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Development of Measures to Improve Occupational Safety during Operation of Reservoirs in Spring

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Introduction. The paper considers the problem of ice formation on the spray ring of vertical steel tanks (VST) in spring, which threatens the safety of operating personnel when carrying out technological operations. The necessity of introduction of means of protection against ice is emphasized, which will make it possible to release commercial operators from performance of high risk operations of ice clearing from dry pipelines.

Problem Statement. The task of the research is to substantiate the use of possible ways of icing control on the tank spray ring.

Theoretical Part. As the basic information, the modern methods of de-icing used in mechanical engineering, oil industry and construction are presented.

Conclusions. As a result, the work proposes options for the use of means to fight against icing, through which the overall level of safety in the tank farm will increase.

Keywords: occupational safety, tank, spray system, icing, heating cable, anti-icing liquids.

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Introduction. The problem of icing of equipment and structures is acute for industrial sphere, because it directly affects their durability, as well as the level of safety during their operation. This is especially true for the northern regions of Russia, where temperature differences during the day in the period from March to May can reach more than 10°C [1].

Modern reservoirs located in the continental zone repeatedly experience a cycle of freezing and thawing of water that forms on the spray ring. The VST spray system is a ring of hollow pipelines located on the upper ring and designed to extinguish a fire at the time of ignition, as well as to cool the wall of a burning tank. When an emergency situation occurs, the spray system also works on neighboring structures to eliminate the possibility of fire spreading. On the dry pipes of the spray system there are technological openings for the supply of spray water. In spring, melt water crystallizes on the ring when negative temperatures occur at night, as a result of which ice forms on it, which can reach more than 2 m in length even with regular cleaning.

The accumulation of large masses of ice on the spray ring makes life-threatening the following daily production operations performed by commercial operators [2]:

– opening and closing of the main gate valves;
– sampling;
– drainage of water bottoms;
– measurement of the oil product innage;

– maintenance of the equipment located at the base of the tank (siphon crane, bottom sediment washing device, receiving and distributing device, etc.).

The gravity of ice masses continuously acting on the dry pipe can lead to wear and destruction of the equipment. In addition, it is possible to disrupt the normal functioning of the spray system in case of emergency situations.

The seasonality problem is typical only for spray ring tanks operated in the north of the country. This sets a very narrow range of its distribution, prevents the oil industry from developing general standards to protect the spray ring from ice, so enterprises cope with its consequences on their own [3, 4].

Problem Statement. The main objective of the study is to substantiate the use of technical and chemical means of ice control on the spray ring of the VST to improve the reliability of equipment and safety of operational personnel.

At the moment, the main way to deal with ice is mechanical cleaning of the dry pipe by commercial operators using a working tool, because often there are no specialized scrapers on the site. This method of ice removal can lead to damage to the tank shell, and the uncontrolled fall of the knocked-down ice threatens the equipment on the first ring.

The process of cleaning ice masses refers to high-risk operations, since a number of dangerous factors begin to act on the operator [5]:

– height of more than 1.8 m;

– slippery surface that can cause a fall;

– uncontrolled fall of knocked off ice;

– the impact of meteorological factors (wind, snow);

– physically hard work, time-consuming.

Therefore, in order to avoid possible injuries and falls, enterprises should develop regulatory documentation regulating this process and provide a list of copper-plated equipment suitable for cleaning hazardous industrial facilities.

Reduction of the volume of high-risk work performed, as well as the existing harmful and hazardous production factors, is one of the tasks of occupational safety at hazardous production facilities. The development of appropriate documentation does not solve this problem [6, 7]; therefore it is necessary to consider alternative options for icing control.

Theoretical Part. The prevention of ice formation can be considered as a promising direction in solving the problem of icing. The oil industry has long used specialized heating cables in explosion-proof design for heating oil products in railway tanks, tanks, pipelines. One of the main characteristics of cables is their ability to self-regulate the heating temperature depending on the external environment. A special self-regulating matrix of the cable is able to reduce the passing electric current along special conductor paths due to the expansion of the polymer inside the cable at a positive ambient temperature, and vice versa, to increase the heating temperature due to an increase in current when the polymer shrinks [8].

Justification of the possibility of introducing a heating cable to the tank spray ring should begin with an analysis of industrial safety documentation. The use of electrical equipment in explosion-proof design on the premises is permissible according to GOST12.2.020-76. Now there are a large number of companies specializing in industrial heating of equipment and structures, so that problems with cable selection do not arise.

The main task when selecting a heating cable is the question of its position during installation. There are several options here:

– spiral mounting;

– installation along the dry pipe line.

Spiral mounting is used for heating pipes of relatively small diameter. This method lays the cable in coils and allows you to warm up a large surface area. Its obvious disadvantage is that the dry pipe is a perforated pipe, and the overlap of these holes will disrupt the normal operation of the equipment.

It would be preferable to fix the heating cable parallel to the dry pipe from above. Thus, the cable will always be visible during inspection, meltwater will not drain onto it, and there will also be no obstacle to the operation of the irrigation system. In Fig. 2, the heating cable on the spray ring is indicated in black.

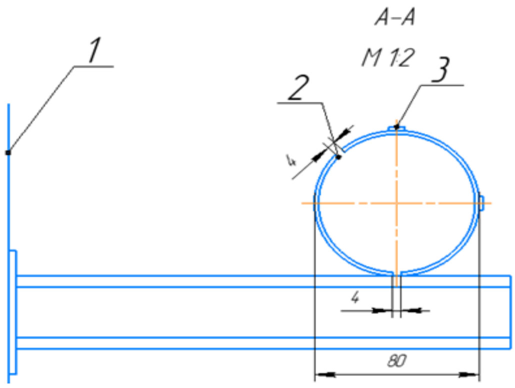

Fig. 1. The layout of the heating cable on the irrigation ring of the VST:
1 — VST wall; 2 — technical hole; 3 — heating cable

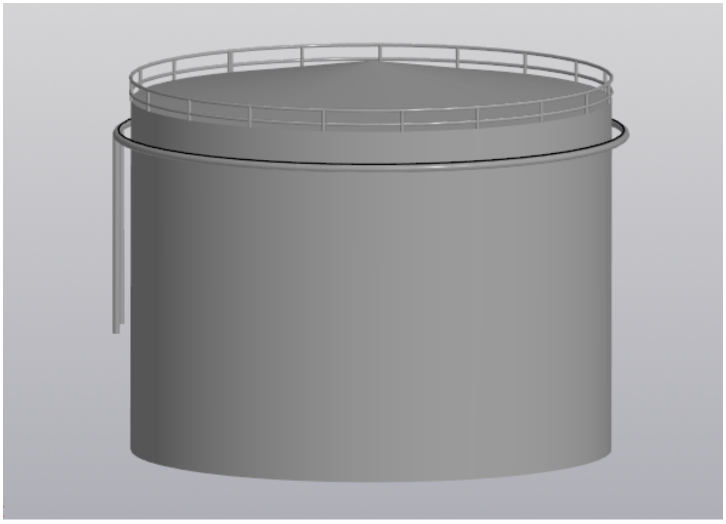

Fig. 2. 3D model of a tank with a heating cable

Although at the moment there are many options on the market for heating cables, a universal one with all the required technical characteristics has not yet been offered. This may be a direction for further research on the problem of protection from icing of reservoirs.

The introduction of a heating cable on the spray ring of the tank effectively solves the problem of icing and the formation of ice, which reduces the likelihood of accidents and complication of the spray system.

Another way to control icing is the use of special de-icing liquids (DIL). The chemical method is used in the aviation industry to protect aircraft before flight. In addition, hydrophobic compounds are used to treat roofs and cornices of public buildings [9].

The basis of de-icing compositions are organosilaxanes or other polymers, which, after the addition of additives in the form of chemical fillers, solvents and corrosion inhibitors, allow the coating to obtain an anti-adhesive structure that works on the principle of reducing the adhesion of the surface to the liquid, so that water drains without having time to crystallize.

After the treatment with de-icing compositions, the surface acquires a number of properties:

– hydrophoby;

– fire resistance;

– resistance to atmospheric precipitation;

– anticorrosion.

Long service life and low economic costs of coating can make the chemical method the most popular one among the proposed solutions. Coating the spray ring with a hydrophobic composition in theory can show an excellent result.

At the moment, the optimal composition of de-icing liquids has not been proposed, so further research in this direction is relevant.

Thus, the use of special de-icing liquids can solve the problem of icing and the formation of ice that forms on the spray ring of tanks, which also reduces the likelihood of accidents and difficulties in the operation of the spray system.

Conclusions. The existing problem of icing threatens the safety of operational personnel [10]. The study suggests the effective methods to control icing. The introduction of the proposed methods will improve the safety of the operation of tanks in the most dangerous period of the year. In order to choose the most suitable method, it is necessary to check them in practice.

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N. Kh. Abdrakhmanov — structure of the article, critical analysis, editing; A. V. Fedosov — scientific supervision, formulation of the main goal of the study, development of research methods, processing of the initial observations, text editing; O. S. Duachenko — development of the basic research concept, statement of the problem, participation in the study.

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Use of mobile apps for periodic knowledge tests and qualification assessment of slingers

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Introduction. The article is devoted to the issues of improving the processes of periodic knowledge testing and assessing the qualifications of slingers to improve the level of professional skills, readiness to use appropriate devices, equipment and personal protective equipment.
Problem Statement. In view of the often formal organization of regular (periodic) knowledge checks of slingers, which potentially leads to accidents at work, there is a need to apply new forms of organization and conduct of these activities.
Theoretical Part. Periodic knowledge testing involves an oral examination in the commissions of the organizations that operate cranes. As an alternative to regular knowledge checks, the independent qualification assessment at Qualification Assessment Centers is of particular importance. Taking into account the widespread digitalization of production and the widespread use of IT technologies, it is proposed to develop and apply mobile applications for periodic knowledge checks of slingers, allowing them to visualize and choose the right solutions for performing labor functions.
Conclusions. The high level of professional training of the slinger is an important component in the issue of increasing the level of safety in the operation of lifting structures, so special attention must be paid to the training of qualified personnel.

