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STUDY OF THE INFLUENCE OF THE INCREASED CARBON CONTENT IN ELECTRODES ON STRUCTURE AND PROPERTIES OF THE WELDING SEAM DURING WELDING OF 110G13 STEEL

The object of research is the effect of the carbon-forming component of coated electrodes for welding and surfacing of Gadfield steel (110G13L and analogs) on the structure and properties of the weld.

One of the most problematic areas in the welding and surfacing of high-carbon steel is the high irregularity of the rod and coating melting rates. Therefore, the non-melted part of the coating is literally poured into the weld pool, which leads to significant chemical and structural inhomogeneity of the welded metal. The main hypothesis of the study is the assumption that it is possible to increase the homogeneity of the deposited metal by changing the conditions for the transition of carbon from the electrode to the weld pool by using an electrode rod made of carbon steel.

In the course of the study, electrode rods with different carbon contents were used. With an increase in the carbon content in the composition of the electrode rod, the fluidity of the drops increased, which contributed to a decrease in the strength of the welding current without harm to the welding and technological characteristics. This allows to reduce the generation of heat in the base metal, that is an effective measure to prevent hot cracks in the weld metal and heat affected zone

Studies of the composition of the electrode metal droplets and the weld material showed that with an increase in the carbon content in the electrode rod from 0.08 % to 0.8 %, the carbon content in the droplets increases from 0.3 % to 0.97 %. The carbon content in the weld metal is 1.1 %. The assimilation of manganese by a drop increases with an increasing of coating and the droplet interaction time. A significant increasing in the rate of coating melting was obtained. This is due to the fact that the concomitant decrease in the content of graphite in the coating contributes to a decrease in the refractoriness of the electrode coating.

The use of high carbon steels for the manufacturing of electrode rods for welding and surfacing of Gadfield steel improves the properties of the welded metal and sanitary and hygienic parameters.

Keywords: *welded joints, Gadfield steel, arc welding, hot cracks, coated electrode, weld metal, heat-affected zone, electrode rod, manganese assimilation, welding current.*

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1. Introduction

The object of research is electrodes for high-manganese Hadfield steel (110G13) welding. It has been successfully used in mechanical engineering for about a hundred years. Due to the work-hardening properties of the work surface with an impact tough core, 110G13 steel is even now practically unalterable for the manufacturing of many products, which work under the influence of shock, shock-abrasive loads and high specific static pressures, for example, links of tractor's tracks, cheeks of crushers, rail crossings, turnouts. Along with its unique properties, steel has a rather low cost, so its use has undeniable advantages [1–3].

As is known, the main problem of high-manganese austenitic steel welding is its tendency to form hot cracks [4–6]. The following causes for this phenomenon are considered: the presence of a number of internal defects (liquation, non-metallic inclusions) and the large length of grain boundaries, due to which the accumulation of low-melting eutectics at their boundaries is pronounced. To reduce the probability of cracking, the seams are immediately cooled directly after welding and (or) weld metal, which has an austenitic-ferritic structure, is used [7–9].

However, coated electrodes are currently the main electrode material for repair and restoration of 110G13 steel products. Mainly electrodes with alloying systems based on Cr-Ni (OZL-6, NII48G), Cr-Mn-Ni (ANV-2v), Cr-Mn (ANVM-2).

It is known that to reduce the probability of hot cracking during manual arc welding, the amount of ferrite component in the weld metal is intentionally increased to reduce the length of the grains, thereby increasing the length of the grain boundary line [10–12]. In practice, this means a significant introduction of chromium (up to 30 %) into the weld metal. However, this measure has an extremely negative effect on the difference between the mechanical properties of the base and the weld metal, increasing internal stresses and reducing the tendency of the metal to self-strengthening as a result of work hardening [13]. One of the effective measures to reduce the grain size of the weld metal and the heat affected zone (HAZ) is the immediate cooling of the joints with water. Cooling is carried out not only at the end of welding or surfacing, but also during it, which significantly worsens the sanitary and hygienic working conditions and, most often, leads to safety violations during welding [3, 6].

Reduction of harmful impurities in the main metal in most cases is difficult because of the metallurgical features of the melting of this steel. Their partial withdrawal from the metal of the weld seam is carried out by refining the bath as a result of the interaction between calcium components of slag and molten metal. In Fig. 1 the microstructure of steel 110G13 in the cast state is shown. It is austenite with of large size grains, contaminated with harmful impurities and non-metallic inclusions.

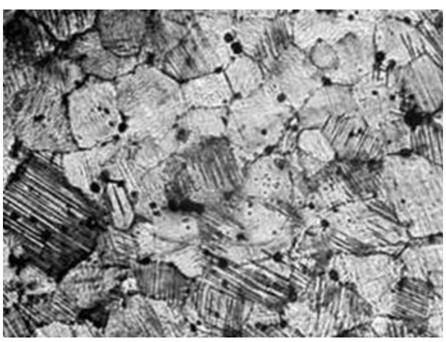

Fig. 1. The microstructure of steel 110G13 in the cast state (×500)

It is obvious that the successful welding and surfacing of Gadfield steel, as well as a number of austenitic steels, is a kind of compromise between several factors: contamination of the weld metal with harmful impurities, grain size, homogeneity of the weld metal and others.

