ARPHA Proceedings

Proceedings CAUSummit 2024, 0053-0058
doi: 10.3897/ap.7.e0053

World Summit: Civil Engineering-Architecture-Urban Planning Congress

Peculiarities of Obtaining Complex Fe-Mn-B Ligatures by SHS-metallurgy Technology Using Production Wastes

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Abstract. By the method of SHS-metallurgy in Fe-Mn-B system complex ligatures with a wide range of alloying elements content have been developed and obtained. Traditional methods of obtaining ligatures, ferroalloys or modifiers are associated with the duration of the process, loss of valuable products, high energy consumption and environmental pollution. SHS-metallurgy method is devoid of these disadvantages and at the same time allows to form the target product consisting of both refractory and light-melting elements in one technological stage. In the process of synthesis of materials the effect of self-purification - thermodesorption of volatile impurities is manifested, and the resulting products are cleaner than the initial reagents. In addition, technological methods of SHS metallurgy, centrifugal force and gas pressure lead to reduced losses of the target product. This leads to minimization of environmental pollution, which is very important in the current trends of environmental pollution. The content of alloying components varied widely. As iron, steel rolling waste in the form of magnetite was used. In addition, the carbide-forming elements V, W and Mo, both together and separately, were introduced into the complex ligature by SHS. Dosed introduction of the required number of alloying elements allows to achieve the required structure and properties of iron-carbon alloys due to the formation of strengthening phases in the structure of the metal matrix.

Keywords: Ligatures, synthesis, SHS

Published by CAUSummit and peer-reviewed under the responsibility of “World Summit: Civil Engineering-Architecture-Urban Planning Congress - CAUSummit-2024”.

INTRODUCTION

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Improving the performance characteristics of alloys used in various industries is possible through alloying during their production. An important role in the process of alloying alloys is played by alloying elements, which make it possible to improve the strength, hardness, corrosion resistance and other characteristics of the material. Moreover, each alloying element has its own characteristics of influence on the properties and structure of the alloy.

Depending on the requirements, two or more component alloys can be used when alloying. The composition, quantity, percentage of digestibility, melting temperature of the ligature and other parameters are also important. Therefore, the selection of the composition of the alloy and its production is an important technological task.

Each alloying element has its own narrow area of influence on changing the properties of the alloy. For example, manganese increases the impact strength and hardenability of steel. It also promotes the formation of ferrite, which increases corrosion resistance. High manganese content can improve the weldability of steel. Boron increases the hardness and wear resistance of steel. It also promotes the formation of borides, which improves hardness. High boron content can reduce the ductility of steel. Special boron steels are used as structural materials in nuclear power engineering.

In general, in production alloying is carried out by introducing first a refractory alloy and then a low-melting alloy into the melt. In this case, the order of introduction of alloying elements, for example, into steel depends on the degree of affinity of the element for oxygen. This makes it possible to minimize the waste of alloying elements, and the quality of alloying depends on the degree of absorption of the alloying element by the alloy.

In industry, such alloys are obtained by fusing alloying components [1-7]. With such methods, obtaining alloys and carrying out the alloying process is associated with energy costs. In addition, the process of obtaining master alloys occurs with abundant release of harmful gases and loss of valuable products. Thus, the environmental situation in production is deteriorating. The loss of valuable components during the smelting of alloys is associated with different melting temperatures of alloying elements, which makes the production of complex alloys unprofitable.

As is known, the functional properties of iron-carbon alloys can be significantly improved due to the formation of strengthening phases in the structure of the metal matrix. Studies [8-14] have proven that alloying with carbide-forming elements such as V, W, Mo, Mn and B significantly increases their physical and mechanical properties, wear resistance and corrosion resistance. This is ensured due to the formation of dispersed nitrides, complex carbides, carbonitrides and intermetallic compounds, which are located along the grain boundaries, strengthen them and reduce diffusion permeability. In addition, it should be noted that manganese as an alloying element is of greatest interest in unstable austenitic steels that can be strengthened under the influence of deformation. It is obvious that the presence of a complex alloy consisting of refractory and low-melting elements will allow alloying to be carried out in one stage to obtain an alloy with the desired properties.

The development of multicomponent alloys, the production process of which will not be associated with the loss of valuable products, with minimal energy consumption, is possible using the environmentally friendly technology of self-propagating high-temperature synthesis (SHS), in particular SHS metallurgy [15-16]. SHS metallurgy technology makes it possible to obtain multicomponent complex alloys with different compositions of alloying elements. In a short period of time, ligatures are obtained without waste. This feature is due to the fact that the synthesis temperature is higher than the melting point of the components involved in the formation of the alloy.