Keywords: slinger, professional training, certification, knowledge testing, information technology.

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Introduction. The profession of a slinger is in demand in many industries where lifting devices are operated, in which a hook is used as a lifting body — lifting cranes or loader cranes. These include construction, warehousing, port and railway cargo terminals, machine-building industry and others. The profession of a slinger is associated with the risk of an injury in the course of work due to the impact of hazardous and harmful production factors, such as: increased noise and vibration, increased dust and gas contamination of the air of the working area, the risk of falling of the transported cargo or its elements [1]. Despite the apparent improvement in accident and injury statistics at the facilities operating lifting devices (Fig. 1) [2], the situation cannot be called optimistic. Slingers are still at risk.

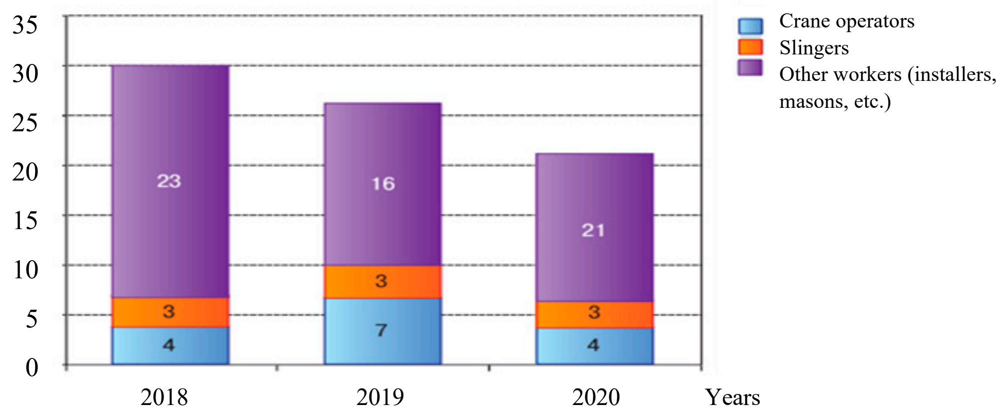

Fig. 1. Personnel who died during the operation of lifting cranes in 2018-2020 [2]

Earlier, in the works devoted to the issues of personnel safety [3, 4], the causes of injuries and accidents were considered in detail, including the role of the "human factor" and the low level of professional training of personnel [5].

Problem Statement. In order to avoid injury to slingers and improve the quality of service of lifting cranes, it is necessary to apply new approaches and methods within the framework of maintaining the level of professional knowledge of employees.

Currently, an employee who has received a professional education as a slinger is placed at the full disposal of the head of the relevant department at the enterprise, where the attitude to further maintaining the level of his professional knowledge is not always guaranteed to be high. The annual regular checks of slingers' knowledge provided for [6, 7] are often carried out formally, while the scope of professional knowledge of employees is narrowed to the level of performing certain actions, sometimes without affecting issues related to the personal protection of the slinger during the performance of these labor actions. Such an approach to conducting periodic knowledge checks potentially leads to accidents at work, the causes of which are the negligent attitude of management and employees to the use of protective equipment, special inventory devices, etc. The range of necessary knowledge for the assessment of the qualifications of slingers should not be limited only to knowledge of labor actions. The skills of identification and rejection of lifting accessories, selection and use of inventory devices, as well as the use of personal protective equipment, special clothing and shoes for specific work are also of great importance.

Theoretical Part. The problem of insufficient qualification of personnel at the facilities operating lifting cranes potentially leads to serious consequences, such as industrial injuries, including fatal ones, and entails significant material damage to the operating organization.

The experience has shown that periodic knowledge assessment assumes an oral exam, which is conducted by the commission organized by the organization itself. In rare cases, a pre-certification lecture is held. As a rule, shortcomings and mistakes made in specific works on objects are discussed. As an alternative to regular knowledge assessment, an independent assessment of qualifications in Qualification Assessment Centers (QAC) that carry out their activities in accordance with the requirements of legislation becomes more important [8].

The experience of Qualification Assessment Centers in qualification assessment of, for example, employees of the elevator industry [8, 9], shows a positive trend in the level of preparedness of personnel to perform labor functions and actions. An important role is played by the competence and independence of the qualification assessment event itself in the QAC, which allows an objective assessment of each attested person. The qualification assessment procedure involves several stages — theoretical stage and practical stage. The process of knowledge assessment is recorded on video. Then the video material is sent to the Council for Professional Qualifications for Certain Types of Professional Activities. This body provides and controls the activities of independent assessment of qualifications. Its powers include: verification, processing and recognition of the results of an independent qualification assessment; making a decision on the issuance of certificates of qualifications by the Qualification Assessment Center; sending information about the issued certificates of qualifications to the national qualifications development agency for inclusion in the register.

Currently, a slinger can pass a qualification assessment in the QAC independently or if send by an employer. The mandatory nature of passing an independent qualification assessment has not yet been defined at the legislative level. However, this problem is widely discussed in professional communities.

Regardless of forms and locations of qualification assessment or knowledge testing of slingers, these events also require the use of other forms and approaches, in particular, the use of IT technologies. IT technologies are processes, methods of searching, collecting, storing, processing, providing, distributing information and the ways of implementing such processes and methods [10].

Information technologies have become part not only of our everyday life, but have also become indispensable in production processes. Today, anyone has access to a huge amount of visual information. It is known that visual information is remembered and reproduced faster than other types. This fact can be applied in the development of mobile applications and training cases to test the knowledge of slingers.

The occupational standard "Slinger" [11] is currently under approval. This document can be used to form an understanding of the distribution of functions and requirements for the skills and knowledge of slingers in production activities. Operating organizations develop production instructions for slingers, guided by the standard instruction [12].

Thus, with all the provisions of the above documents, it is possible to consider the requirements for the performance of labor functions. For example, for the labor function "Preparatory work before starting simple work", among the necessary skills are indicated: "Use of personal protective equipment", "Compliance with occupational safety and fire safety requirements ", etc., and the necessary knowledge is the knowledge of the procedure for the use of specific personal protective equipment.

As a rule, in the process of conducting a periodic examination of the knowledge of slingers, the main attention of the qualification commission is focused on the knowledge of the principles of the correctness of slinging, hanging cargo on a hook, cargo escort and other specific labor actions. At the same time, almost no attention is paid to the knowledge, skills and abilities of choosing and using personal protective equipment and special clothing. Realizing the importance of all the slinger's competencies, including those mentioned above, it is proposed to develop practical materials in the form of training cases or mobile applications. They are planned to include situational tasks or issues with a graphic image as tasks, in which, for example, it is necessary to choose a set of workwear for a specific type of work: work performed at a distance of 30 m and closer to the outer conductor of the power line; at height; in conditions of dust or increased noise level. It is also important to include questions on the topic of "First aid". In other words, the tasks should be a visualization of control tests to test knowledge and skills. Tests can be of various levels: the first is recognition, the second is reproduction; the third is the solution of situational problems; the fourth is the solution of original non-standard problems. For slingers, it may be enough to conduct tests of the first level, and for managers — of the second and higher levels.

In order to start knowledge tests, you need to select a test (Fig. 2). After that, a question will appear in which, for example, you need to choose one correct answer from four suggested ones (Fig. 3); the correct answer will be highlighted in green, the wrong one – in red. Then you need to move on to the next question. The results are shown at the end of the test.

Fig. 2. Mobile application (test selection)

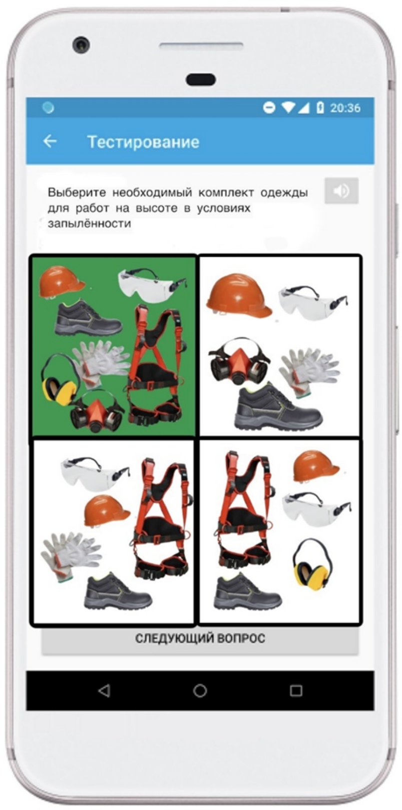

Fig. 3. Mobile application (answer to a question selection)

The use of visualized materials for periodic knowledge verification of slingers will determine the level of readiness of workers for real labor actions, and the use of information technology will make it easier to assimilate theoretical and practical information and apply it in further work. Such a procedure will further exclude a formal attitude to the examination of the slingers' knowledge, both on the part of the commission members and on the part of the examinee, since the participation of an employee in an event where he must answer a question, make a decision in a situational task already confirms his personal participation and can guarantee the memorization of the necessary information obtained using mobile phones, applications and educational internet cases.

Conclusions. A high level of professional training of a slinger is an important part in the issue of increasing the level of safety during the operation of lifting devices. Therefore, special attention should be paid to the training of qualified personnel. Training and knowledge testing of personnel should be carried out using modern technologies, including mobile applications, educational Internet cases. This will contribute to a wider development of theoretical and practical training, which will further minimize violations of industrial safety requirements and, consequently, increase safety during the operation of lifting devices.

