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DEVELOPMENT OF A NEW IRON-BASED SHAPE MEMORY ALLOY

Досліджено технологію отримання нового сплаву на основі заліза з ефектом пам'яті форми, який містить: залізо, марганець, кремній, вуглець, хром, нікель, кобальт, мідь, ванадій, ніобій, молібден, сірку і фосфор. Вивчено окалійностійкість і корозійну стійкість сплаву. Результати досліджень показали, що ступінь відновлення форми запропонованого сплаву становить 73–95 %.

Ключові слова: *сплав на основі заліза, ефект пам'яті форми, окалійностійкість, корозійна стійкість.*

1. Introduction

One of the special properties of the alloys is a shape memory effect, which is widely used in various technical fields (special engineering, instrumentation, aerospace equipment, household appliances, etc.) [1–3]. At the same time the most widely used alloys are Ti–Ni-based alloys that are used primarily in the medical field, thanks to a unique combination of performance properties [4–6]. However, this alloy is quite expensive and its use in machinery is not advisable. In this regard, researches for finding and developing new shape memory alloys are relevant and iron-based alloys have the greatest interest for metallurgy and mechanical engineering [7–9]. For development of appropriate alloys it is necessary to consider the ratio of high mechanical and performance properties with adequate values of the coefficient characterizing the shape memory effect.

2. The object of research and its technological audit

The object of research is the technology for obtaining an iron-based shape memory alloy. One of the most problematic moments in this process is a necessity to increase the shape recovery degree while maintaining high mechanical characteristics.

Technological audit is performed to identify the characteristics of the process in terms of production of a new alloy with the required properties. The aim of audit is determination of the following alloy characteristics: mechanical alloy characteristics, oxidation resistance, corrosion resistance, shape recovery degree.

Technological scheme of development of a new iron-based shape memory alloy is shown in Fig. 1.

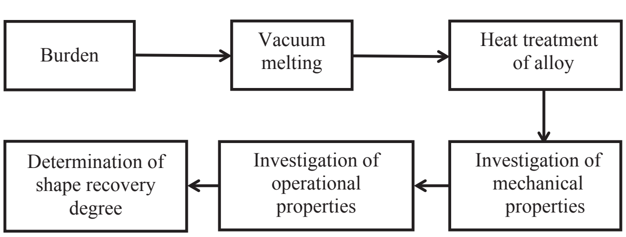

Fig. 1. Technological scheme of development of a new iron-based shape memory alloy

Chemical composition of the alloy is theoretecally selected based on the given parameters of mechanical, operational, and special properties. Its detailed description is given in [10]. Burden composition is: FeMn (81,2 %), FeSi (75,8 %), C (100 %), FeCr (60,3 %), Ni (100 %), Co (100 %), Cu (100 %), V (60 %), FeNb (65 %), FeMo (60 %). Alloy smelting is carried out in a vacuum induction furnace ОКБ-862 (Russia), the appearance of which is shown in Fig. 2.

Fig. 2. General view of the vacuum induction furnace ОКБ-862

The device operates as follows. Burden is loaded in the crucible with a capacity of 15 kg, then furnace shell is closed and a vacuum $2\cdot10^{-3}$ mm Hg is created. Then the furnace is heated to completely melt of all of the components and the molten metal is poured under vacuum into a prepared form. Deoxidation to reduce the content of harmful impurities is made by aluminum.

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The heat treatment of produced samples of a new alloy is carried out in two modes to identify the most efficient:

1) quenching at a temperature of 1180 °C and aging (temperature 1000 °C, duration 1 hour with followed air cooling);

2) quenching at 1180 °C and aging (temperature 800 °C, duration 10 hours with followed air cooling).

The first aging mode is characterized by the presence of large amounts of vanadium carbides, while the second mode is characterized by the presence of large amounts of chromium carbides.

The main focus to improve the development of a new iron-based shape memory alloy is a selection of the burden, smelting and heat treatment. The most important should be considered a necessity of temperature control and duration of heat treatment. This allows to improve practical conditions to obtain the necessary properties of the alloy.