In the field of research in the production of alloys using SHS metallurgy technology, we have a number of scientific and applied results, which are confirmed by patents and publications [17-19]. This article reveals the features of obtaining complex alloys in the Fe-Mn-B system using SHS metallurgy technology. In a subsequent scientific article, we will describe the effect of the complex alloys we obtained on the properties when producing structural boron steels grade 30Mn5B (22Mn5B) and bainitic cast iron.

In works [20-22], we used manganese production waste as one of the components of the exothermic mixture. In this work, one of the components used waste from steel rolling production in the form of scale.

The calculation of exothermic compositions was carried out under the condition that the amount of boron in the target product would be up to 1%. In view of the fact that the amount of boron in steels and cast irons is not large, and when alloying with boron ferroalloys, the boron content in boron ferroalloys is recommended to be 0.7-2.0% [23].

EXPERIMENTAL INVESTIGATIONS AND OBTAINED RESULTS

Thermodynamic calculations of more than ten exothermic compositions were carried out in the Fe-Mn-B system. Taking into account the results of thermodynamic calculations, preliminary experiments were carried out on a high-pressure SHS reactor and a laboratory centrifugal SHS installation. During the experiments, preliminary technological synthesis parameters were determined for all exothermic compositions and the depth of dispersion, the yield of the target product were determined, and the structure and chemical composition of the resulting products were studied. Based on the experimental results obtained, several promising exothermic compositions have been identified.

In the Fe-Mn-B system, based on selected promising exothermic compositions, further extensive research was carried out to establish optimal process parameters on the most practical and productive process equipment. The studies have shown that the most productive equipment of the two installations is a laboratory centrifugal SHS machine. To establish this fact, the synthesis of promising exothermic compositions was carried out under various technological conditions:

- in a SHS reactor under inert gas pressure 2MPa, 4MPa and 6MPa;
- on a laboratory SHS centrifugal machine was carried out at overloads of 275, 635, 1135 and 1750 a/g.

Experiments have established that for the same exothermic compositions, the completeness of yield in a centrifugal unit is at least 7% greater, and the depth of dispersion of the reaction mass is more than 5% less than in a high-pressure reactor.

At the same time, the appearance of the resulting master alloy in a centrifugal machine is monolithic, cylindrical in shape Figure 1a, and in the SHS reactor the resulting material is shapeless, in which a significant amount of the product is distributed in the slag Figure 1b.

It has been established that the most advantageous exothermic charge is: MnO_2:Fe_3O_4:B_2O_3:CaF_2:Al=60.8:9.5:3.0:3.5:32.0.

a **b**

FIGURE 1. 1a- external view of the obtained ligature on the centrifugal machine; 1b- appearance of the ligature obtained in SHS reactor.

From this charge, under the conditions of SHS centrifugal casting, the alloy was obtained at an overload of 1750 a/g. The completeness of the target product yield is quite high and amounts to 85%. In this case, the synthesis of the alloy is accompanied by a large release of heat and a significant scatter of the reaction mass ~12%. An innovative approach and the introduction of finely dispersed manganese metal powder into the exothermic mixture led to an increase in the manganese content in the master alloy. This was facilitated by the excess heat of the synthesis reaction, due to which the manganese melted and was evenly distributed in the alloy. This made it possible to introduce an excess amount of manganese into the alloy, thereby reducing the depth of spread of the reaction mass.

Thus, the manganese content was increased by at least 26%. The depth of dispersion of the reaction mass decreased and did not exceed ~4%, which from an environmental point of view makes the technology for producing a complex alloy very profitable.

Figure 2a shows the dependence of the completeness of the ligature yield on the magnitude of the overloads (a/g) depending on the increase in manganese content 0-100 grams. in an exothermic charge of the composition: MnO_2:Fe_3O_4:B_2O_3:CaF_2:Al=60.8:9.5:3.0:3.5:32.0. It can be seen that for all compositions, with increasing overload, the spread of the reaction mass decreases. Figure 2b shows the dependence of the depth of scatter of the reaction mixture and changes in the manganese content of 0-100 grams. in an exothermic charge of the composition: MnO_2:Fe_3O_4:B_2O_3:CaF_2:Al=60.8:9.5:3.0:3.5:32.0 at various overloads (a/g). It is seen,

It can be seen that the completeness of the yield of the target product increases linearly and reaches a maximum at overload of 1750 a/g with an excess of manganese of 70 grams. Thus, experiments have established the maximum limit for the dissolution of manganese, after which, despite a drop in the scatter of the reaction mass, no increase in manganese was observed. In fig. Figure 3 (a and b) shows the structure, distribution of elements and chemical composition of the obtained alloys without and with an excess of manganese of 70 grams.

