



Contact melting and structure formation in the system: α -iron-nanomaterials - common quality carbon steel

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Abstract

In this paper, processes of contact melting between steel plates, which arises after feeding the contact pulse of a contact welding machine, are studied, for cases when nanomaterials in the form of carbon nanofibers and powders of refractory metals are being located between the plates. It was established that the addition of carbon nanotubes allows to ensure the passage of contact melting with lower energy costs and to obtain high carbonaceous layers of considerable hardness, and the addition of doping elements makes it possible to control the structure, grainy and physical and mechanical properties of the formed material.

Key words: contact melting, carbon nanofibers, nanopowders, scrap metal, high carbon structures, microhardness.

Introduction

Contact melting for a long time attracts the attention of researchers and engineers. Welding, obtaining fusible materials, consolidation of powder materials, coating - here is an incomplete list of applications of this process. The research and development of the theory of contact melting are devoted to a number of modern and earlier works, which have not lost their relevance yet. [1].

Analysis of the problem and the study of information sources revealed the existence of different concepts of the essence of contact melting and various hypotheses of the essence of the process. In the work, the definition of contact melting was adopted as the process of transition to a liquid state of solids that make eutectic pairs at a temperature lower than the melting points of each of the substances of the system [2]. During the contact of crystals of heterogeneous components, liquid eutectics are formed in the surface layers.

At contact melting, the aggregate state of substances varies (from solid to liquid), so it will be fair to use the Arrhenius formula to describe the process. By means of approximation using the package of mathematical programs, the value of the activation energy of the process of contact melting of *the iron – carbon* system is obtained.

It was investigated that in the Fe - X - C system there are exothermic effects [1], as follows:

- mixtures based on refractory metals (Cr, W, Mo, V) are characterized by exothermicity, insufficient for carrying out in them processes of synthesis of metal-carbide materials due to their own energy resources and need external heating;
- in closed systems on the basis of chromium and vanadium, eutectic melting is possible under heating to 1040 -1230°C;
- the use of high-dispersion powders (less than 10 microns) increases the thermality of mixtures by 10% or more;
- in the system "(*metal powders + carbon material*), metal substrates and gas phase" metal and carbon oxidation, the formation of a gas phase with a certain carbon potential, metal carbidization and carbon coagulation of the metal substrate may occur. Probability and mass flows of processes depend on thermodynamic and kinetic factors, in particular on the specific area of powders, heating temperature, density of the mixture.



An additional source of energy required to initiate contact melting may be nanomaterials in the form of metal powders, carbon nanofibers, fullerenes, graphene, and the like.

Methods of experiments

Initial samples from Armco iron plates (technically pure iron with a total content of impurities of about 0.16%, in particular not more than 0.025% C, 0.035% Mn, 0.05% Si, 0.015% P, 0.025% S, 0.05% Cu) 0.2 mm thick and standard quality steel of DSTU 2651: 2005 with a thickness of 2 mm was subjected to point welding with a compression force of 2400 N at a current of 3500 A, a pulse duration of ≈ 2 seconds. Between the plates at the welding site were installed carbon fiber nanofibers with a surface density of about 15 mg / mm², as well as compositions in the form of carbon nanofibers with the addition of molybdenum nanopowders; Carbon nanofibers with the addition of vanadium nanopowders. The action with such parameters led to the formation of point connections, but the melting of the surface of the samples under the electrodes did not occur. This testifies that welding was carried out with minimal energy input. Microstructural studies of the surface layers of the samples were carried out using optical microscopes MBBS-6 and MIM-8. For the performance of microstructural studies, the welded plates were cut in the center of the weld joint and polished according to standard technology. Chemical etching of the surface of the samples was carried out in a 4% solution of HNO₃ in alcohol. Microhardness was measured by a microhardness tester PMT-3M.

Characteristics of prototypes

The conducted studies of the source plates at point welding without additional gaskets showed the preservation of a clear boundary between the welded materials, the zone of thermal impact on steel common quality carbon steel length ≈ 1400 microns, while the signs of diffusion processes were not detected (Fig. 1) [3]. Fig. 2 shows the microhardness of welded joints of plates on the thickness of the cross-section.

