DOI 10.52209/1609-1825_2021_2_47 UDC 621.074

Ni-hard-Class Cast Irons, Prospects for Their Improvement

[1]*ISSAGULOV Aristotle,* Dr. Tech. Sci., Professor, Executive Director, aristotel@kstu.kz,
[1]*IBATOV Marat,* Dr. Tech. Sci., Professor, Rector, m.ibatov@bk.ru,
[2]*KOVALYOV Pavel,* Cand. Tech. Sci., Associate Professor, kovalev_pv@spbstu.ru,
[1]**SHCHERBAKOVA Elena,* PhD, Senior Lecturer, sherbakova_1984@mail.ru,
[1]*DOSTAEVA Ardak,* PhD, Senior Lecturer, ardak_erkekyz@mail.ru,
[1]*ARINOVA Sania,* PhD, Lecturer, sanya_kazah@mail.ru,
[1]Karaganda Technical University, Kazakhstan, 100027, Karaganda, N. Nazarbayev ave., 56,
[2]Peter the Great St. Petersburg Polytechnic University, Russia, 195251, St. Petersburg, Polytechnicheskaya str., 29,
*corresponding author.

Abstract. *The goal is to carry out an informational analysis of the world trends in improving Nihard cast irons. The effect of additional alloying on the properties of Nihard is considered. It is shown that introduction of certain elements can change not only the character and nature of the carbide phase but also the very form of the presence of carbon in cast iron. The analysis shows that the use of modification and some types of heat treatment also has a positive effect on the properties of Nihard. It is noted that one of the tendencies to increase wear resistance of Nihard is developing a structure that is resistant to a specific wear mechanism. It has been established that the transfer of a part of the carbide phase into spheroidal graphite has a positive effect on the properties of Nihard. On the basis of the carried out information analysis, the tendencies of improving the composition of Nihard cast irons, taking into account the raw material base of the Republic of Kazakhstan, have been formulated.*

Keywords: *ni-hard, alloying elements, wear resistance, graphite inclusions, modification, heat treatment.*

Introduction

Ni-hard cast iron is a group of cast irons with a high content of the chemical elements such as nickel and chromium. Ni-hard alloys have high hardness and high wear resistance. Ni-hard alloys are currently divided into two subgroups [1]:

1 – alloys with a content of the chemical elements: 2.6-3.3% Cr, 4% Ni, 2% Cr (they are called ni-hard-1 and ni-hard-2);

2 – alloys with a content of the chemical elements: 3% C, 9% Cr, 5% Ni, 2% Si (it is called ni-hard-4).

These alloys are certified under different names and are widely used as wear-resistant materials in almost all countries.

Table № 1 [2] indicates the chemical composition and the analog of the name of the ni-hard class cast irons of different grades.

Research results

The review paper [3] provides a detailed comparison of the properties and structure of Class 1 ni-hards with different content of alloying elements. Three ASTM Class 1 alloys, A532 B1, B2, and T1, were considered as samples for research. Studies have shown that the matrix of the T1 alloy (an alloy with a low nickel content) consists of bainite and martensite, while the matrix of the B1 and B2 alloys (alloys with a high nickel content) is represented by austenite and martensite. The ultimate strength increased from 340MPa to 450Mpa in the T1 alloy after heat treatment, while the ultimate strength did not change and was 350Mpa after annealing in alloys with a high nickel content (B1 and B2 alloys). The wear resistance of the alloys did not change after heat treatment. The structure of the primary carbides also remained unchanged. Summarizing the conclusions of the authors, it can be noted that changes in the matrix of alloys of this class of ni-hards do not affect the wear resistance even with a slight increase in the hardness of the matrix as a result of any effects. In other words, changing the content of such chemical elements as Ni, Cr, Si, C within the specified limits of a certain class is not able to improve the wear resistance of the nihard-1 alloy even when performing heat treatment.

Nihard-4 alloy is the most widely used material as a wear-resistant material used in the mining and metallurgical industries. This alloy was developed by International nickel company. Chromium-nickel cast iron of the grade ChH9N5 is an analog of the nihard-4 alloy in the CIS [4].