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Analysis of existing approaches to the assessment of hazards and occupational risks of workers of industrial enterprises of the Republic of Kazakhstan

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Introduction. Timely and effective identification and assessment of all hazards and occupational risks is one of the urgent problems in the prevention of occupational injuries of industrial workers. Both legislative and regulatory acts and a number of foreign and domestic authors offer various approaches to such an assessment, the analysis of the advantages and disadvantages of which is the subject of this article

Problem statement. The objective of this study is a critical analysis of the existing approaches to the assessment of hazards and occupational risks of workers in industrial enterprises.

Theoretical part. As the basic information, state regulatory methods were used, as well as methods for assessing the occupational risks of employees of industrial enterprises, proposed by various authors.

Conclusions. According to the results of the analysis, the ways of solving the problem of preventing occupational injuries of industrial workers on the conditions of "preliminary" assessment of their occupational risks, i.e. before the occurrence of negative events, are determined.

Keywords: workers, occupational injuries, occupational disease, workplace, dangerous and harmful production factors, occupational risk, assessment.

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Introduction. Any human activity, including labor, contains various potential hazards that are the cause of occupational injuries and occupational diseases. The consequences may be accidents, emergencies, fires, etc.

Practical experience shows that absolutely zero values of risk to human life and health are unattainable in any kind of the activity. However, there are different levels of risk depending on the type of potential hazards. Thus, the main task of occupational injuries prevention is to determine the magnitude of the potential hazard of any type of work activity. We are talking about hazard as a potential threat of negative impact on human life, health and/or the environment. Currently, we distinguish potential (hidden) and real hazards, and certain conditions or reasons are necessary for the implementation of the former into the latter [1].

The number of man-made hazards, as well as the degree of their negative impact in the modern world is constantly growing. The Republic of Kazakhstan is no exception, where more than 200 people die and more than 2,000 people are injured with various degrees of severity every year as a result of industrial injuries. About 15,000-16,000 emergencies and accidents are registered annually, and the overwhelming number of them (more than 90 %) is man-made accidents. Out of 1.6 million employees of industrial enterprises of the country surveyed in 2019, 370 thousand employees or one in four (22 %) were employed in harmful and hazardous working conditions. One in two (45.9 %) worked in conditions of increased noise and vibration levels, one in three (32.6 %) worked under the influence of increased gas pollution and dustiness of the working area, 94 thousand people (5.6% of the number of employees of the surveyed enterprises) were engaged in physically demanding jobs [2–4].

Problem Statement. One of the problems in the field of injuries, accidents and emergencies prevention is a timely, objective and complete assessment of the existing or emerging potential hazards. At the moment, there are a large number of methods of such assessment (numerical, point, etc.). The most common assessment of hazards is risk, i.e. the probability of an undesirable event occurring in the system, which can be identified with a certain and sufficient degree of accuracy from statistical data [5]. According to another definition, risk is an objective or subjective measurement of the probability and possibility of consequences of a dangerous event concerning human or the environment well-being [6]. Most scientists and researchers in the field of life safety use the following general definition: risk is a quantitative assessment of hazards [7, 8]. English scientist V. Marshall in his book "The main dangers of chemical production" gave the following definition to this concept: risk is the frequency of the implementation of hazards, in other words, risk in numerical terms is the ratio of any number of negative situations (n) to their possible number (N) for a certain period of time [8].

For the first time, the concept of "risk" became widely used after the First World Congress on Life Safety, held in September 1990 in Cologne under the motto "Life in Safety".

In the world practice, the maximum permissible (acceptable) level of individual risk of death of an employee at work is considered to be a level equal to 10^{-6} per year, i.e. if 1 person per 1 million dies, and negligibly small — 10^{-8} per year [5]. From these positions, for a comparative analysis, we will determine the risk of death or injury of workers in the conditions of the economy of the Republic of Kazakhstan. Table 1 presents statistical data on occupational injuries for the period from 2018 to 2020 in the whole country [2]. The number of victims of industrial accidents in 2020, in comparison with 2018, did not change significantly and amounted to 2,033 people (in 2018, the number of victims was 2,160 people). However, in 2020, most enterprises of the republic did not work most of the time due to quarantine measures caused by the COVID-19 pandemic. In 2020, 203 people died as a result of industrial accidents, in 2018 — 215 people. The mortality rate decreased by 5.6%. This is explained not by an increase in the level of safety and labor protection of workers, but by the downtime of enterprises due to the quarantine.

Table 1

Statistical data on injuries of workers in the sectors of the economy of the Republic of Kazakhstan for the period from 2018 to 2020

No.	Indicator name	Value of indicators by year		
		2018	2019	2020
1	Number of people employed in the sectors of the economy of the Republic of Kazakhstan, thousand people	8 704.0	8 773.2	8 750.1
2	Number of dead workers in production, people	215	190	203
3	Number of injured workers in production, people	2 160	2 111	2 033
4	Actual risk of death of workers at work	$2.47×10^{-5}$	$2.16×10^{-5}$	$2.31×10^{-5}$
5	Actual risk of injury to workers at work	$2.48×10^{-4}$	$2.4×10^{-4}$	$2.32×10^{-4}$

The data presented in Table 1 indicate that the risk of death of workers at work in the republic as a whole is more than 2 times higher than the generally accepted world level of acceptable risk. Moreover, the calculation was carried out for the economy as a whole, both in more and less traumatic industries. If such a calculation is made for the most traumatic industries of the country, it will be: for the construction industry — 9.43 $\times 10^{-5}$, for the mining industry — 11.1 $\times 10^{-5}$, for the engineering industry — 5.48$\times 10^{-5}$. All this indicates an unacceptably low level of occupational safety and health (hereinafter referred to as OSH) of industrial enterprises workers of the Republic of Kazakhstan.

Although the above risk assessment according to the method of V. Marshall is elementary and simplified, it is quite effective and widely used.

The objective of the conducted research was a critical analysis of the existing state regulatory documents in the Republic of Kazakhstan, methods or approaches proposed by various authors to assess occupational risks, as well as the development of priority areas for their improvement.

Theoretical Part. Paragraph 2 of Article 182 of the Labor Code of the Republic of Kazakhstan obliges the employer to constantly monitor the level of occupational risks in order to prevent it, as well as to replace the used hazardous technologies and production equipment with safer ones [9]. In this regard, the relevant OSH services of enterprises should have fairly simple and effective methods for assessing the occupational risks of employees. The review of regulatory documents and scientific literature on the subject of the study allowed us to identify the main approaches and methods of assessing hazards and risks in the field of industrial safety (hereinafter referred to as IS) used in the republic.

Regulatory methods for hazards and risks assessment based on statistical data on occupational injuries and accidents. Currently, there are several state methods in the Republic of Kazakhstan, which are mandatory for all state control and supervisory authorized bodies, as well as enterprises and organizations. The regulatory methodology recommended at the state level for assessing the level of industrial safety of an industrial facility is set out in Order of the Acting Minister for Investment and Development of the Republic of Kazakhstan of December 26, 2014 No. 300 [10]. The main purpose of these Rules is to determine the degree of protection of individuals and legal entities, the environment from hazardous and harmful production factors (hereinafter referred to as HHPF) by monitoring the IS level both by the state authorized bodies in the field of IS, and by the relevant departments of enterprises and organizations. The general level of hazard of a production facility (hereinafter referred to as HPF) is determined by the enterprise operating this facility once a year by the calculation method according to the following indicators: the condition of industrial buildings and technological structures; the condition of technical devices, including dangerous ones; accidents and incidents that have occurred; the frequency of accidents at work; fatal accidents that have occurred at work. The final overall level of hazard of the object is determined by the sum of the above indicators.

The use of the presented methodology for assessing the level of industrial safety of production facilities is difficult for the following reasons:

— out of the recommended seven calculated indicators, four are indicators of accidents and incidents that have occurred, the frequency of accidents and fatal accidents that have occurred at work. They are statistical and do not reflect the real state of affairs. These negative events can also occur in modern well-equipped production due to erroneous, incorrect actions of personnel, as well as in case of gross violation of safety regulations. At the same time, at a small enterprise with a small number of employees, outdated technologies and equipment, accidents may not occur at all. As a result, it is possible to draw an incorrect conclusion about the low level of industrial safety of the first one. In addition, in real life, many statistical data are displayed unreliably when reporting to the authorized state bodies, it is extremely difficult to get their real picture;

— generalization and consolidation into a single statistical array of all the events under the general indicators "accidents that have occurred" and "incidents that have occurred" creates the problem that within these indicators all the events that have occurred are the same, i.e. equated to each other. In accordance with this, an explosion at an enterprise with the death of a large number of people and the destruction of any equipment without casualties are the equivalent events. However, there is no exactly the same accident or incident, i.e. based on this indicator, it is practically impossible to draw any conclusions about the IS level of a particular enterprise or facility. The situation is similar with the indicator of fatal accidents at work. Past experience shows that for most industrial enterprises during the reporting period (a year or more) it is either negligible or practically zero. Based on the above, it can be concluded that using only accident and injury indicators to assess the level of hazards and risks of an industrial enterprise as a whole, and to determine the level of industrial safety of individual hazardous production facilities leads to unreliable and erroneous conclusions;

— a number of important indicators are missing, such as, for example, ensuring the safety of the technological process, the timeliness of routine maintenance and the level of their organization, the qualification and knowledge of the personnel of the IS requirements, which directly affect such an assessment;

— there is no doubt that this methodology has been developed only for state supervisory bodies that conduct only an external assessment of production safety as a whole, without delving into the causes and consequences of its low level, as well as without assessing the occupational risks of employees.