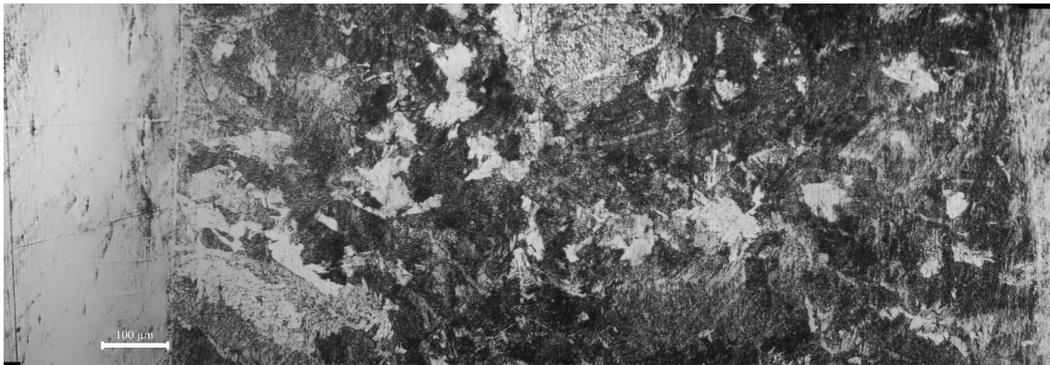


Fig. 1. Panorama of the point welded connection of the source materials (Armco iron and steel of common quality carbon steel)

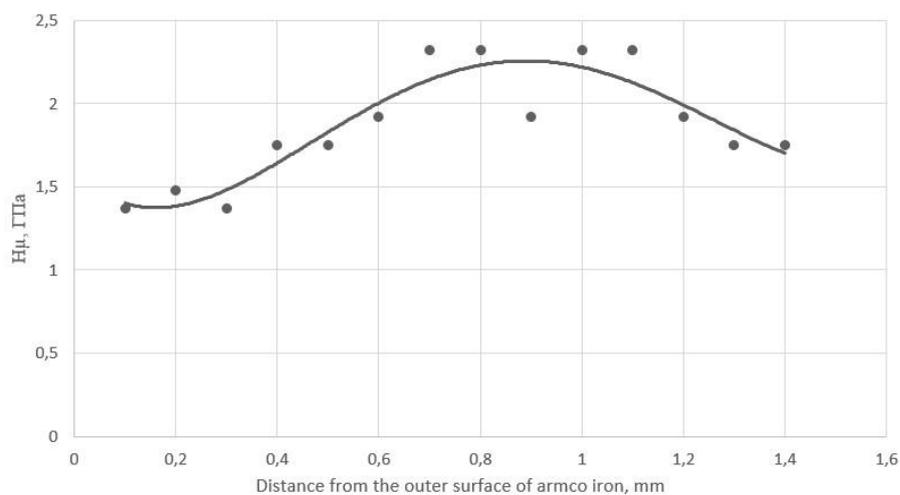


Fig.2. Distribution of microhardness in the sample of a point welded connection of raw materials

The following experiments with point welding of plates of Armco iron and common quality carbon steel and gaskets were conducted:

- 1 - carbon nanofibers;
- 2 - molybdenum powder Mo brand of PMC;

3 - vanadium powder V - VEL-1 (99.99% purity);

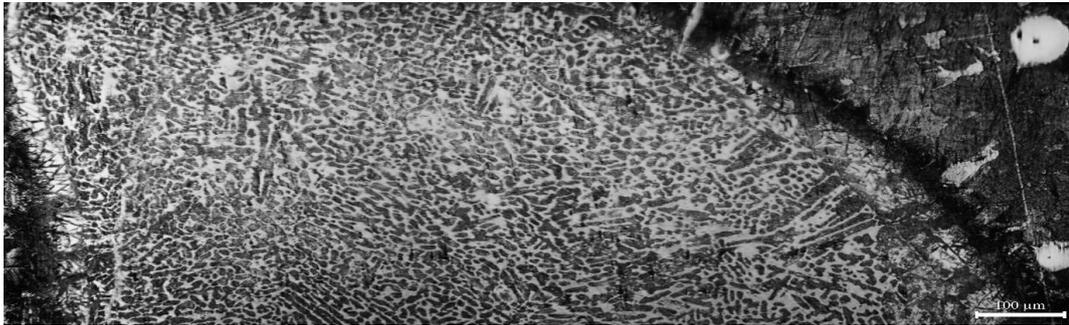
4 - carbon nanofibers and a layer of molybdenum powder in thickness up to 0,1 mm;

5 - carbon nanofibers and a layer of vanadium powder in the thickness of 0.1 mm.