3. The aim and objectives of research

The aim of research is to develop a new iron-based shape memory alloy.

To achieve this aim it is necessary to solve the following tasks:

1. Investigate the process of obtaining iron-based shape memory alloy.
2. Investigate the mechanical properties and performance properties of obtained alloy.
3. Determine the shape recovery degree of obtained alloy.

4. Research of existing solutions of the problem

Analysis of published data shows that the cheapest group of shape memory alloys is iron-based austenitic alloys. One of application of such alloys is their use as load-bearing elements for weldless joint of structures, high-pressure pipelines, elastic elements, etc. [10–12].

There are a number of iron-based shape memory alloys, and this effect is known in some austenitic steels [10–15]. However, disadvantages of the known alloys are low corrosion resistance, for example, due to the high content of manganese, low oxidation resistance, brittle phase formation, and insufficient viscosity and strength values. Also, the main disadvantage of this group of alloys is a low shape recovery degree. The cause for these disadvantages is a chemical composition of the alloy.

A widely used steel 4Cr15Ni7Mn7W2MoSi [13] is a heat resistant austenitic steel that is used in industry as gas turbine blades, fasteners, operating at a temperature of 650 °C for a limited time. However, disadvantage of this steel is insufficient amount of precipitation-hardening particles that affect the strength of the steel and low values of shape memory effect coefficient.

In particular, [14] is devoted to the iron-based shape memory alloys, but the disadvantages of this alloy is an insufficient shape recovery degree, and low mechanical properties. This is due to the fact that it doesn't contain such essential alloying elements as copper, vanadium, niobium, molybdenum. Also, this alloy has a sufficiently low corrosion and oxidation resistance, which has a negative effect on the further use of this product. A similar circumstance is noted in [15]. Also, disadvantage of this alloy is the technological complexity and the high cost of production. Besides, there is no information about heat treatment.

Thus, the results suggest that it is relevant to develop an iron-based alloy, which combines important properties such as a high degree of shape recovery, strength, viscosity, corrosion resistance and oxidation resistance.

5. Methods of research

Material for research is a new iron-based shape memory alloy, which contains iron, manganese, silicon, carbon, chromium, nickel, cobalt, copper, vanadium, niobium, molybdenum, sulfur, and phosphorus (weights, %):

– manganese from 4 to 20;
– silicon from 1,0 to 4,5;
– carbon from 0,1 to 1,0;
– chromium from 10,0 to 25,0;
– nickel from 1,0 to 10,0;
– cobalt from 1,0 to 10,0;
– copper from 1,0 to 4,0;
– vanadium 0,5 to 2,0;
– niobium from 0,3 to 1,5;
– molybdenum from 0,5 to 2,0;
– sulfur, up to 0,01;
– phosphorus up to 0,045;
– the rest is iron.

Input variables of the process are the chemical composition of the alloy.

Output variables of the process are mechanical, operational and special properties.

Mechanical tests are conducted at room temperature in accordance with GOST 1497-84 on the universal machine, corresponding to GOST 28840-90. Standard test specimens are tested in uniaxial stretching at room temperature, the length of the samples is 100 mm.

6. Research results

It is found that alloy has sufficient mechanical properties, described in detail in [16]. Visual examination of oxidation resistance involves heating to temperatures of 600–1000 °C (step – 50 °C) in the open air and subsequent surface examination.

The results show that the surface oxidation isn't observed for heating of the samples in this temperature range.

Experiment on the corrosion resistance of alloy is carried out gravimetrically in 10 % sulfuric acid solution. During the experiment it is found that alloy is corrosion resistant and doesn't change a mass in 10 % solution of sulfuric acid.

Research of microstructure confirms the presence of precipitation hardening in the alloy, after the aging mode, wherein an amount of carbide inclusions for second processing mode is more than after the first processing mode.