Another state regulatory methodology for assessing the level of hazard and risks of a production facility is set out in the joint order of the Minister for Investment and Development of the Republic of Kazakhstan No. 1206 of 15.12.2015 and the Minister of National Economy of the Republic of Kazakhstan No. 814 of 28.12.2015 [11]. Evaluation indicators are formed here by means of objective and subjective criteria. According to objective criteria, the subjects or objects subject to verification are divided into 2 groups — high and not classified as high risk. For subjects or objects of the first group, a special procedure for inspections based on semi-annual schedules, unscheduled inspections and other forms of control and supervision is applied. For subjects or objects of the second group — only unscheduled inspections and other forms of control and supervision. According to the indicators of subjective criteria, a mechanism is used to encourage bona fide subjects or objects in the form of exempting them from a special procedure for checking the IS state. In the document under consideration, these criteria for significance are divided into 3 degrees of violations according to IS: gross, significant and insignificant. When determining the indicator of the degree of risk, the specific weight of each of the unfulfilled IS requirements is assessed. Then they are summed up and a general indicator of the degree of risk of the subject or object of high risk is found, depending on the magnitude of which such a subject or object is exempt from a special procedure for conducting inspections based on semi-annual schedules (from 0 to 60 points) or is not exempt (from 60 to 100 points).

At the same time, if at least one unfulfilled requirement of a gross degree of IS is revealed, then the overall indicator of the degree of risk of the subject or object being checked is equated to the indicator 100 and no further calculation is made.

The criteria for assessing the degree of risk, according to which the above calculation is made, are given in the annex to this order. It contains more than 1000 evaluation indicators.

The application of this technique in the work of the OSH service of a manufacturing enterprise for internal use to assess the level of danger and risks is difficult for the following reasons:

— it is fully focused on the external assessment of the enterprise as a whole by the state supervisory bodies;

— this technique is very time-consuming, since in order to determine the overall indicators, it is necessary to evaluate more than 1000 additional evaluation indicators given in this methodology.

Following on from the above-mentioned methods, there are Guidelines on risk management at the HPF, approved by Order of the Committee for State Control over Emergencies and IS of the Republic of Kazakhstan No. 46 of October 1, 2013. It establishes the general procedure for conducting a comprehensive analysis and assessment of the IS state at the HPF [12].

So, according to them, the main stages of risk analysis are: identification of risk; analysis of its level or quantitative magnitude of the degree of danger to workers, equipment and production environment or the environment; final assessment by comparison with the acceptable levels.

The main stages of risk analysis are: determination of the frequency of occurrence of initiating and all undesirable events; assessment of the consequences of the occurrence of undesirable events and a generalized risk assessment. To solve the first of these tasks, statistical data on accidents, occupational injuries and occupational diseases at the HPF, as well as expert assessments of specialists are used. The final (generalized) risk assessment determines the actual state of the IS level, taking into account the risk indicators from all negative situations that may arise at the HPF.

The main disadvantages of the considered Guidelines are the difficulty of collecting reliable initial data for calculations, as well as the fact that the error of a certain value of the risk value, even with all the necessary initial data, is very big. For this reason, it is very difficult to use the results of risk analysis for periodic and continuous monitoring of the IS level at HPF in order to determine the impact of certain measures taken on this condition.

If the above Guidelines regulates risk management only at hazardous production facilities, then later the Rules of Occupational Risk Management of 11.09.2020 provides for such management at all industrial enterprises of the Republic of Kazakhstan [13]. These Rules stipulate the procedure for occupational risks management, and unlike other methods, they include not only the stages of their identification and assessment, but also the stages of carrying out corrective measures, as well as control and monitoring the levels of occupational risks.

The risk identification stage is provided for each profession or workplace of the enterprise by type of activity and includes the collection and analysis of information, a comprehensive survey with technical measurements, determination of all harmful production factors based on the results of the survey with filling in the Register of Occupational Risks approved by the head of the enterprise.

All previously identified harmful production factors are subject to assessment, according to the results of which the level of their hazard is determined according to 5 degrees of occupational risk: degree 1 — acceptable, degree 2 — low, degree 3 — medium, degree 4 — high and degree 5 — very high risk.

To determine the occupational risk degree, the following analytical expression is used:

$$ПР = 0.7 \cdot \frac{B+T}{2} + 0.2 \cdot \frac{O_б + C_{из}}{2} + 0.1 \cdot З,$$

where В — an indicator of harmfulness of working conditions, characterizing the probability of impact of harmful production factors on working ability of an employee of this profession at the workplace; Т — an indicator of injury risk of working conditions, characterizing the probability of impact of hazardous production factors on working ability of an employee of this profession at the workplace; $O_б$ — an indicator of safety of production equipment used by an employee at the workplace; $C_{из}$ —an indicator of provision of the employee with personal protective equipment; З — an indicator of morbidity of workers in this profession [13].

The next stage of corrective measures provides for their implementation according to the developed Action Plan of the enterprise for effective management of these risks in order to reduce the identified levels to lower and acceptable.

The final stage of control and monitoring of occupational risks provides, firstly, control and verification of all the developed corrective measures, and secondly, monitoring of risks by collecting and analyzing analytical indicators of the results of the assessment to form complete information on reducing the degree of their danger.

The advantage of this technique is that it is precisely its content that meets the requirement of preliminary determination of the levels of occupational risks and the development of measures to reduce them before emergencies occur. The disadvantages include the following:

— the frequency of such an occupational risks assessment by the enterprise has not been determined;

— it is not clear why, with the requirements for a comprehensive survey of working conditions with instrumental measurements identical to the existing workplace certification methodology (which will be discussed below), these Rules were not combined.

Methodology for occupational risks assessment developed in the system of workers' accident insurance. In accordance with Paragraph 14 of Article 182 of the Labor Code of the Republic of Kazakhstan, it is the duty of the employer to insure employees against accidents in the performance of their labor (official) duties. The mechanism of such insurance is described in detail in the following regulatory documents:

— Law of the Republic of Kazakhstan "On compulsory insurance of an employee against accidents in the performance of labor (official) duties" of 07.02.2005 No. 30 [14];

— "Rules for classifying economic activities as occupational risk classes" of 30.06.2005 [15].

Thus, according to these documents, in case of an insured event (accident), an insurance premium is paid to the injured (insured employee), the amount of which is determined by the agreement of the parties (the employer and the insurance company) on the basis of an insurance tariff differentiated by types of economic activity of enterprises, depending on the class of occupational risk multiplied by the insurance sum under the insurance contract. The assignment of economic activities is provided for 22 different classes of occupational risk. The indicator of occupational risk for a specific type of economic activity in the analyzed year is defined as the ratio of the value of the annual actual amount of accrued payments for compensation for damage caused to the life and health of an employee in the performance of labor (official) duties to the size of the annual wage fund.

The assessment of occupational risk degree of a particular type of economic activity of an enterprise or organization is based on the following statistical indicators: the number of victims of accidents during the year; the annual actual accrued amount of payments to victims of accidents, including the average amount of accrued payments per victim; the annual number of victims of occupational diseases; the amount of accrued payments to victims of occupational diseases per year, including the average amount of accrued payments per victim; the number of deaths in accidents per year; the annual amount of actually accrued payments in case of death of employees, including their average size; the annual wage fund for this type of economic activity; the average annual number of employees for this type of economic activity [15].

Although it is possible to draw conclusions about the degree of injury risk of various industries by types of economic activity according to the considered method of occupational risk assessment, its use by the OSH services of enterprises is difficult due to the narrow focus on the insurance sector. Also, all the calculations are made here based on the negative consequences that have already happened (the number of deaths, victims of accidents and occupational diseases, etc.).

The legislation also provides for the right to apply to the insurance company in certain cases for help from experts in this field to establish the degree of occupational risk.

Expert methods of hazard identification and risk assessment. Currently, various expert methods are widely used in the problem of hazards and occupational risks assessment. The use of such methods becomes particularly relevant in the absence of statistical data on injuries and occupational diseases, as well as basic indicators for determining the risk by calculation. The main tasks of experts, who, as a rule, are attracted from among leading scientists or experienced practitioners in this field, are: identification of hazards and objective assessment of occupational risks of employees based on the characteristics of the production process and environment, the existing labor organization and other factors, including a criterion assessment of the degree of acceptability and unacceptability; assessment of measures and technical means used for their effectiveness in protecting employees; documentation of all the procedures.

Expert methods of hazard identification and risk assessment, for all their simplicity and clarity, are characterized by a high degree of dependence of the results of such identification on the subjective opinion of specific persons involved as experts. In this regard, such methods are insufficient for a full-fledged study of the actual state of OSH in production. The accumulated experience in the field of IS shows that reliable and complete information about working conditions and levels of occupational risks cannot be obtained without instrumental measurements of the values of HHPF indicators of the production environment.

Matrix methods of occupational risk assessment. Direct quantitative assessment of occupational risk levels can be implemented through the risk assessment method using the "probability-damage" matrix. The essence of this method is that for each specific situation, the probability rank of its implementation is determined — low, medium or high (matrix columns) — and the potential damage from its occurrence — small, medium, great (matrix rows). The optimum zone is located at the intersection of the corresponding column and row. But this method is also characterized by the disadvantages of the above methods. It is detached from the conditions of real production, does not take into account the state of the production environment, production equipment, etc.

Methods of risk assessment based on the classification of working conditions in the workplace during the certification of workplaces. In accordance with Paragraph 2 of Article 183 of the Labor Code of the Republic of Kazakhstan, the employer is obliged, at his own expense, to conduct periodic, at least once every 5 years, workplace certification (hereinafter referred to as WC) according to working conditions in accordance with the rules, recommendations and methodology approved by the authorized state body in the field of labor relations and industrial safety [9]. Such a document in the Republic of Kazakhstan is the "Rules for mandatory periodic certification of production facilities according to working conditions" of 28.12.2015 [16]. According to these Rules, the certification of workplaces and production facilities of enterprises and organizations is a comprehensive assessment of the compliance with the rules and regulations in the field of OSH and includes the following stages: instrumental measurements and assessment of the levels of harmfulness and danger of labor; instrumental measurements and assessment of the levels of severity and intensity of labor; assessment of the level of injury safety and provision of employees with collective and individual protection means; provision of training and instruction means.