From the above data on the chemical composition of the components, it can be seen that the main doping elements are vanadium or molybdenum in the presence of carbon. That is, systems of the type Fe-C-X were created, where X is molybdenum Mo or vanadium V. In stationary systems, the alloying element X forms, in the absence of carbon, solid substitution solutions in austenite or ferrite. In each of the experiments, we have two elements (Fe and X) which have comparatively small diffusion mobility and one element (C), which has 4-5 orders of magnitude a larger diffusion coefficient (carbon forms solid solutions and diffuses between the nodes of the iron lattice) [4].

Results of research and discussion

Microstructural studies have revealed some features of the microstructure, which were observed during spot welding without the use of gaskets made of carbon nanofibers or powders. Fig. 3 shows a series of panoramic microphotographs of the structure inward from left to right from the surface of Armco iron, to the main steel of common quality carbon steel



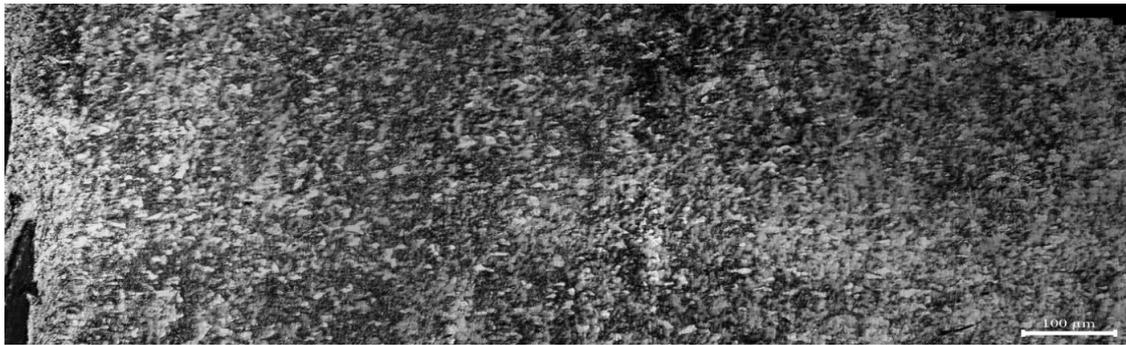
a) carbon fiber nanofibers



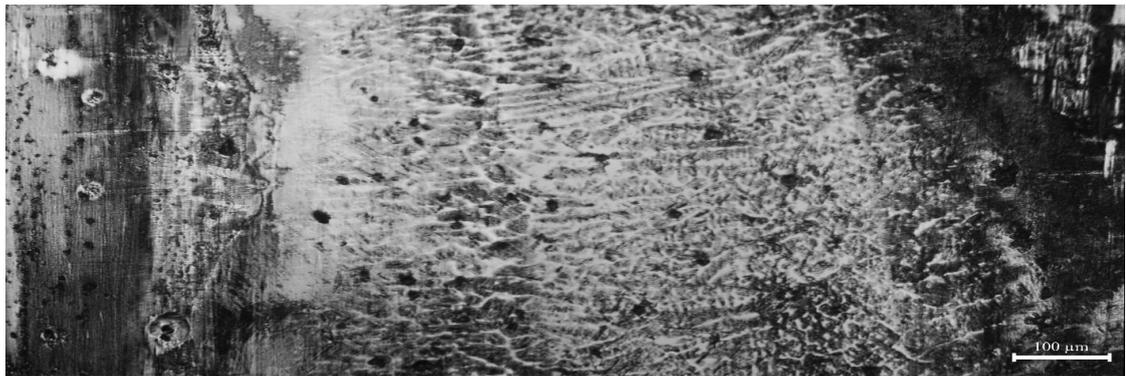
b) carbon fiber nanofibers with vanadium powder



c) vanadium powder



d) molybdenum powder



e) carbon fiber nanofibers with a molybdenum powder

Fig. 3. Panoramic photographs of microstructures of the nucleus of contact melting between Armco iron and common quality carbon steel in the presence of a gasket with doping components (on the left - Armco iron)

Study of the nucleus of contact melting between Armco iron and common quality carbon steel in the presence of carbon nanofibers between them (Fig. 3a) showed that a microstructure that corresponds to a high-carbon alloy with a structure of ledeburite was formed. Welding at the same time happened with a lower level of energy attachment, indicating the occurrence of contact melting processes [5, 6].