Chemical composition and analog of the name of ni-hard class cast irons of different grades

Cast iron	Mass fraction, %						Hardness, HB (HRC)
	C	Si	Mn	Cr	Ni	Mo	
ni-hard-1 Ni-Cr-HC Ni-Cr-GB	3.0-3.6 2.9-3.7	0.8 0.8	till 1.3 till 1.3	1.4-4.0 1.1-1.5	3.3-5.0 2.7-4.0	till 0.1 0.1	550-600 550-600
ni-hard-2 ChH4N2 Ni-Cr-LC	2.5-3.0 2.8-3.6	0.0-1.0	0.8-1.3 till 1.3	0.8-2.5 1.4-4.0	3.5-.5.0 3.3.-5.0	till 0.1	400-650 550-600
ni-hard-4	2.8-3.2	0.2-0.8	0.4-0.6	7.5-9.0	5.5-6.5	-	54-62
ChH9N5 Ni-HCr 300Cr-Ni-Si 952 W4	2.8-3.6 2.5-3.6 2.5-3.5 3.3-3.6	1.2-2.0 1.0-2.2 1.5-2.2 2.0-2.4	0.5-1.5 till 1.3 0.3-0.7 3.5-4.0	8.0-9.5 7.-11.0 8.-10.0 7.0-9.0	4.0-6.0 4.5-7.0 4.5-6.5 3.0-3.5	≤0.4 till 1.0 0.5 1.5	490-610 500-600 430-690 400-700
ChH8N4FSch	3.1-3.6	1.2-1.8	0.5-0.6	8.-10.0	4.0-6.0	-	58-63
Alloy 3-2-1	3.1-3.6	0.2-0.6	0.5-0.8	1.0-2.0	1.5-3.2	0.4-1.1	55-62

The authors study the wear resistance of the nihard-4 alloy in comparison with high-chromium cast iron in [5]. The mass fraction of such a chemical element as chromium varies from 3 to 15%.

As a result of the performed studies, it was found that a different mechanism of surface destruction occurs in different operating modes. The different mechanism of destruction of the surface determines the degree of wear.

Thus, it can be concluded that in each specific case, it is necessary to create a surface that will have maximum resistance to the wear mechanism, and not to achieve maximum hardness of the material.

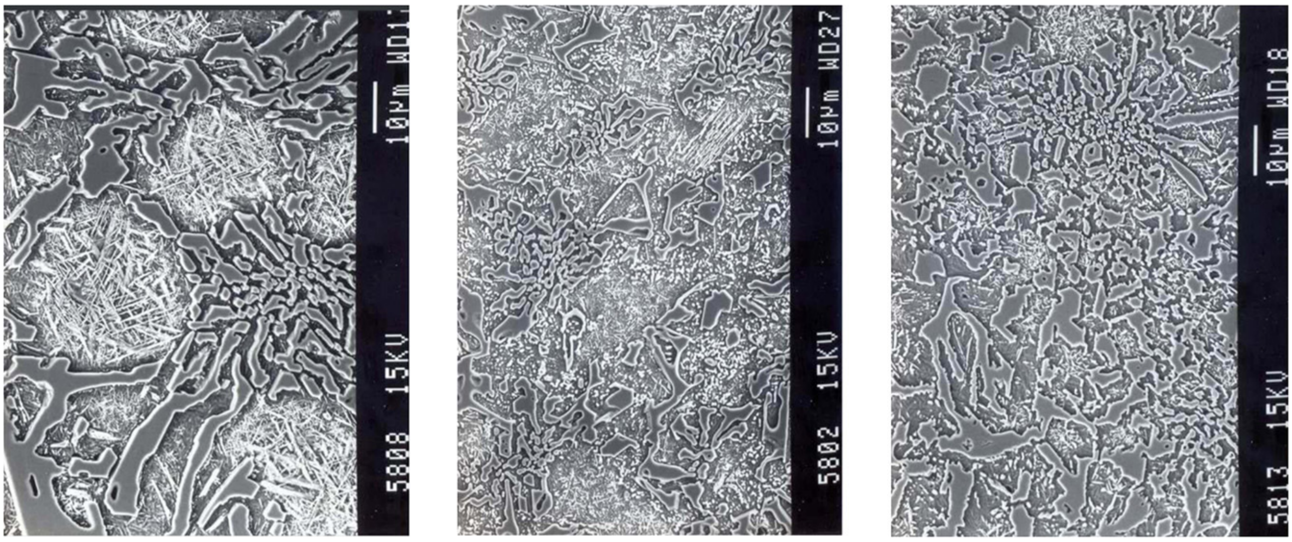
The authors Gushchin N.S., Alexandrov N.N. propose a new class of cast irons that have properties close to ni-hards. It is proposed to use medium-alloyed chromium-nickel cast irons with spherical graphite as such alloys. The difference in the form of the presence of carbon is the main difference between the proposed alloys and ni-hards. Carbon is present in the form of carbides of various genesis and types in ni-hards, while carbon is found in the form of carbides, and in the form of spherical graphite in the proposed alloys.