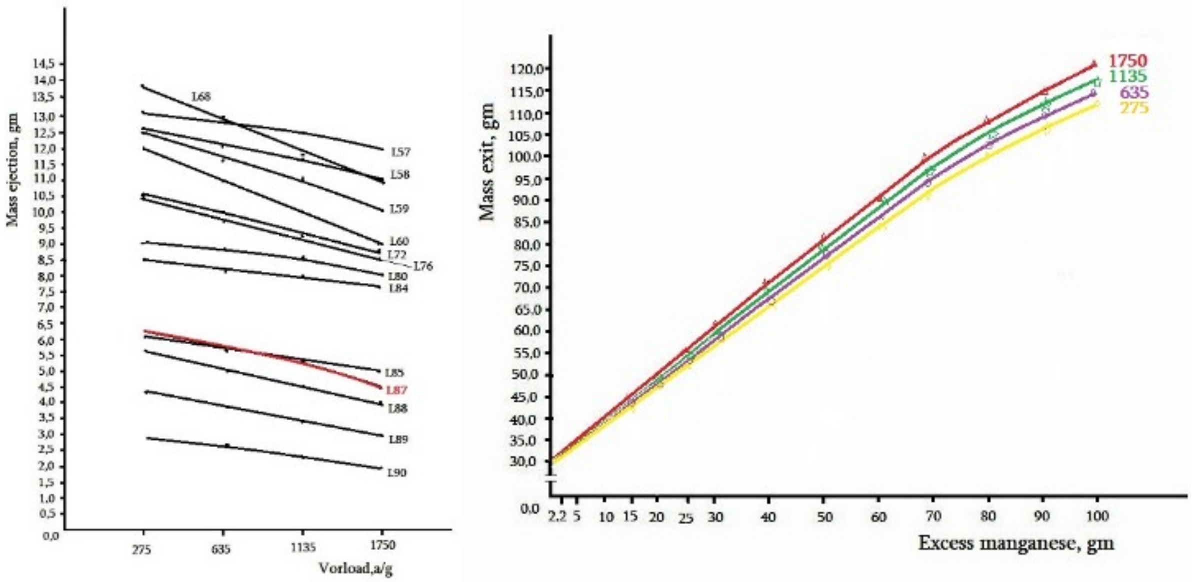
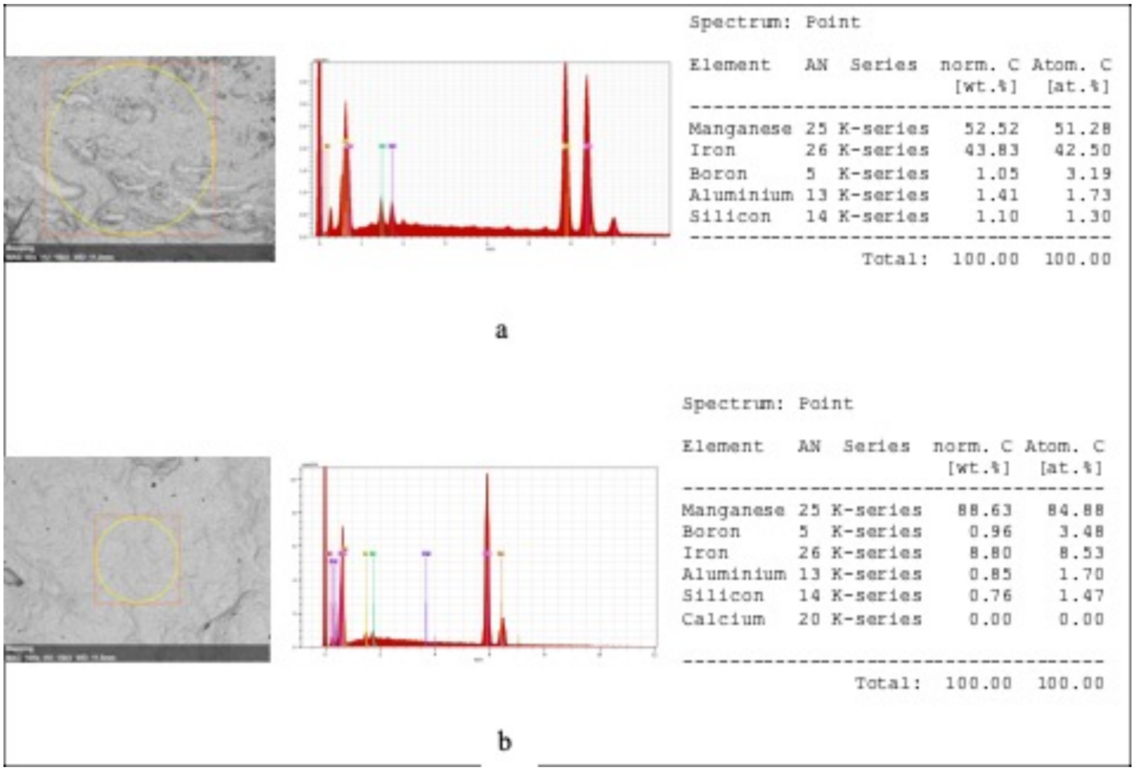