Fig. 3b shows a panoramic photo of a section of the nucleus of fusion of two steel plates, among which is a gasket of carbon nanofibers and vanadium powder. In the photograph on the left you can see the steel plaster of Armco iron, which practically did not melt and did not change its chemical composition. This is due to the fact that diffusion in α -iron does not occur [7, 8]. Almost all processes of melting and contact melting with diffusion processes are limited by the volume of common quality carbon steel. During the study of fig. 3b, the main three zones are observed: the first adjacent to α -iron, formed as a result of the carbide formation of vanadium carbonate from nano fabric that dissolved. This process is promoted by the high surface energy that this tissue has. The first zone is characterized by an increase in microhardness from Armco iron to the second zone (Fig. 4), which lies deeper. In the second zone, there was a process of intensive mixing of iron from common quality carbon steel, vanadium and carbon nano tissue. This led to the formation of a fine-grained composite structure with high hardness. The length of this zone is approximately 0.6 mm. The third zone directly touches the base metal [9, 10]. Structure formation in this zone takes place under conditions of higher heat transfer rate to common quality carbon steel. The result is a coarse-grained structure and less hardness.

Fig. 3c shows a panoramic photo of a section of a core of fusion of two steel plates between which is a gasket of vanadium powder. Study of microstructure and microhardness of structural components allows us to draw conclusions about the formation of vanadium-doped steel. On the left, we see a clear line of separation between Armco iron and crystallized melting zone. The microhardness of the melting core is much lower than for doping carbon nanotubes.

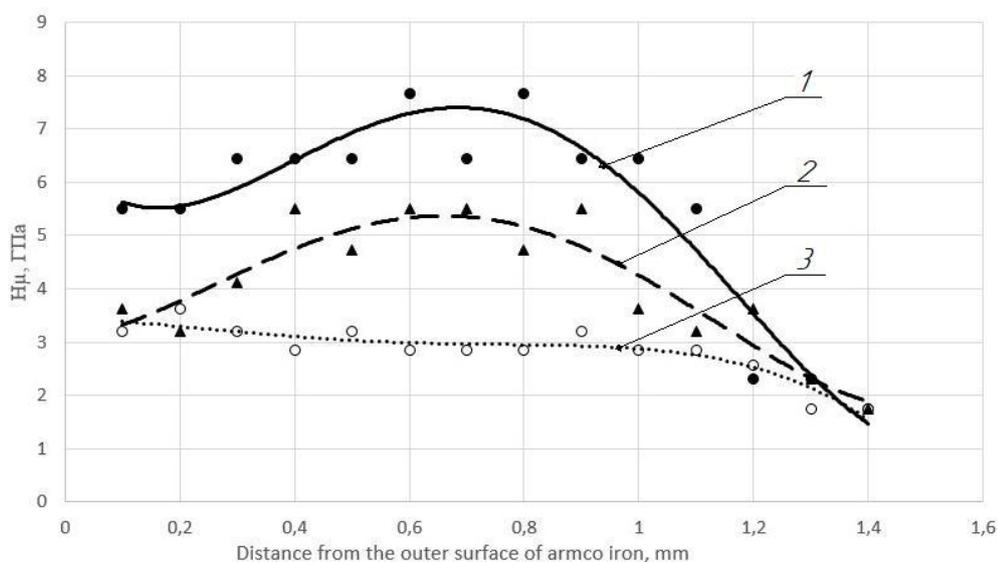


Fig. 4. Distribution of the microhardness of the cross-section of the fusion nucleus of two steel plates:
 1) in the presence of carbon nanofibers between them;
 2) in the presence of carbon nanotubes and powder vanadium between them
 3) in the presence of vanadium powder