The effect of heat treatment on the properties of ni-hard was studied in [6]. The wear process of three ni-hard 4 alloys after heat treatment was analyzed in studies (Figure 1). The heat treatment was carried out at temperature 820°C for 4 hours, followed by air cooling to room temperature. The tempering was then carried out at three temperatures: 300, 450 and 550°C for four hours, followed by air cooling to room temperature.

Various types of abrasives were used in the work: silicon carbide, corundum and flint. The results of the studies have shown that the nature of the abrasive used has a significant impact on the wear resistance of the alloys. The microstructure after quenching, containing 27% of the residual austenite, has the greatest resistance to abrasion. The microstructure after quenching at 550°C has the worst results. The study demonstrated a very weak correlation between the wear resistance and the hardness of the alloys under study. In this regard, the authors developed their own model of «equivalent hardness» to explain the abrasive behavior. «Equivalent hardness» is the sum of the products of the volume fraction of each phase (matrix and carbide) and its microhardness. The authors point out that the relationship between wear resistances and «equivalent hardness» is unambiguous.

The scientific work of the authors K. Thilipkumar, R. Sellamuthu, and R. Saravanan is related to the study of the effect of the surface modification process (SMP) on the microstructure, wear rate, and hardness of the ni-hard-4 alloy. The alloy was modified with tungsten. The microstructure was studied in a modified layer. The hardness measurements showed that the hardness increased from 597 HV for the substrate to 1738 HV in the modified layer. The wear rate was 4.3 x 10^{-3} mm^3/m for the substrate and 0.21 x 10^{-3} mm^3/m for the modified layer. Wear was calculated from the weight loss of the sample. Analysis of the elemental composition showed that the presence of tungsten is 5.21% on average. Thus, the authors showed that the modification with a refractory and carbide-forming metal can improve the wear resistance and hardness of the surface by more than 2 times.

A number of studies have investigated the effect of alloying elements on the structure and properties of the ni-hard 4 alloy. The authors of the study «Materials and Design Effects of vanadium addition on microstructure, mechanical properties and wear resistance of ni-hard 4 white cast iron» studied the effects of vanadium on the wear resistance, microstructure, mechanical properties and wear resistance of ni-hard 4 white cast iron. Six laboratory



a b c

Figure 1 – Microstructure of ni-hard – 4 alloy with different nickel content: a – 5.24%; b – 5.12; c – 5.21% (SEM)

alloys with different vanadium contents were used as samples. The results showed that with an increase in the vanadium concentration, chromium carbides were refined, and the volume fraction of carbides decreased. The microstructure of ni-hard 4 white cast iron became finer, and the hardness and wear resistance improved without reducing the fracture toughness after increasing the vanadium content by 2%. The results of the wear resistance tests showed that the wear resistance of ni-hard 4 white cast iron modified with vanadium in an amount of 2% improves by about 40% compared to the base ni-hard 4.

The study [7] evaluated the effect of titanium additives (1.2, 0.7, and 0.2 mass %) in ni-hard 4 cast iron with a nominal composition: Si=1.5%, Mn=0.5%, C=3%, P=0.05%, S=0.05%, Mo=0.1%, Cr=8%, and Ni=5.5%. At the end of the melting, the effect of titanium on the hardness, tensile strength, wear resistance, and microstructural changes of Ni ni-hard 4 cast iron was evaluated. The results were compared with ni-hard 4 cast iron, which does not contain titanium. The comparison showed that the morphology of the carbide changes from coarse lamellar to dendritic due to the addition of titanium. The results showed that the hardness, strength and wear resistance are increased by increasing the percentage of titanium. Strength and wear resistance improved by 35, 22.5 and 85%, respectively, in samples with 1.3% titanium, compared to samples without titanium. This behavior is a consequence of the replacement of chromium carbide with solid titanium carbides, as well as the grinding of grain (Figure 2).