The object of study at the WC is the system "production environment – technological equipment – employee". Production environment is analyzed from the side of the presence of physical, chemical, biological, psychophysiological HHPFs in it, technological equipment — according to the level of safety of the production process as a whole, and the employee — according to the indicators of severity and intensity of work, which allow us to assess the state of his/her health at the workplace.

In the complete absence of HHPFs in the workplace or in their presence, but the compliance of the actual levels with sanitary and hygienic standards and safety requirements (for example, MPC, MPL), as well as when meeting the requirements for injury safety and PPE provision of workers, it is summarized that the working safety conditions in the workplace comply with the established requirements of OSH in accordance with Article 184 of the Labor Code of the Republic of Kazakhstan and they can be assigned, according to the Hygienic criteria for assessing and classifying working conditions, to the 2nd (permissible) class of working conditions [17].

Workplaces are considered not to meet the established OSH requirements if they have one of the following factors or a combination of them:

— the actual values of any harmful factor exceed the existing requirements and norms;

— the requirements for workplace injury safety are not met;

— the PPE provision of employees does not comply with the current standards.

Depending on how much the levels of the actual values of HHPF exceed the existing norms, the working conditions, according to Hygienic criteria, should be assigned to the following classes of working conditions: 3.1; 3.2; 3.3; 3.4 and 4, and subsequently the measures to prevent or localize them should be developed [17].

Thus, the WC covers all the main components of the production process (workers – equipment – production environment), and according to its results, the OSH service of the enterprise can successfully assess the occupational risks of its employees. Another advantage of this method is that, using it, it is possible to assess possible hazards and occupational risks "before" the occurrence of negative incidents and take measures to prevent them, unlike other methods considered, focused on such an assessment "after" the incidents have occurred, based on the analysis of already dead, injured workers, occurred accidents, etc.

However, there are also a number of disadvantages of the risk assessment methods based on the WC, namely:

— such certification is a rather expensive event, and although it is legally imputed to the duties of employers, the latter, whenever possible, evade it, which is facilitated by the restrictions adopted over the past years for supervisory functions in the field of IS by the Industrial Safety Committee of the Ministry of Emergency Situations of the Republic of Kazakhstan as a result of the moratorium on inspections announced by the President of the Republic of Kazakhstan in 2014 for subjects of small and medium-sized businesses and extended until January 1, 2023;

— formal certification, unreliability of the results obtained. Accredited organizations are engaged in WC, with which the employer enters into an agreement to conduct it, but, as the saying goes, "he that pays the piper calls the tune," therefore, in the results obtained, such organizations do not reflect the actual state of affairs, but the wishes of the employer. It comes to the point that a number of organizations accredited in the field of WC do not even have specialized laboratories and material equipment. Therefore the Ministry of Labor and Social Protection of the Republic of Kazakhstan has imposed restrictions on the certification of workplaces according to working conditions by organizations that do not have their own accredited laboratories, and initiated a mechanism to deprive them of the relevant license;

— all these circumstances predetermine not only difficulties, but also the impossibility of an objective assessment of occupational risks based on unreliable WC results.

Conclusions. The analysis of the existing approaches and methods to the assessment of hazards and occupational risks of industrial workers in the Republic of Kazakhstan allowed us to draw the following conclusions:

— the main aspect in solving this problem is to conduct a preliminary stage and the nature of such an assessment, i.e. such a mechanism that makes it possible to conduct risk assessment "before" the occurrence of negative events, and not "after" their occurrence (emergencies, accidents, etc.);

— currently, there is no single approach among scientists and practitioners to the category of occupational risk, the mechanism of its identification and measurement. The very content of the concept of risk may vary depending on the specifics of the employee's profession, the nature of the work performed, etc.;

— the considered regulatory and proposed by various authors methods or approaches to occupational risk assessment have certain disadvantages. For example, some of them are limited only to assessing the condition of individual workplaces and do not take into account the size of possible accidents (the methodology for determining the IS level by accident rate), others are characterized by a certain subjectivity (expert methods), some methods are abstract in nature and do not use sufficient factual statistical data during such an assessment (matrix methods), some are complex in application (normative and probabilistic assessment methods);

— the results of the analysis of various approaches to occupational risk assessment indicate that none of them individually provides objectivity and conditions for the "preliminary" assessment, i.e. before the occurrence of negative events, with the exception of two of them: "Rules of occupational risk management" and "Rules of mandatory periodic certification of production facilities for working conditions". However, the latter also require improvement;

— the search and development of new methods for occupational risk assessment that have sufficient simplicity and reliability when used in real production conditions, preventing the occurrence of injuries to workers, and in general, man-made accidents are quite relevant.

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Analysis of occupational injuries in the construction industry and ways to reduce it

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Introduction. In the construction industry, there has recently been a positive trend towards a decrease in injury rates. The authors have identified the specific conditions of construction work as a source of occurrence of prerequisites for accidents. The paper provides the analysis of a statistical sample of data on accidents and occupational injuries in the construction industry, which shows that the sources of the vast majority of cases of industrial injuries are avoidable factors.

Problem Statement. The objective of this study is to determine the relationship between the accident rate in the construction industry and several factors related to the education and qualifications of employees.

Theoretical Part. As the basic information, the data of statistical reporting on occupational injuries provided by the Federal State Statistics Service, as well as materials from literary sources of domestic and foreign authors, were used. The method of complex assessment of the qualification of personnel is proposed.

Conclusions. Functional dependences of the frequency of accidents at the enterprise on the criterion of qualification of personnel are determined. Based on the results obtained, it can be concluded that the level of education of employees of construction enterprises, the correspondence of their basic education to the profile of the enterprise's activities and the frequency of professional development positively affect the overall state of the occupational safety system at the enterprise, including the reduction in the number of accidents.

Keywords: occupational safety, construction industry, occupational injuries, occupational risk, accidents at work, dangerous and harmful factors.

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Introduction. One of the most important and difficult problems in the construction industry is ensuring the safety of workers, since construction is one of the industries the activities of which are associated with harmful and hazardous working conditions. However, in the Russian Federation, occupational injury rates in the construction industry have remained at an unacceptably high level in recent years. Statistical data on occupational injuries in the construction industry substantiate the relevance of reducing the injury of workers in this industry. The state of working conditions and occupational safety often remains unsatisfactory, and the number of workers in harmful conditions continues to grow. At the same time, unfavorable working conditions give rise to a high level of occupational injuries and occupational diseases.

Problem Statement. The objective of this study is to determine the dependence of the accident rate coefficient in the construction industry on a set of factors that determine the level of education and qualifications of employees.

Theoretical Part. Occupational safety at the enterprise is aimed at preservation of the life and health of employees, as well as the prevention of occupational diseases and accidents that can lead to occupational injuries [1]. In accordance with Article 212 of the Labor Code of the Russian Federation of 30.12.2001 No. 197-F3 (ed. dated 29.12.2020), the employer is obliged to provide employees with safe working conditions [2]. However, in practice, the state of working conditions and occupational safety at the enterprise often remains unsatisfactory, and the number of employees engaged in work with harmful and (or) hazardous working conditions continues to grow.

To analyze statistical observations in the construction industry, it is necessary to consider which types of work characterized by harmful and hazardous working conditions have the greatest impact on workers. Table 1 provides information on the proportion of construction industry workers engaged in work with harmful and (or) hazardous working conditions, heavy work and work related to the intensity of the labor process for 2016-2020 in accordance with the data of the Federal State Statistics Service [3].

Table 1

The proportion of construction industry workers engaged in work with harmful and (or) hazardous working conditions, heavy work and work related to the intensity of the labor process for 2016-2020.

Gender of employees	Proportion of employees by year, %				
	2016	2017	2018	2019	2020
Work with harmful and (or) hazardous working conditions					
Male	42.1	41.2	40.8	44.0	41.3
Female	15.9	14.2	13	12.3	10.6
Heavy work					
Male	24.1	24.7	25.3	27.7	26.7
Female	7.9	7.6	6.6	6.7	6.0
Work related to the intensity of the labor process					
Мужской	8.2	7	4.9	4.7	4.3
Female	2.4	1.6	1.2	1.0	1.0

According to Table 1, it can be concluded: the average proportion of construction industry workers engaged in work with harmful and (or) hazardous working conditions in 2016 was 37.9%, in 2017 — 37.0%, in 2018 — 36.7%, in 2019 — 39.4%, in 2020. — 36.9%, i.e. in the period from 2016 to 2019 the trend was upward, and in 2020 this indicator decreased. The average proportion of construction industry workers engaged in heavy work in 2016 was 21.5%, in 2017 — 22.1%, in 2018 — 22.5%, in 2019 — 24.7%, in 2020 — 23.8%, the situation is similar to the previous indicator. The average proportion of construction industry workers engaged in work related to the intensity of the labor process in 2016 amounted to 7.3%, in 2017 — 6.2%, in 2018 — 4.3%, in 2019 — 4.2%, in 2020 — 3.8%, i.e. there remained the downward trend of this indicator. The percentage of men and women employed in jobs with harmful and (or) hazardous working conditions during the study period remained approximately at the same level. Thus, in recent years, the percentage of workers associated with harmful and (or) hazardous working conditions, as well as with heavy work, only increased, but in 2020 the situation began to change slightly for the better.