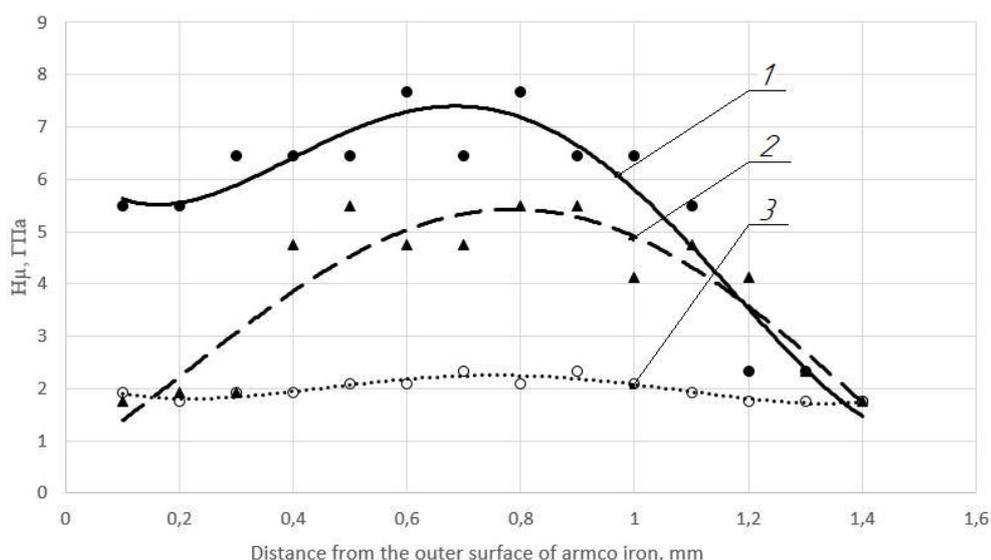


Fig. 5. Distribution of microhardness of the cross-section of the fusion nucleus of two steel plates:
 1) in the presence of carbon nanofibers between them;
 2) in the presence of carbon nanotubes and molybdenum powder between them
 3) in the presence of molybdenum powder between them

In the case of doping with the addition of molybdenum (Fig. 3d) in the gap between the welded plates, the presence of a structure characterized by high uniformity and fine grains and uniform microhardness throughout the cross section was revealed. At the same time, the layer of Armco iron (α -Fe) disappeared due to doping with molybdenum.

When doped with the addition of a double layer of carbon nanofibers and molybdenum powder (Fig. 3e), the processes of structure formation proceed with much more complex kinetics. On microstructure photographs, appeared defects in the form of gas vapors. This is a consequence of the large sorption capacity of carbon nanofibers. As the process takes place in the air, a sufficient amount of gases is released into the fiber, which is released when the composition is heated. The process of melting and crystallization occurs within a fraction of a second and is not sufficient to isolate the gas bubbles from the melting zone. It should also be noted that Armco iron did not take part in the process of formation of the structure. In addition, the process of stratification into separate zones is viewed. Under the plate with Armco iron formed the structure of doped with molybdenum white cast iron, which continues onto the high-carbon zone with columnar crystals and high hardness.

Conclusions

1. For the first time contact melting between sheet metal reinforcement (0.2 mm) and a common quality carbon steel plate with the addition of layers of molybdenum and vanadium nanopowders and carbon nanotubes between them was studied.
2. It was established that the addition of carbon nanotubes allows ensuring contact melting with fewer energy costs.
3. Adding carbon nanotubes allows you to obtain high-carbon layers of high hardness, and adding doping elements allows you to control the structure, grainy and physicomechanical properties of the material.
4. It was established that Armco iron does not participate in super-rapid processes of carbonization, leaving its structure and properties. This allows using such contact welding technology to form wear-resistant surface layers that correspond to Sharp's principle, after mechanical removal of a soft layer of iron armor.

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Савуляк В.І., Осадчук А.А. Контактне плавлення та структуроутворення в системі: α -залізо – наноматеріали – сталь звичайної якості.

В роботі вивчені процеси контактного плавлення між сталевими пластинами, яке виникає після подачі на контакт імпульсу струму від машини контактного зварювання для випадків, коли між пластинами розміщені наноматеріали у вигляді вуглецевих нановолокон та порошків тугоплавких металів. Встановлено, що додавання вуглецевої нанотканини дозволяє забезпечити проходження контактного плавлення з меншими енергетичними витратами та отримати високовуглецеві шари значної твердості, а додавання легувальних елементів створює можливість керувати структурою, зернистістю та фізико-механічними властивостями утвореного матеріалу.

Ключові слова: контактне плавлення, вуглецеві нановолокна, нанопорошки, тугоплавкі метали, високовуглецеві структури, мікротвердість.