An interesting scientific study was carried out to identify the influence of such a chemical element as tungsten on the microstructure and properties of high-chromium cast iron. The results of the experiments showed that tungsten is almost evenly distributed in both the matrix and the carbides. Tungsten carbides are represented by the following types: WC1-x, W6C2. 54, CW3 and W2C. As the tungsten content increased, the bulk hardness and microhardness of the matrix gradually increased and reached a peak with the following values: hardness-62 HRC and microhardness-913 HV. All alloys containing tungsten showed better results in impact tests than alloys without tungsten, and alloys containing 1.03 wt. % W, showed the highest impact strength at 8.23 J/cm^2. The introduction of tungsten in the studied quantities significantly improves the wear resistance of high-chromium cast iron, and alloys containing 1.03 wt. % W increases the wear resistance by more than 2 times compared to cast iron without tungsten additives.

Authors Mourad M. M., El-Hadad S., Ibrahim M. M. modified the ni-hard IC Ni–Cr–GB alloy by adding various amounts of Mo. The influence of the molybdenum content on such properties of cast samples as strength, tensile strength, impact energy, hardness and wear resistance was studied. It was noted that the additive is up to 0.96 wt. % Mo has a positive effect on the carbide phase and thus improves the mechanical properties and wear resistance of the alloy. However, a further increase in the molybdenum content negatively affected the strength and wear resistance. The authors conclude that the content of molybdenum in ni-hard cast irons should be strictly regulated, since even a small difference in the level of the additive can play a significant role in changing the wear resistance.

Conclusions

Thus, it is possible to determine the global trends in the production and improvement of Ni-hard-class cast iron based on the information analysis:

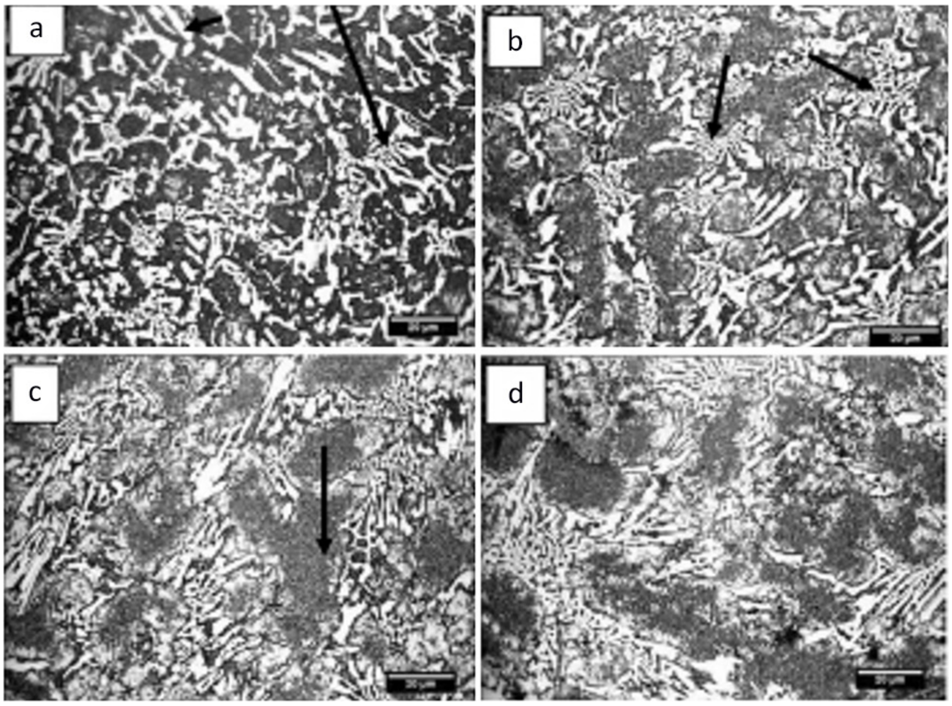


Figure 2 – Changes in the microstructure of ni-hard-4 with different titanium content, %: a – 0; b – 0.2; c – 0.7; d – 1.3

1. Alloying with strong carbide forming agents such as W, V, Ti, and Mo improves the wear resistance and hardness of ni-hards.