Unfavorable working conditions give rise to occupational diseases and a high level of occupational injuries, which is one of the main indicators characterizing occupational risk in the workplace [4-6]. In the Russian Federation as a whole, the level of occupational injuries has remained quite high in recent years, but there is a downward trend. Table 2 shows the data of the Federal State Statistics Service on Occupational Injuries in the Russian Federation for 2016-2020.

Table 2

Data on occupational injuries in the Russian Federation for 2016-2020.

Gender of employees	Indicators by year				
	2016	2017	2018	2019	2020
Number of victims of industrial accidents, thousand people.					
Male	18.6	17.6	16.6	16.3	14.4
Female	8.1	7.8	7.0	7.0	6.1
Number of victims of fatal industrial accidents, thousand people.					
Male	1.21	1.07	1.00	0.99	0.85
Female	0.08	0.07	0.07	0.06	0.07
Number of victims of industrial accidents per 1000 employees (accident frequency coefficient)					
Male	1.6	1.6	1.5	1.4	1.2
Female	0.9	0.9	0.8	0.8	0.7
Number of victims of fatal industrial accidents per 1,000 workers					
Male	0.103	0.094	0.089	0.087	0.072
Female	0.009	0.008	0.008	0.007	0.008

According to the Table 2 the number of victims of industrial accidents in 2016 amounted to 26.7 thousand people, in 2017 — 25.4 thousand people, in 2018 — 23.6 thousand people, in 2019 — 23.3 thousand people, in 2020 — 20.5 thousand people. Of these, with a fatal outcome in 2016 — 1.29 thousand people, in 2017 — 1.14 thousand people, in 2018 — 1.07 thousand people, in 2019 — 1.06 thousand people, in 2020 — 0.91 thousand people. The number of victims of industrial accidents per 1,000 employees in 2016 was 1.3, in 2017 — 1.3, in 2018 — 1.2, in 2019 — 1.2, in 2020 — 1.0. Of these, with a fatal outcome in 2016 — 0.062, in 2017 — 0.056, in 2018 — 0.054, in 2019 — 0.053, in 2020 — 0.045. The number of victims of industrial accidents during the study period remained almost at the same level, but there was a downward trend. The percentage of men and women injured in industrial accidents remained approximately at the same level.

The number of person-days of disability for victims at work remained at the same level and amounted to 49.0 per victim in 2016, 48.7 in 2017, 49.3 in 2018, 50.6 in 2019 and 49.9 in 2020.

Funds were spent on labor protection measures per employee in 2016 — 11479.8 rubles, in 2017 — 12964.7 rubles, in 2018 — 14246.4 rubles, in 2019 — 14862.4 rubles, in 2020 — 18825.3 rubles, i.e. there was a gradual increase in this indicator.

Table 2 shows that in recent years there has been a decrease in injuries in the Russian Federation as a whole, but at the same time, the frequency of accidents at work remain almost at the same level. With the current official indicators of occupational injuries in the Russian Federation, the urgency of improving occupational safety in the construction industry is obvious.

According to the Federal Service for Labor and Employment of the Russian Federation, an analysis of industrial injuries in the Russian Federation was conducted, according to which the most significant cause of injury is unsatisfactory organization of work, resulting in a third (32.4%) of accidents. For this reason, the influence of the human factor on the occurrence of accidents at work increases: unsatisfactory organization of work, imperfection of the technological process, shortcomings in the organization and conduct of training of workers on labor protection, unsatisfactory maintenance and shortcomings in the organization of workplaces, etc. [7, 8]. To solve the problem of this study, the authors propose to introduce the following parameters related to the level of education and qualifications of employees:

1. The coefficient of compliance of the basic education (specialty, training direction) of the company's employees with the positions held α. It is calculated by the formula:

$$\alpha = \frac{K_0}{K} \times 100\% \,,$$

where K_0 — the number of employees with the appropriate basic education; K — the total number of employees.

2. The coefficient of the level of education of employees of the enterprise β'. It is proposed to introduce the following scale of education level:

- incomplete secondary — 1;
- complete secondary (school) — 2;
- secondary vocational — 3;
- incomplete higher education — 4;
- complete higher education — 5.

The coefficient β' is calculated by the formula:

$$\beta' = \frac{\beta}{5\sum_{i=1}^{5} x_i} \times 100\% \,,$$

where x_i — the number of employees with the appropriate level of education. The parameter β is calculated by the formula:

$$\beta = 1x_1 + \ldots + 5x_5.$$

3. The coefficient of professional development by employees of the construction company γ'. Specialists in the field of construction must undergo professional training at least once every five years (Article 55.5-1 of the Town-Planning Code of the Russian Federation) [9]. Since this requirement is the minimum for this parameter, we will take the following scale: professional training 1 time in 5 years — 1; 2 times — 2; 3 times — 3; 4 times — 4; 5 times — 5. The coefficient γ' is calculated by the formula:

$$\gamma' = \frac{\gamma}{5\sum_{j=1}^{5} x_j} \times 100\%,$$

where x_j — the number of employees who have completed professional training the corresponding number of times. The parameter γ is calculated by the formula:

$$\gamma = 1x_1 + \ldots + 5x_5.$$

The generalized function of the qualification of the company's personnel Δ is calculated by the formula:

$$\Delta = \frac{\alpha + \beta' + \gamma'}{3}.$$

This function was calculated for data provided by twenty enterprises of the construction industry in the South of Russia. The authors summarized the data for 2016-2020 in Table 3.

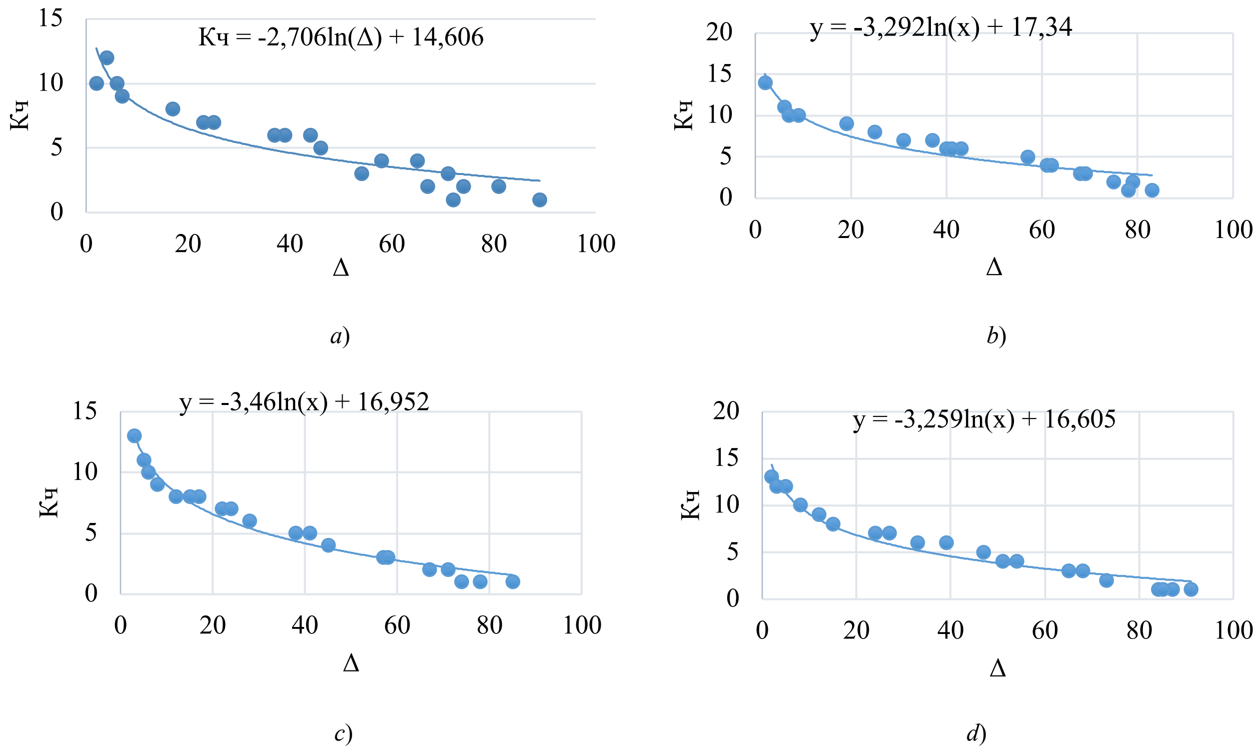
Table 3

Data of construction industry enterprises for 2016-2020.

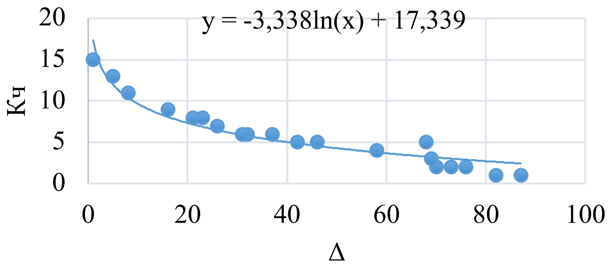
Company number	2016		2017		2018		2019		2020	
	Number of accidents	Δ, %	Number of accidents	Δ, %	Number of accidents	Δ, %	Number of accidents	Δ, %	Number of accidents	Δ, %
1	2	72	2	75	2	71	1	87	2	70
2	4	53	3	68	1	85	4	51	3	69
3	10	1	10	6	8	12	12	5	13	5
4	6	44	5	41	6	28	8	15	5	42

Company number	2016		2017		2018		2019		2020	
	Number of accidents	Δ, %	Number of accidents	Δ, %	Number of accidents	Δ, %	Number of accidents	Δ, %	Number of accidents	Δ, %
5	4	65	3	67	4	38	2	73	6	37
6	1	89	1	83	3	68	1	91	1	87
7	2	74	4	61	1	77	4	68	2	73
8	5	46	6	43	5	41	4	46	6	32
9	3	71	2	79	4	45	3	66	5	58
10	6	39	7	37	8	17	7	27	9	22
11	2	81	4	62	3	57	1	84	3	75
12	12	4	14	2	13	3	13	1	14	1
13	7	23	8	25	7	22	5	38	7	26
14	4	58	5	57	3	57	5	54	5	68
15	8	17	9	19	9	14	10	8	9	16
16	6	37	6	42	6	24	6	33	6	31
17	10	6	11	6	11	5	12	3	11	8
18	7	26	8	31	9	8	7	24	5	46
19	8	6	10	9	10	6	9	12	8	23
20	3	67	1	78	1	74	1	85	1	82

Further, it seems possible to establish a relationship between the accident frequency coefficient Кч and the generalized function Δ, which characterizes the qualifications of the company's personnel. Figure 1 provides the calculation results of such dependencies



a) *b)* *c)* *d)*



e)

Fig. 1. The dependence of the accident rate coefficient on the education and qualifications of employees for 2016 (a), 2017 (b), 2018 (c), 2019 (d), 2020 (e)

Conclusions.