The problem of nonuniform distribution of alloying elements in the weld metal during surfacing of high-carbon steels in most cases is associated with uneven melting of the electrode coating, which periodically literally «sprinkles» pieces into the bath and does not have time to dissolve in it. This is due to the use of graphite electrode coatings as a carbon-forming component, which significantly impairs the melting of the electrode coating.

The aim of research is to increase the homogeneity of the weld metal by changing the conditions of transition of carbon from the electrode to the welding bath by using a carbon steel rod electrode. It is known that most electrodes based on the factors of the highest manufacturability and the lowest cost have rods from steel SV08 and SV08A. The electrodes, providing chromium-nickel or chromium-manganese austenite, have rods made of steel, which practically does not differ in chemical composition from the weld metal, for example Sv-08H18N9T, Sv-08H21N10G6, etc. Electrodes for welding of Gadfield steel parts when high strength and ductility of the weld metal is required have following parameters. The rod is made of manganese-nickel steel with composition: C=0.25...0.30 %, Ni=3...4 %, Mn=14...16 %. Coating of these electrodes has the following composition: marble – 55 %; fluorspar – 20 %; ferromanganese – 15 %; starch – 10 %.

However, the main source of carbon in the weld metal continues to be graphite electrode coating, which significantly complicates its melting. In this regard, it is proposed to increase the amount of carbon in the rod (at the level of 1...1.1 %) while reducing it in the coating without changing the average carbon content in the weld metal.

Therefore, it is important to study the effect of carbon-forming component of coated electrodes for welding and surfacing of Gadfield steel on their welding and sanitary performance.

2. Methods of research

To confirm the theoretical assumptions about increasing the homogeneity of the weld metal, it is proposed to make 5 batches of electrodes, which provide a weld metal type 110G13 at different carbon contents in the electrode rod (Table 1).

Table 1

Compositions of electrodes for surfacing of 110G13 steel with cores from 08A, 20, 40, 60C2, U8A steels

Components of coating	Content, %				
	Composition 1	Composition 2	Composition 3	Composition 4	Composition 5
Graphite	5.6	5.1	4.4	3.6	2.8
Fluorspar	8				
Marble	17				
Rutile	3				
Ferromanganese	46	46	46	46	46
Quartz sand	4				
Ferrosilicon	3	3	3	1	3
Ferrum powder	1.4	1.9	2.6	5.4	4.2
Liquid glass (in terms of dry residue)	12				
Rod	08A	Steel 20	Steel 40	Steel 60S2	Steel U8A

Due to the high content of alloying elements in the weld metal, the coating weight ratio is selected in the range of 100...110 %. The diameter of the electrode rod is 5 mm. Surfacing beads in a copper box was performed in two layers on a plate made of 65G steel with preheating at a direct current of 200...220 A of reverse polarity. The arc was powered by a VD-306 rectifier. Stability of arc combustion and spattering – satisfactory, the formation of beads and separation of the slag crust – are typical for the electrodes of the main type.

3. Research results and discussion

With the increasing of carbon content in the composition of the electrode rod, the fluidity of the droplets increased to some extent, which can reduce the strength of the welding current without possible degradation of the welding characteristics. This can reduce the release of heat into the base metal, which is an effective measure to avoid hot cracks in the weld metal and the heat affected zone (HAZ).

After surfacing the beads, the largest electrode droplets were selected for further research. Analysis of the chemical composition of the droplets that was performed on the X-ray spectral analyzer Thermoscientific ARL OptimX is given in Table 2.

Table 2

Chemical composition of electrode sprays

Element content, %	Composition Number				
	1	2	3	4	5
C	0.25…0.45 0.3	0.35…0.58 0.47	0.52…0.65 0.59	0.75…0.91 0.83	0.92…1.02 0.97
Mn	3.2…6.8 5	3.4…6.9 5.2	4.2…7.0 5.6	4.8…7.1 6.0	5.2…7.5 6.4
Si	0.25…0.35 0.3	0.3…0.37 0.34	0.32…0.38 0.35	1.8…1.9 1.85	0.35…0.45 0.4

Analysis of the chemical composition of the electrode droplets shows that the increase in carbon content in the rod with a simultaneous decrease in graphite in the coating, significantly affects the homogeneity of the chemical composition of the droplets. Within a same electrode composition, this may be due to a more uniform melting of the coating. Thus assimilation of carbon and manganese at a drop stage increases (Fig. 2, 3).