FIGURE 2. a - Dependence of the full yield of ligature on the value of overloads (a/g) depending on the increase of manganese content 0-100 grams in the exothermic charge of composition: MnO_2:Fe_3O_4:B_2O_3:CaF_2:Al=60.8:9.5:3.0:3.5:32.0; b - Dependence the mass ejection depth and change of manganese content 0-100 grams in exothermic charge of composition: MnO_2:Fe_3O_4:B_2O_3:CaF_2:Al=60,8:9,5:3,0:3,5:32,0 at different overloads (a/g).



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Spectrum: Point

Element    AN  Series   norm. C Atom. C
                         [wt.%]  [at.%]
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Manganese  25  K-series   52.52   51.28
Iron       26  K-series   43.83   42.50
Boron       5  K-series    1.05    3.19
Aluminium  13  K-series    1.41    1.73
Silicon    14  K-series    1.10    1.30
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                  Total:  100.00  100.00
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Spectrum: Point

Element    AN  Series   norm. C Atom. C
                         [wt.%]  [at.%]
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Manganese  25  K-series   88.63   84.88
Boron       5  K-series    0.96    3.48
Iron       26  K-series    8.80    8.53
Aluminium  13  K-series    0.85    1.70
Silicon    14  K-series    0.76    1.47
Calcium    20  K-series    0.00    0.00

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                  Total:  100.00  100.00
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FIGURE 3. Structure, distribution of elements and chemical composition of the obtained alloys; a- charge composition MnO_2:Fe_3O_4:B_2O_3:CaF_2:Al=60.8:9.5:3.0:3.5:32.0 without excess manganese; b - mixture composition MnO2:Fe_3O_4:B_2O_3:CaF_2:Al=60.8:9.5:3.0:3.5:32.0 with an excess of manganese 70 grams.

In addition, any fine waste from ferroalloy production can be used as manganese metal powder, which will significantly expand the range of alloy production. In addition, instead of manganese oxide, waste from manganese production in the form of pyrolusite can also be used. The obtained scientific achievements are patented for the acquisition of intellectual property.

Based on the developed exothermic mixture in the Fe-Mn-B system, complex alloys with carbide-forming elements V, W and Mo of the following compositions were also obtained:

MnO_2:Mn:Fe_3O_4:B_2O_3:V_2O_5:Al=91,2:105:28.0:12,0:85,6:87,2.

MnO_2:Mn: Fe_3O_4:B_2O_3:WO_3:Al=91,2:105:39,3: 0:12,0:94,2:79,5.

MnO_2:Mn: Fe_3O_4:B_2O_3:MoO_3:Al=91,4:105:56,4:12,0:68,4:87,0.

The minimum losses of the reaction mass and the maximum yield of valuable product were observed in compositions that consisted of 50% of the mixture of the composition MnO_2:Fe_3O_4:B_2O_3:CaF_2:Al=60.8:9.5:3.0:3.5:32.0 and 50% of one of the exothermic mixtures of stoichiometric composition to obtain a carbide-forming alloy in the Fe-Mn-B -V, Fe-Mn-B-W and Fe-Mn-B -Mo systems, Figure 4.

FIGURE 4. Appearance of complex carbide-forming ligatures obtained in the systems Fe- Mn-B -V, Fe-Mn-B W and Fe-Mn-B -Mo.

The minimum losses of the reaction mass and the maximum yield of valuable product were observed in compositions that consisted of 50% of the mixture of the composition MnO_2:Fe_3O_4:B_2O_3:CaF_2:Al=60.8:9.5:3.0:3.5:32.0 and 50% of one of the exothermic mixtures of stoichiometric composition to obtain a carbide-forming alloy in the Fe-Mn-B -V, Fe-Mn-B-W and Fe-Mn-B -Mo systems, Fig.4.

CONCLUSION

For the production of carbide-forming ligatures, it was also established that the most promising is also the SHS centrifugal machine. Optimum technological parameters of the synthesis of these complex ligatures were established during the experiments. Investigated structure and chemical composition of obtained ligatures.

After conducting experiments and establishing optimal technological parameters for the synthesis of complex ligatures, the necessary number of ligatures was obtained. The developed complex ligatures will be used for alloying steel and cast iron to improve their physical and mechanical characteristics, the scientific results of which will be presented in subsequent publications.

ACKNOWLEDGMENTS

The work was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG) [grant number STEM-22-761].

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