A methodology for a comprehensive assessment of the qualifications of personnel has been developed, as a result of which it is possible to establish functional dependencies of the criterion of such an assessment with the frequency of accidents at the enterprise. The methodology has been tested on the example of a number of enterprises in the construction industry.

The level of education of employees of construction enterprises, the correspondence of their basic education to the profile of the enterprise's activity and the frequency of professional training positively affect the overall state of the occupational safety system, including the reduction in the number of accidents in accordance with certain functional dependencies characteristic of each enterprise.

It is recommended that the heads of enterprises assess the state of the qualification of personnel guided by a generalized criterion of this condition, predict the probabilistic frequency of accidents and make appropriate decisions on the modernization of OHSAS in the following directions: to recruit specialists of the appropriate level; to encourage employees to improve their skills, increase the level of education, targeted training in accordance with Decree of the Government of the Russian Federation of October 13, 2020 No. 1681 "On employer-sponsored training in educational programs of secondary vocational and higher education" (with amendments and additions); to take into account the achieved level of qualification when making personnel decisions.

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V. A. Kukareko — formulation of the basic concept, goals and objectives of the study, calculations, preparation of the text, formation of the conclusions; V. L. Gaponov — scientific supervision, analysis of the research results, revision of the text; S. L. Pushenko — scientific supervision, analysis of the research results, correction of the conclusions.

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Overview of changes in legislation establishing the requirements for the assessment of occupational risks at the enterprise

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Introduction. The paper analyzes the requirements for the implementation of occupational risk assessment at the enterprise. Until recently, this procedure did not actually have the necessary legislative basis, so the authors offer a detailed review of the key changes in the normative-legal regulation of occupational safety, which specifically touched upon the management of occupational risks.
Problem Statement. The purpose of this study is a detailed consideration of innovations in the field of the occupational safety, which came into force on March 1, 2022.
Theoretical Part. The Labor Code of the Russian Federation was used as the basic information for the study.
Conclusions. The results of the analysis indicate the need to create effective tools for the regulatory procedure of occupational risk assessment.

Keywords: occupational safety, risk, occupational risk assessment procedure, risk management, occupational safety management system.

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Introduction. As international and domestic practice shows, any production is a source of increased danger, and the responsibility for creating safe working conditions lies entirely with the employer. Risk assessment is one of the most effective tools to achieve this goal [1–2].

Problem Statement. Currently, there are no requirements for the assessment of occupational risks level. The organization has the right to conduct it both independently and by concluding an agreement with a specialized organization.

However, the main problem is that there are virtually no regulations for the occupational risks assessment procedure, as a result of which many employers treat it formally, endangering the personnel of their enterprise.

In this regard, there is a need to assess the changes that have occurred in the regulatory control of this issue.

Theoretical Part. An integral part of the production activity of any employer is the occupational health management system (OHMS), the structure of which is described in Regulation of the Ministry of Labor No. 776n of 29.10.2021.

This regulation establishes general requirements for the organization of work on occupational safety on the basis of regulatory documents, principles and management methods. The OHMS functioning is carried out through the compliance with state regulatory requirements for occupational safety, obligations assumed and the application of local documents in the implementation of processes provided for in the sections of OHMS [3-4].

One of the main problems of OHMS is that it implies a direct response to the occurrence of a hazardous situation, and not to its prevention. For this reason, the assessment of potential hazards by risk indicators and the development of preventive measures based on this assessment become the primary tasks of occupational safety management [5].

According to the Labor Code of the Russian Federation, we understand occupational risk as "the likelihood of harm to health as a result of exposure to harmful and (or) hazardous production factors when an employee performs duties under an employment contract or in other cases established by this Code and other federal laws" [6].

There are many methods by which you can determine the level of occupational risk at an enterprise: matrix, point, direct, indirect, lists of control questions, brainstorming (Delphi method), etc. The use of these methods has not been enshrined in law, so the employer has the right to choose one of them himself or develop a methodology depending on the specifics of the enterprise [7].

Occupational risk assessment is traditionally carried out in several stages: hazard identification, risk analysis, which includes determining the level of risks, the acceptability of the level of risks and the need for safety measures, the choice of risk management methods and their implementation, repeated risk analysis to verify the achievement of the acceptability of the risk level.

The concept of occupational risk management is currently the most relevant one, as it allows minimizing the number of accidents and occupational diseases at work [8].

In this regard, the role of occupational risk assessment as a tool to improve the effectiveness of the management system is increasing and there is a need to improve the procedure.

Within the framework of this study, an analysis of key changes in occupational safety related to occupational risks assessment was carried out, which came into force on March 1, 2022 (Table 1).

Table 1

Analysis of key changes related to occupational risks assessment

Changes	Essence of changes	Comments
Federal Law No. 311 of 02.01.2021 "On Amendments to the Labor Code of the Russian Federation" comes into force, which makes amendments to a number of provisions of the Labor Code	Federal Law No. 311 fixes such concepts as "labor protection requirements", "occupational risk" and "occupational risk management". Occupational risk management is interpreted as a set of interrelated measures and procedures that are elements of the occupational safety management system and include the identification of hazards, assessment of occupational risks and the application of measures to reduce the levels of occupational risks or to prevent their increase, monitoring and revision of identified occupational risks [6]	The new occupational safety policy launches the process of reorientation towards the reduction of the number of hazards in the workplace. It is quite natural that in order to implement a new policy, it became necessary to legislate its basic concepts
Section X of the Labor Code of the Russian Federation underwent significant changes	There was a so-called transition to a target-focused policy [9]	The amendments made to section X of the Labor Code of the Russian Federation allow personalizing the occupational safety management system by switching to a target-focused policy that takes into account the results of occupational risks assessment and, as a result, the individual characteristics of each workplace
Amendments have been introduced to Article 209.1 of the Labor Code of the Russian Federation	According to the updated version of Article 209.1, one of the basic principles of ensuring occupational safety will be the reduction of the level of occupational risk in the workplace [9]	It is easier to prevent the cause than to eliminate the consequences. The procedure for occupational risks assessment will become mandatory, since its prevention is established as one of the basic principles of ensuring safety
Amendments have been introduced to Article 214 of the Labor Code of the Russian Federation	According to the new version of Article 214 of the Labor Code of the Russian Federation, the employer is obliged to ensure the systematic identification of hazards and	Micro-injuries received at the workplace can provoke temporary disability. Therefore, to keep records of them, issuing a certificate as an act of investigation, is for the convenience of

Changes	Essence of changes	Comments
	occupational risks, their regular analysis and assessment, investigation and accounting of accidents, accounting and consideration of the causes and circumstances of micro-injuries (microtrauma) [6]	the employer himself. The Ministry of Labor advises each enterprise to develop its own local act containing the procedure for this accounting. This practice is successfully applied and allows preventing accidents at many foreign enterprises
Amendments have been introduced to Article 214.1 of the Labor Code of the Russian Federation	According to the amendments, an employee has the legal right not to start his/her work duties until the occupational risk factors are eliminated	It is better to conduct an occupational risks assessment immediately before a special assessment of working conditions, since if the special assessment of working conditions identifies dangerous working conditions of Class 4, the employer will have to declare a downtime with the retention of the employee's position, as well as his average earnings
Amendments have been introduced to Article 214.2 of the Labor Code of the Russian Federation	The employer now has the right to conduct video and audio recordings at work to ensure control over the safety of work carried out	Sometimes the level of occupational risk at the workplace can be increased even by the employee himself, who doesn't follow the occupational safety regulations. Thanks to video and audio recording, the employer will be able to continuously monitor the labor process, which will allow him to intervene in time if violations are committed, avoiding undesirable consequences. It must be remembered that this method can be used strictly with consent, otherwise the employee will be able to sue because of an illegal invasion of his/her privacy
Amendments have been introduced to Article 218 of the Labor Code of the Russian Federation	Risks are now divided (depending on the cause) into the following categories: injuries and occupational diseases	It is not always possible to understand what kind of insurance event occurred with an employee. Injuries as a result of an accident and occupational diseases are investigated in different ways, if you take an accident for occupational disease and do not report it within a day, the employer will be fined. Dividing the risk into categories will make it possible to clearly determine what measures need to be taken to manage it in a particular case
Order of the Ministry of Labor of the Russian Federation No. 796 of 28.12.2021 came into force, approving the recommendations on the choice of a method for the assessment of occupational risk level and on its reduction	The Ministry of Labor has developed the recommendations on the choice of a method for occupational risks assessment. The recommendations contain criteria, the process and stages of choosing the necessary methodology, a selection of methods used in domestic and foreign practice, as well as the examples of evaluation tools [8]	Methodological recommendations will not have normative weight, the employer still has the right to independently choose the evaluation methodology depending on the specifics of the enterprise
Amendments have been introduced to Article 221 of the Labor Code of the Russian Federation	The procedure for handing out personal protective equipment (PPE) has changed. According to the experience of foreign countries, handing out will be based on the results of the occupational risk assessment procedure [10]	This approach is more effective than handing out according to standards, since the number of PPE is determined depending on the actual working conditions

Changes	Essence of changes	Comments
Amendments have been introduced to Article 218 of the Labor Code of the Russian Federation	The analysis of occupational risks must now be carried out not only for the existing enterprises, but also for those facilities that are just about to be put into operation	This is nothing more than one of the preventive measures aimed at eliminating the danger at the initial stage of the enterprise. An employer who has carried out an occupational risks assessment at the stage of commissioning of a production facility has the opportunity to independently detect and promptly eliminate all the shortcomings

As it can be seen from the table, the trends in legislation clearly tend to introduce a risk-based approach.