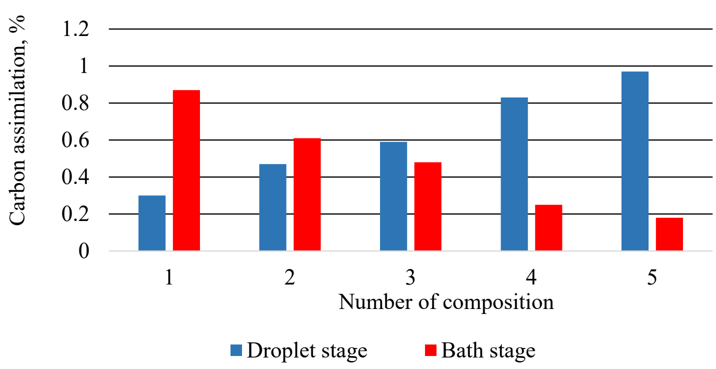

Fig. 2. Assimilation of carbon at the stage of the droplet and at the stage of the bath

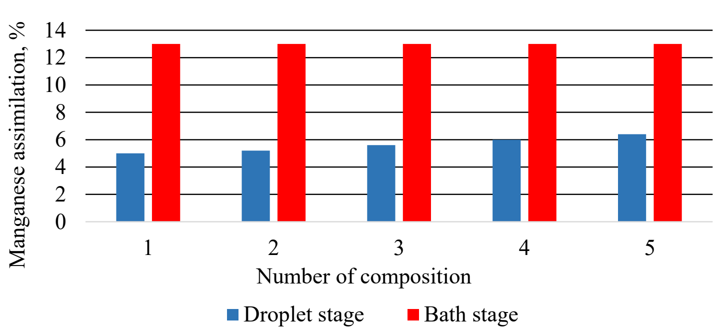

Fig. 3. Assimilation of manganese at the stage of the droplet and the stage of the bath

The increase in carbon content at the droplet stage is due to the increase in its content in the electrode rod. The carbon content in the drop during surfacing with electrodes of composition 1–0.3 %, and composition 5–0.97 %, although its content in the surfacing is 1.1 %. It is obvious that the increase of carbon in the rod leads to a more uniform distribution in the metal of the welding bath, increasing its homogeneity, alignment of the austenitic structure and mechanical properties of the weld metal.

Assimilation of manganese at the stage of the droplet can be the proof of more uniform melting of the coating. Given that the manganese content in the electrode rods (compositions 1...5) is approximately the same (0.2...0.35 %), it is possible to conclude that the increase in manganese content in the droplet indicates a more complete absorption of the coating. This is due, other things being equal, to the interaction time of the coating and the droplet. Pieces of coating are not so intensely sprinkled from the end of the electrode, which allows the droplets and the coating to interact at all stages of melting. The average content of manganese in the droplet (composition 1) is about 5 %, while its content in the droplets when deposited by other compositions of the electrodes steadily increases to 6.4 %. Moreover, good assimilation of manganese can improve the sanitary and hygienic characteristics of electrodes.

As is known [1, 2], a more complete alloying of the droplet can significantly improve the homogeneity of the weld metal. This is especially important when surfacing steels prone to cracking, as with the uniform distribution of alloying elements, the size of austenitic grains decreases.

The main sources of cracks in the austenitic structure are residual carbides, low-melting eutectics, manganese oxides and various defects of a metallurgical nature (pores and slag inclusions).

In [4, 5] it was shown that with a decrease in the size of micro- and macrograin of high-manganese steel, its mechanical properties, low-temperature toughness, crack resistance and wear resistance increase dramatically. The use of carbon electrode rods allows to get as close as possible to the high crack resistance without the introduction of the electrode metal ferritizers, which significantly reduces the difference between the mechanical properties of the base and electrode metal. These requirements must be applied to the weld metal in cases where surfacing or welding of casting defects is carried out on the working part of the product. This is the inner surface of the armor of ore grinding mills, cone crushers, etc., i. e. those products or their parts for which uniform wear of the working surface are important.

The results of the research can be used at enterprises for the production of welding materials, in particular coated electrodes. Further development of the research direction may consist in the analysis of the microstructure and properties of the metal, welded with electrodes with high-carbon steel rods.

4. Conclusions

Investigations have shown that with increasing of carbon content in the electrode rod from 0.08 % to 0.8 %, the carbon content in the droplets increases from 0.3 % to 0.97 %, although its content in the weld metal is 1.1 %.

The assimilation of manganese by the droplets increases with increasing of the interaction time of the coating and the droplets, because the coating sleeve does not crumble into the bath and does not expose the end of the electrode. This is achieved by reducing the amount of graphite in the coating.

The use of carbon steels (60C2, 65G, 70, U8A, etc.) for the manufacturing of coated electrodes for welding 110G13 steel will improve the homogeneity of the weld metal, reduce the probability of cracking and improve the sanitary and hygienic performance of the welding process.

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