New technology for doped Fe alloys production

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Abstract

SHS is recognized as an attractive process for producing high-temperature, hard materials that difficult and/or expensive to produce by conventional fabrication methods. The goal of this work is to investigate new express technology of doped Fe alloys materials. The high density, homogeneity of the components, and the low processing temperatures achieved and minimum synthesis time are all of paramount importance in fabricating Fe alloys as functional materials.

Introduction

A new trend in modern science and technology, the Self-propagating High-temperature Synthesis (SHS) of refractory inorganic materials (carbides , borides, nitrides, silicides, etc.), have been formulated in 1967 by the scholarship of Prof. Merzhanov. In more than 30 years, large variety of SHS processes was suggested by Russia and Kazakstan investigators, original equipment was designed, raw-material base and economic efficiency were analyzed. In the early 80-s American and Japanese scientists joined Russia -Kazak researchers in these studies [1].

The SHS method is based on the exothermic interaction of two or more chemical elements or compounds, which proceeds in oriented combustion regime. The process propagates in a thin layer of a green mixture after the local initiation of the reaction along the whole system due to the heat transfer from hot products to a cold starting mixture [2]. The rate of propagation and the reaction temperature depend on (1) thermodynamic (heat of the new chemical compound formation, heat capacity of the reaction products, initial temperature and green mixture composition), (2) physical (thermal conductivity of a powder mixture, mixture density, external pressure, shape and size of the powder particles, polydisperse phase, wear- and hardening degree or the presence of defects in the particle structure), (3) technological (uniformity of the mixture after stirring, the activation degree of powders), and (4) chemical (the degree of powder impregnation, concentration of adsorbed impurities and dissolved gases) system properties.

The goal of this work is to investigate new express technology of doped Fe alloys materials, to utilize the unstable conditions of burning for obtaining materials with unusual compositions.

Experimental part

There exists in the literature a large amount of experimental data for various systems. We have, therefore, restricted our comparison to solid-solid systems because of their potential for advanced applications. SHS provides the production of multi-layers corrosion-resistant coatings onto various surfaces, the formation of a gradient transition layers between the substrate and the coatings.

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That leads to the formation of adhesion-strong connections, resistant to sudden temperature gradients as well as other materials for the needs of electro-technology, radio electronics, machine building, chemical industry, etc. Let consider a problem, which arises for a chemist or a material scientist, who begins the study of SHS, that of apparent irregularity of the process. Indeed, after initiation the combustion wave propagates quite spontaneously. The velocity of its propagation, the temperature, and the concentration in each spot of the SHS wave is determined by the internal parameters of the system, i.e. by the stock of chemical energy, the reaction kinetics, thermal conductivity. The peculiarities of the SHS are: high self-heating of the reaction mass as a result of chemical reactions, which allows to synthesize and form materials at temperatures of 800 to 350 0℃ owing to the system internal resources only without external heating; high rates of processes (up to 0.15 ㎧); high degree of transforming the reagents into final products and evaporation of volatile impurities, which is connected with high temperatures.

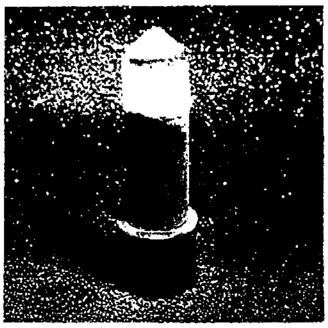

Fig.1. A combustion wave propagation along the mixture.

SHS is a prospective scientific and technological field, which is based on the principle of maximum utilization of chemical energy of the reacting substances for obtaining inorganic compounds, materials and articles of various purposes. SHS is a kind of combustion. The process is so simple, that any of you may reproduce it. You mix powders. The obtained mixture is compacted into a pellet of the porosity not less than 30% (pellets of higher porosity are not handy because they are too brittle and those of higher density are hard to be ignited). Combustion may be initiated by a tungsten wire under electric current (by the way, there is a lot of ways for to ignite a pellet; since the product quality is not dependent on the method of ignition, its choice depends on the convenience only).

The peculiarity of this process is the absence of flame, i.e. combustion does not yield gaseous products. The initial reagents, intermediate and final products are in the condensed state. It appeared to be interesting that the combustion products were all high-quality refractory compounds. It takes hours to synthesize these materials by the conventional furnace method, while the combustion wave does it for a few seconds. Combustion does not require complicated equipment and is energy-saving. Besides, the product purity is determined by the purity of the initial reagents only. The process has been found to critically depend on the composition and thickness of the layers. Combustion products differ in microstructure, phase composition, physical and mechanical properties from similar bulk samples.

