple gray cast iron. We believe that the low local partial pressure of oxygen in gas atmosphere inside the deepening of carbon material during plug welding-in, short-time plug performance and presence of electric contact alloy in the metal among additions of strong deoxidizers can explain this phenomenon.

Longitudinal sections in Figure 2 show normal microstructure of ECP. Dense well-formed plug–carbon material interface and fine distributed shrinkage porosity in the plug volume can be observed in Figure 2, *a*. It is seen from Figure 2, *b* that the layers of carbon material attached to the plug are deeply saturated by electric contact alloy.

Contact electric resistance as well as mechanical force of plug tear-out from carbon body control the technology of plug welding-in. The tear-out force depending on plug alloy makes from 600 to 1000 kg. Figure 3 shows two torn-out plugs. Cone shape of torn plug indicates maintenance of welding technology. Alloy in this case penetrated deep into metal by transporting capillary channels. Such a plug can be torn out applying 1000 kg force, its contact resistance is minimum. Other plug being cylindrical on shape with «bold» surface, has been torn out at minimum forces below 600 kg and has increased value of contact resistance. This plug is made with technology violation.

Technology and procedure of welding in of plugs in the carbon material block is our know-how and can be transmitted to a client after license purchasing. ECP is produced using an arcotron, i.e. special nozzle-free plasma torch operating on oxide cathode.

The oxide cathodes (Figure 4) are a development of the E.O. Paton Electric Welding Institute. They belong to the category of non-consumable electric-arc electrodes as tungsten and carbon ones. But the oxide cathodes in contrast to them can operate in all oxygen-containing gases up to pure oxygen. Their life time is $2-4\cdot10^{-8}$ g/K like in tungsten electrodes in argon atmosphere. Cathode spot reaches 2 mm in diameter on liquid oxide alloy at large arc currents and current density makes 300 A/mm^2 on it. It is recommended that welding current on the arc does not exceed 750–800 A. Diameter of the anode spot on carbon material reaches 20 mm. The parameters indicated for welding arcs are unique.

Lower by an order voltage stress in the arc column, high self-stabilizing, noiseless as well as flat maximum of temperature in a cross-section of arc column and

Figure 3. Appearance of the plugs after tear-out test: upper is performed with technology compliance, and lower — with violation

Figure 4. Oxide cathodes of welding arc for different technologies

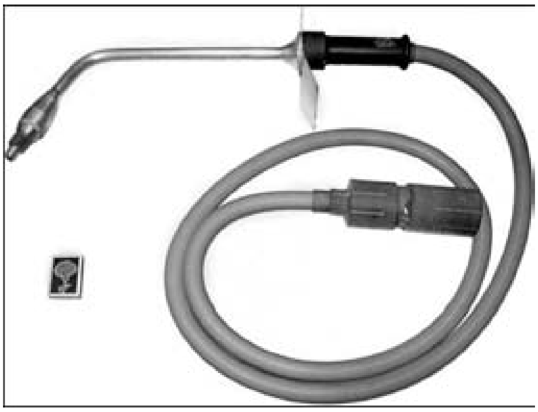

Figure 5. Special arcotron D-4A

anode spot make an electric arc of oxide cathode differ from free arcing.

A series of torches for different currents, beginning from 50 A, having commercial name «arcotron», were developed for oxide cathode application in welding. It is nozzle-free plasmatron with heat efficiency 95 % from point of view of design. Works on ECP welding

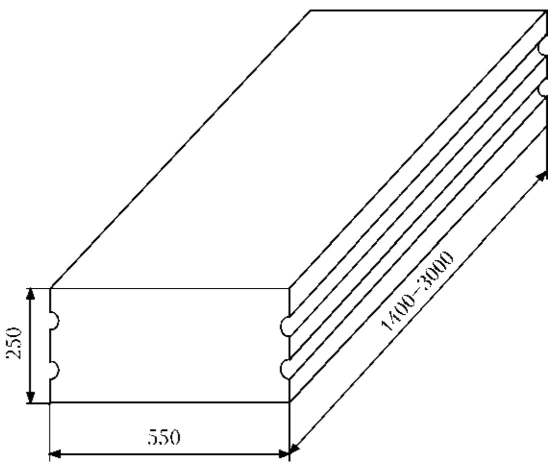

Figure 6. Scheme of typical hearth block of new design

Figure 7. Fragments of two contact assemblies for hearth of aluminum electrolytic cell

in the carbon body are performed with the help of D-4A arcotron (Figure 5).