2. The improvement of the properties of ni-hards due to the introduction of additional doping is due to structural changes, in particular, the genesis, dispersion and redistribution of the carbide phase.

3. One of the trends in improving the properties of chromium-nickel cast irons, ni-hards in particular, is the transfer of a part of the carbide phase to free graphite of a spherical shape.

4. Creating a structure with a high level of resistance to a specific type of wear mechanism is another way to improve the performance of ni-hards

These conclusions allow us to formulate trends in improving the composition of Nihard-class cast iron, taking into account the raw material base of the Republic of Kazakhstan:

- complex alloying with ferroalloys of Kazakhstan content for the formation of the desired elemental composition and structure;
- formation of a mixed structure in which carbon is present both in the carbide phase and in the form of graphite inclusions;
- creating a metal matrix of the bainite type, which will avoid or simplify the heat treatment of cast products.

These studies were carried out within the framework of the grant of the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan AP08855477 «Development and implementation of technology for the production of ni-hard-class cast irons with improved performance properties for parts of mining and metallurgical equipment».

СПИСОК ЛИТЕРАТУРЫ

1. Ni-hard. Data Base and application // – URL: https://nickelinstitute.org/media/1728/ni_hardmaterialdataandapplications_11017_.pdf (28.10.2020 г.).
2. Тахиров А.А. Особенности формирования структуры среднелегированного хромоникелевого чугуна и технология изготовления тонкостенных отливок с повышенной износостойкостью: Дисс. ... к.т.н. / АО «ЦНИИТМАШ». Москва, 2017.
3. O. Dogan, J. Hawk, J. Rice. Comparison of Three Ni-Hard I Alloys // J. Materials Science and Technology. – Volume 1. 2004/09/01.
4. ГОСТ 7769-82 Чугун легированный для отливок со специальными свойствами. Марки.
5. Jinzhu, Liu, Shizhuo, Li, Yongfa, Man//Wear resistance of Ni-hard 4 and high-chromium cast iron re-evaluated // Wear, Volume 166, Issue 1,15. June 1993. – P. 37-40.
6. Al-Rubaie, Kassim and Pohl, Michae // Heat treatment and two-body abrasion of Ni-Hard 4 / J. Wear, – 2014. – №4. – Volume 312.
7. Branch.N. Najafabadi.V.N. Investigating the Effect of Titanium Addition on the Microstructure and Mechanical Properties of NH4 Cast Iron Investigating the Effect of Titanium Addition on the Microstructure // Journal of Modern Processes in Manufacturing and Production. Volume 5, Iss. 1. – 2016.

Нихард класының шойындары, оларды жетілдіру перспективалары

[1]**ИСАҒҰЛОВ Аристотель Зейнуллинович,** *т.ғ.д., профессор, атқарушы директор, aristotel@kstu.kz,*
[1]**ИБАТОВ Марат Кенесович,** *т.ғ.д., профессор, ректор, m.ibatov@bk.ru,*
[2]**КОВАЛЁВ Павел Валерьевич,** *т.ғ.к., доцент, kovalev_pv@spbstu.ru,*
[1]***ЩЕРБАКОВА Елена Петровна,** *PhD, аға оқытушы, sherbakova_1984@mail.ru,*
[1]**ДОСТАЕВА Ардак Мухамедиевна,** *PhD, аға оқытушы, ardak_erkekyz@mail.ru,*
[1]**АРИНОВА Сания Каскатаевна,** *PhD, оқытушы, sanya_kazah@mail.ru,*
[1]Қарағанды техникалық университеті, Қазақстан, 100027, Қарағанды, Н. Назарбаев даңғылы, 56,
[2]Ұлы Петр Санкт-Петербург политехникалық университеті, Ресей, 195251, Санкт-Петербург, Политехническая көш., 29,
**автор-корреспондент.*

Аңдатпа. *Мақаланың мақсаты – нихард класындағы шойындарды жетілдірудің әлемдік трендтеріне ақпараттық талдау жүргізу. Қосымша қоспалаудың нихардтардың қасиеттеріне әсері қарастырылады. Кейбір элементтерді енгізу карбид фазасының сипаты мен табиғатын ғана емес, сонымен қатар шойындағы көміртектің болу формасын да өзгерте алатындығы көрсетілген. Талдау модификацияны және термиялық өңдеудің кейбір түрлерін қолдану нихардтардың қасиеттеріне де оң әсер ететінін көрсетті. Нихардтардың тозуға төзімділігін арттыру тенденцияларының бірі тозудың нақты механизміне төзімді құрылым құру болып табылатыны атап өтілді. Карбид фазасының бір бөлігін шар тәріздес графитке ауыстыру нихардтардың қасиеттеріне оң әсер ететіні анықталды. Жүргізілген ақпараттық талдау негізінде ҚР шикізат базасын ескере отырып, нихард класты шойындардың құрамын жетілдіру үрдістері тұжырымдалды.*