Metal-thermal synthesis is one of the varieties of gasless synthesis. The development of the SHS-technologies has led to a considerable extension of both the chemical level of the products synthesized and the raw materials used in SHS [3]. The synthesis from elements could not completely meet the requirements of industry, that is why cheaper sources for the SHS materials have been found, metal and non metal oxides, metal reductants (aluminum, magnesium), and other additives [4,5].

The chemical scheme of aluminum-thermic SHS process can be written as

$$XO_m + \mu YO_n + \nu Y + (m + \mu n)Al \rightarrow XY_{\mu+\nu} + (m + \mu n)Al_2O_3,$$

Where X,Y are chemical elements of a refractory compound; μ, ν, m, n are stoichiometric coefficients. For example,

$$3TiO_2 + Fe_2O_3 + 4Fe + 6Al \rightarrow 3TiFe_2 + 3Al_2O_3$$

The combustion product appears to be a two-phase compound, aluminum oxide being distributed uniformly over the product. Therefore, an additional technological stage of chemical washing-off is introduced to separate the product from aluminum oxide. The combustion temperature of the process being higher than that of the metal melting point is a distinctive feature of the Al-thermic process. The combustion product is a multicomponent high-temperature melt. The phase separation in the melt takes place under gravity (light aluminum oxide comes up to the surface, while a heavy refractory compound stays at the bottom).

On the first stage of our researches, a systematic works of the activation of initial combustible mixtures on the basis of Al, Fe, Ti aimed at obtaining maximally active layers were carried out. As a result of this investigation, the inter-relationships between the compound properties and microstructure and the process conditions (ignition temperature, concentration and geometry parameters, etc.) were established [4,5].

On the second stage of work we concentrated our efforts on the initiation of two or more waves of combustion in parallel layers, study of peculiarities of their conjugate propagation and interaction, macro kinetic peculiarities and effects of variation of location and parameters of the layer-energy carrier. The possibility of controlling the micro-tructure and phase formation by means of carrying out SHS under the effect of additional external conditions of electric and magnet fields were studied.

It was emphasized the specification of main regularities of the production of multi-layered materials under the conditions of SHS in the following four schemes:

(1) SHS in a thin layer;
(2) SHS in substrate layers;
(3) Interaction of the SHS layer with an external one;
(4) interaction of two and more SHS waves.

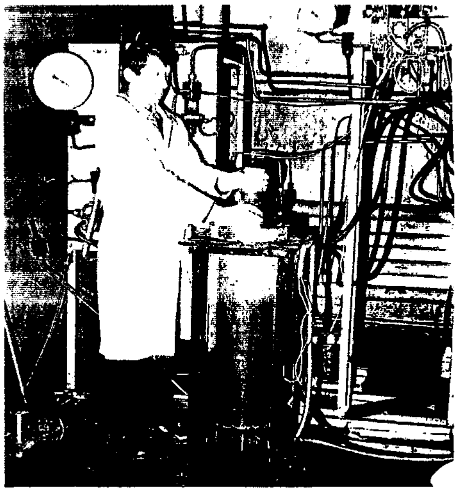

Fig.2. SHS reactor

Results and discussion

Practical application of SHS powders, materials and articles to various fields of industry has forwarded the problem of mastering the control and regulation of their structure formation at any level (crystal, macro- or microstructures). The paper is engaged with the study of the evolution of the medium structure in the processes of chemical conversion at the account taken from heat- and mass-exchange. The most complete information was obtained in the field of structural statics, which studies the relationship between the structure of the SHS final products and the parameters of the green charge and the conditions of their synthesis. In fact, this direction may be considered as physical materials science of SHS products. The obtained experimental results will become the foundation for the development of theoretical models of structure formation in high-temperature processes of the SHS type. In particular, reliable perspectives are provided by computer simulation of the combustion wave if real structures of heterogeneous media are taken into consideration.

In our work, the attempt was made not only to illustrate some special chemical aspects of SHS technology from the material science point of view and to point out how chemistry can be used but also the problems which arise and which have become clear due to the immense work of numerous scientists on the basis of their competencies and their respective potential.

Most of the work in progress is based on the notion that SHS-wave, as well as any other type of combustion, can propagate in the regime of partial or complete burning-out with maximal use of the fuel. In connection with this, conjugate propagation of two or more parallel combustion waves in layered structures open the possibilities of reacting at high temperature, separate layers varying in quantitative and qualitative composition. This work is original for SHS physics and chemistry, and open up possibilities of synthesizing new materials with different layers, pre-designed functional and specific electrophysical properties.

Conclusion

1. Possible strategies for advanced thin layer structural materials (reliability and reproducibility) were realized.
2. As a result we established the optimum conditions for synthesis of a number of Fe alloy composite materials possessing specific properties.
3. The scientific and technical results can be spread to a lot of countries, which investigated self-propagated high-temperature synthesis application.
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4. Authors of the paper can give recommendations and suggestions for future work especially in areas, which would benefit from the expertise of physicists and chemists.

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