Numerous experiments, carried out in laboratory and industrial scales, showed that application of ECP for assembly of cathode units of electrolyte cell allows achieving additionally 50–200 kg of metal per each tone of aluminum at the same electricity consumption. This is achieved due to reduction of loss of electricity in the contacts during its transfer from steel contact jaws to cathode carbon units as well as virtually complete elimination of such an effect as secondary oxidation of aluminum in the pool. The fact is that sufficiently inhomogeneous current density is observed on working surface of the hearth blocks at side supply of electricity to the hearth. It is 16 times higher in the place of current supply than in remote areas of the block. This, naturally, promotes formation of parasitic horizontal currents in the metal pool. Interaction of these currents with magnetic field of the electrolytic cell provokes formation of macrocurrents of metal and electrolyte. Fine drops of aluminum suspended in the electrolyte are carried out to the interface with air and being oxidized. This is secondary metal oxidation.

If ECP is used for energy supply to the block than excellent current homogeneity is achieved. Current density varies in 3 % range along the whole working surface of the block of 550 × 1800 mm. At that, of course, the parasitic horizontal currents come to negligibly small values and secondary oxidation of metal is, virtually, eliminated.

It should be added to mentioned above that interaction of the parasitic horizontal currents with the main magnetic field promotes formation of standing wave of liquid metal pool. The latter makes technologists increasing thickness of electrolyte layer that results in over-expenditure of energy for electrolysis performance.

Besides, change of clamping electric contacts of the cathode units for ECP allows saving 1/3 of cathode carbon materials since simple parallelepiped is used (Figure 6) instead of archaic shape in this case.

Economy of steel rolled metal for current jaws (up to 20 %) is also take place due to uniform density of current in the current jaws of long and short cathode units and as a result of elimination of sodium barrier since in this case its function is performed by flat current jaws to cathode units.

In turn, the electrode plants should reduce price for the cathode units since their production is simpli-

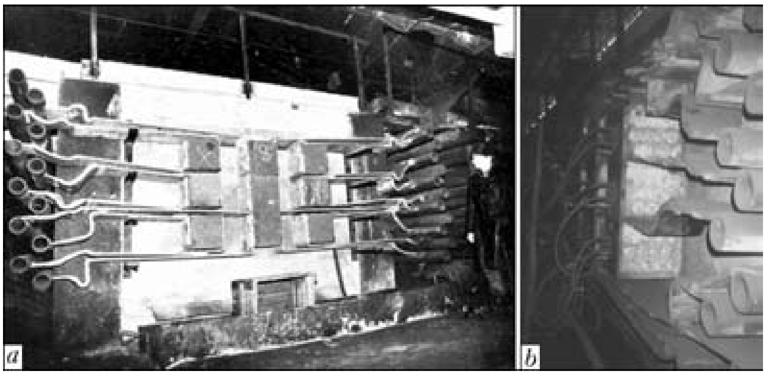

Figure 8. Back ends of graphitization furnaces performed using ECP with free (*a*) and forced (*b*) cooling

Figure 9. Contact assembly of furnace for carbide silicon synthesis made with ECP application

Figure 10. Element of contact assembly of Acheson furnace prepared for erection welding

fied. There is no necessity in extrusion of units on extremely expensive powerful presses.

There are several examples of ECP application in aluminum (Figure 7) and magnesium electrolytic cells, in Acheson furnaces for graphitization of carbon materials (Figure 8) and synthesis of silicon carbide (Figure 9).

Figure 8 shows a back end of Acheson furnace for 100 kA, in which all electric contacts between metallic current jaws and graphitized electrodes, are welded and copper lead is changed for aluminum one.

Contact assembly with air cooling of 20 kA Acheson furnace for silicon carbide synthesis, also made from aluminum, is shown in Figure 9. Figure 10 shows one of the elements of contact assembly of this furnace prepared for manual erection welding.

Characteristic of both examples referring to Acheson furnaces is that they are cheaper than the contacts with copper lead on costs for materials and servicing of contacts for the plant.

Therefore, application of solutions described in the paper, found by the specialists of the E.O. Paton Electric Welding Institute, allows the plants of non-ferrous metallurgy, electrode and tool industry saving electricity and improving work environment.

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