Кілт сөздер: *нихард, қоспалауыш элементтер, тозуға төзімділік, графит қосындылары, модификациялау, термоөңдеу.*

Чугуны класса нихард, перспективы их совершенствования

[1]**ИСАГУЛОВ Аристотель Зейнуллинович,** *д.т.н., профессор, исполнительный директор, aristotel@kstu.kz,*
[1]**ИБАТОВ Марат Кенесович,** *д.т.н., профессор, ректор, m.ibatov@bk.ru,*
[2]**КОВАЛЁВ Павел Валерьевич,** *к.т.н., доцент, kovalev_pv@spbstu.ru,*
[1]***ЩЕРБАКОВА Елена Петровна,** *PhD, старший преподаватель, sherbakova_1984@mail.ru,*
[1]**ДОСТАЕВА Ардак Мухамедиевна,** *PhD, старший преподаватель, ardak_erkekyz@mail.ru,*
[1]**АРИНОВА Сания Каскатаевна,** *PhD, преподаватель, sanya_kazah@mail.ru,*
[1]Карагандинский технический университет, Казахстан, 100027, Караганда, пр. Н. Назарбаева, 56,
[2]Санкт-Петербургский политехнический университет Петра Великого, Россия, 195251, Санкт-Петербург, ул. Политехническая, 29,
**автор-корреспондент.*

Аннотация. *Цель статьи – проведение информационного анализа мировых трендов совершенствования чугунов класса нихард. Рассмотрено влияние дополнительного легирования на свойства нихардов. Показано, что введение некоторых элементов способно изменить не только характер и природу карбидной фазы, но также и саму форму присутствия углерода в чугуне. Анализ показал, что использование модифицирования и некоторых видов термообработки также положительно влияет на свойства нихардов. Отмечено, что одной из тенденций повышения износостойкости нихардов является создание структуры, резистентной к конкретному механизму износа. Установлено, что перевод части карбидной фазы в шаровидный графит положительно влияет на свойства нихардов. На основании проведенного информационного анализа сформулированы тенденции совершенствования состава чугунов класса нихард с учетом сырьевой базы РК.*

Ключевые слова: *нихард, легирующие элементы, износостойкость, графитные включения, модифицирование, термообработка.*

REFERENCES

1. Ni-hard. Data Base and application // – URL: https://nickelinstitute.org/media/1728/ni_hardmaterialdataandapplications_11017_.pdf (28.10.2020 g.).
2. Tahirov A.A. Osobennosti formirovaniya struktury srednelegirovannogo hromonikelevogo chuguna i tekhnologiya izgotovleniya tonkostennyh otlivok s povyshennoj iznosostojkost'yu: Diss. ... k.t.n. / AO «CNIITMASh» / Moskva, 2017.
3. O. Dogan, J. Hawk, J. Rice. Comparison of Three Ni-Hard I Alloys // J. Materials Science and Technology. – Volume 1. 2004/09/01.
4. GOST 7769-82 Chugun legirovannyj dlya otlivok so special'nymi svojstvami. Marki.
5. Jinzhu, Liu, Shizhuo, Li, Yongfa, Man//Wear resistance of Ni-hard 4 and high-chromium cast iron re-evaluated // Wear, Volume 166, Issue 1,15. June 1993. – R. 37-40.
6. Al-Rubaie, Kassim and Pohl, Michae // Heat treatment and two-body abrasion of Ni-Hard 4 / J. Wear, – 2014. – №4. – Volume 312.
7. Branch.N. Najafabadi.V.N. Investigating the Effect of Titanium Addition on the Microstructure and Mechanical Properties of NH4 Cast Iron Investigating the Effect of Titanium Addition on the Microstructure // Journal of Modern Processes in Manufacturing and Production. Volume 5, Iss. 1. – 2016.