Quantitative phase analysis for the presence of residual austenite in the alloy is also done by X-ray apparatus ДРОН-3 (Russia) [4, 5]. Alloy diffractogram after quenching at the temperature 1180 °C and cooling in air shows a burst corresponding to γ-Fe, therefore, the content of retained austenite in the alloy – 100 %.

Samples are thinned by hot rolling. Rolling has three stages:

1. Heating to 500 °C and reforging in the forge shop to a thickness of about 30 mm.

2. Heating to 800 °C and rolling to a thickness of 2,7 mm.

3. Heating to 1190 °C and rolling to a thickness of 2,0–2,1 mm.

Shape recovery properties are measured by tensile test of specimens: thickness – 2,0–2,1 mm, length – 30 mm. Samples are deformed by 5 % at room temperature and then heated above the reverse martensitic transformation temperature. Shape recovery degree (α) is estimated according to the formula:

$$\alpha = ((l_d - l_h)/(l_h - l))\ 100\ \%,$$

where l_i – initial length of the sample; l_d – length of the sample after deformation; l_h – length of the sample after heating.

Research results show that the shape recovery degree of the proposed alloy is 73–95 %.

Thus, the proposed alloy has a high degree of shape recovery while maintaining such important properties as strength, viscosity and corrosion and oxidation resistance.

7. SWOT analysis of research results

Strengths. Strengths of this research are the development and implementation of obtaining a new iron-based shape memory alloy. Advantages of the alloy as compared with the analogues are as follows:

– Lower production cost of shape memory alloy.
– Reduction of time-consuming.
– Optimization of alloy composition.
– Increasing productivity.

Weaknesses. Weaknesses of this research are related to the fact that the shape memory effect of developed alloy is implemented on smaller samples, which greatly reduces the possibility of further use of this alloy.

Opportunities. Additional features for achieving the aim of research are in development of a wider range of chemical composition of the alloy to vary the operational special characteristics. The use of components made of developed alloy can significantly simplify the process of replacing and installing components as load-bearing elements for weldless joint of structures, high-pressure pipelines, elastic elements, etc. Also, implementation of developed technology of obtaining a new iron-based shape memory alloy is capable of replace expensive alloys in this category and significantly reduces the cost of the production process.

Threats. Threats.in the implementation of the obtained research results are related to the following factors:

– Management of companies that are operated machine parts. Investment of additional funds in development of new alloys. The company's policy is to purchase finished products and unwillingness to develop their technologies.

– The market of modern engineering equipment offered by the world's leading companies. Long-term invest forecast can show that purchase of a new type of units can be more appropriate to modernization of physically obsolete.

Thus, SWOT analysis of research results allow to identify the main directions for successful achievement of aim of the research. Among them are: development of new iron-based shape memory alloys.

8. Conclusions

1. It is found that the main direction of improvement of the development process of a new iron-based shape memory alloy is a selection of the burden, smelting and heat treatment. The most important is a necessity of temperature control and duration of heat treatment. This allows to improve an effectiveness of obtaining the necessary properties of the alloy.

2. It is found that the developed iron-based shape memory alloy has sufficient mechanical properties.

Research results show that the surface oxidation isn't observed for heating of the samples in temperature range 600–1000 °C.

3. During the experiment it is found that alloy is corrosion resistant and doesn't change a mass in 10 % solution of sulfuric acid.

It is found form recovery degree of the proposed alloy is 73–95 % while maintaining such important properties as strength, viscosity, corrosion and oxidation resistance.

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РАЗРАБОТКА НОВОГО СПЛАВА НА ОСНОВЕ ЖЕЛЕЗА С ЭФФЕКТОМ ПАМЯТИ ФОРМЫ

Исследована технология получения нового сплава на основе железа с эффектом памяти формы, который содержит: железо, марганец, кремний, углерод, хром, никель, кобальт, медь, ванадий, ниобий, молибден, серу и фосфор. Изучены окалиностойкость и коррозионная стойкость сплава. Результаты исследований показали, что степень восстановления формы предложенного сплава составляет 73–95 %.

Ключевые слова: сплав на основе железа, эффект памяти формы, окалиностойкость, коррозионная стойкость.

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