Conclusions. The issue of changes in occupational safety legislation has been overdue for a long time. It should be expected that the transition period will not happen all at once, it may take from three to five years. So, many of the amendments listed in the work were planned to be introduced in 2021, but this was not done until this year.

Such changes will be able to give impetus to the formation of an effective legal framework regulating the conduct of such a procedure as the occupational risks assessment.

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Analysis and assessment of safety during operation of the shot blasting machine in the foundry

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Introduction. The article discusses the harmful factors of foundry production. The authors analyze and evaluate the workplace of the operator of the shot blasting chamber and offer technical solutions to improve working conditions and reduce the development of occupational diseases.

Problem Statement. The objective of this study is to assess the impact of noise and dust pollution on the production sites of the foundry.

Theoretical Part. In the course of the study, the most polluted areas were identified with the exceeding permissible values of the considered indicators of noise level and dust content. These are the areas of shake-out grids and casting cleaning. Measures to improve the situation were proposed, such as: organization of acoustics taking into account the characteristics of the production room (acoustic screens, soundproof partitions), a suitable sound absorption area of the premises, the improvement of sound absorption by upgrading the body of the shot blasting chamber.

Conclusions. The results of the analysis indicate a sufficiently high level of influence of harmful production factors on the operators of the shot blasting section of the foundry and the need to strengthen labor protection in this area.

Keywords: noise pollution, vibration, dust, foundry, production site, shot blasting equipment, acoustics.

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Introduction. The impact of negative factors on employees of foundry enterprises is considered. The air environment of the working area of foundry operators often does not comply with sanitary and hygienic standards. This is due to the complexity of technological processes and the presence of harmful factors. The greatest amount of dust, noise and vibration is produced by equipment that is used for products processing and grinding by the shot blasting method.

The process of shot blasting makes it possible to grind casting blanks of different shapes. However, this technological process is accompanied by the generation of a large amount of dust, which poses a threat to the workers' health. An integrated approach to reducing dust content and preventing occupational diseases can gradually solve the problem of creating safe working conditions [1].

Monitoring the permissible noise and vibration levels in production is a very complex and costly event. Increased noise and vibration are considered to be those environmental factors that are technically very difficult to bring into the compliance with regulatory values [2]. A large number of occupational diseases associated with hearing impairment manifest themselves in workers after a long time of work. The development of serious problems with the auditory nerve depends on technological processes in which the noise level exceeds the acceptable values. The greatest impact of increased noise is observed at the sites of molders, casting technicians, fettlers and casting cleaners for mass production, where the values of the pollution index reach 1.43–2.74 [3]. Table 1 provides the data.

Table 1

Value of the pollution index by noise factor in the areas of foundries with different noise patterns

№ п/п	Profession	Noise pollution index, Ksh	Number of jobs
1	Moulder	1.43	3
2	Casting technician	2.74	2
3	Fettler	2.46	3
4	Casting cleaner	2.67	1
5	Pouring man	0.79	4
6	Metals and alloys furnace-operator	0.79	4
7	Charge maker	0.22	1
8	Foundry machine engineer	0.45	1
9	Sand mixer	0.71	2

Problem Statement. The initial objective of this study was to analyze the experimental characteristics of noise pollution.

The results of noise level studies have shown that noise pollution significantly exceeds the established norms. The greatest exceedances of permissible sound levels are noted at the workplaces of core and molding jarring machines by 12-23 dB, at shake-out tables — by 17-26 dB, at cleaning equipment — by 16-27 dB [3-4].

According to the sanitary standards, there are the values of permissible sound pressure levels (Table. 2) [5].

The sound field in the working areas of foundries is heterogeneous. This is due to the different modes and operating time of the production equipment. The most dangerous is the periodic mode of operation with the maximum noise level in the area of medium and high frequencies.

Table 2

Permissible sound pressure levels, sound levels and equivalent sound levels in workplaces, industrial premises and on the territory of enterprises

Type of work activity	Sound pressure levels, dB, in octave bands with average geometric frequencies, Hz									Sound levels and equivalent sound levels, dBA
	31.5	63	125	250	500	1000	2000	4000	8000	
Performing all types of work at permanent workplaces in industrial premises and on the territory of enterprises	107	95	87	82	78	75	73	71	69	80

Foundries of mass production are distinguished by the fact that a lower level of automation and mechanization of processes allow you to choose the most rational and isolated position of the equipment. It follows from this that the main methods of protecting workers consist in the rational placement of equipment, the organization of proper acoustics of premises, the installation of sound-proof screens and the improvement of shot blasting equipment housings [6].

The second task of the study was the development of measures to minimize dust and ensure safe working conditions in the dustiest areas of the foundry — shot blasting ones.

Special measures for the use of continuous production technology remove dust immediately in the places where it appears, also prevent the formation and spread of dust mechanization and automation of processes, development, installation and configuration of remote control systems, sealing and isolation of equipment, supply and exhaust ventilation systems [7].

In the foundry, dusty air passes through the dust collector system and then enters the atmosphere. However, the effectiveness of such systems is not sufficient [4].

Theoretical Part. One of the main issues of the study is the question of the characteristics of the sources of emitted noise and dust at the cleaning sites with the highest level of noise pollution.

One of the main and most frequently used methods of surface treatment of metal workpieces is shot blasting. This method allows you to polish the casting most efficiently; it is carried out in a shot blasting chamber.

Figure 1 shows a diagram of the shot blasting section [7].

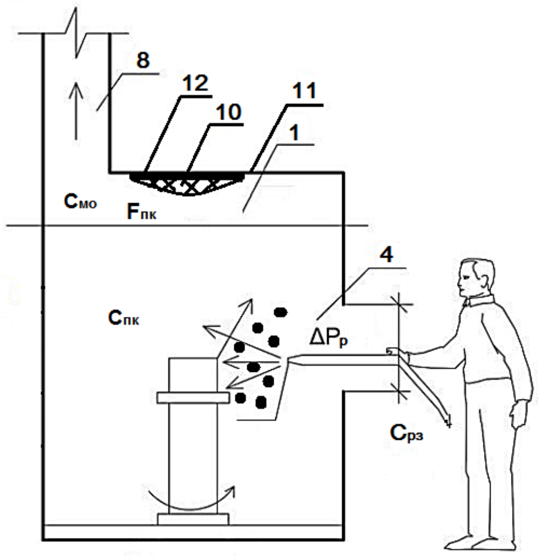

Fig. 1. The system of the shot blasting section of the foundry: 1 – shot blasting chamber; 2 – loading sector of the parts to be cleaned with a sealed door; 3 – control panel; 4 – shot blasting machine feed window; 5 – technological hole with a sealed lid for removing shot; 6 – compressed air line; 7 – air supply to the nozzle; 8 – air duct; 9 – conical air purification cyclone; 10 – VDM (vibration damping material); 11 – structural material; 12 – SAM (sound-absorbing material).Legend: Срз – concentration in the working area, Спк – concentration in the dust chamber, Смо – concentration in the local suction, Fпк – the area of the dust chamber, ΔPр – pressure drop during control

Shot blasting takes place in a chamber, which is a closed metal structure with a size of 2000x2000x2500 mm, its inner surface is made of 3 mm thick steel sheet and covered with 10 mm thick rubber. In the upper part, the chamber is connected by means of a pipe with a diameter of 630 mm to the local exhaust ventilation, which contains the cyclone TSN-11 [7].

Through the feed window, a shot with an average diameter of 2 mm falls on the surface of the product at a speed of 30 m/s. The principle of operation of a simple injection shot blasting machine is based on the operation of a hermetically sealed tank in which there is a shot under compressed air pressure. Under the influence of gravity and compressed air pressure, the shot is fed into the chamber. At the same time, noise of increased intensity is produced.

The amount of dust in the aspiration system to the dust collecting equipment was about 6 g/m^3, in the working area — about 9 mg/m^3 [7]. The degree of influence of dust on human health depends on its granulometric composition. Particles smaller than 10 microns remain in the lungs to a greater extent. Hazard class — 3, MPC = 0.5 mg/m^3. The level of air pollution in the working area forms a large number of factors that must be observed. This is a regular and high-quality repair and maintenance of equipment, the creation of effective modes of operation of aspiration systems and equipment for dust collection [8].

Dust after processing the surface of metal parts with shot turns into multicomponent, therefore, the development of effective measures for cleaning gas dust is required, in this regard, the study of elemental and dispersed compositions of dust particles is considered relevant. Granulometric analysis was used to estimate dust particles by size [3]. The particle distribution density and their size affect the properties of dustlike materials. The dust composition was determined using a Fritsch NanoTec laser particle analyzer, Analisette-22 model, using Fritsch Mas control software. Figure 2 provides the obtained data.

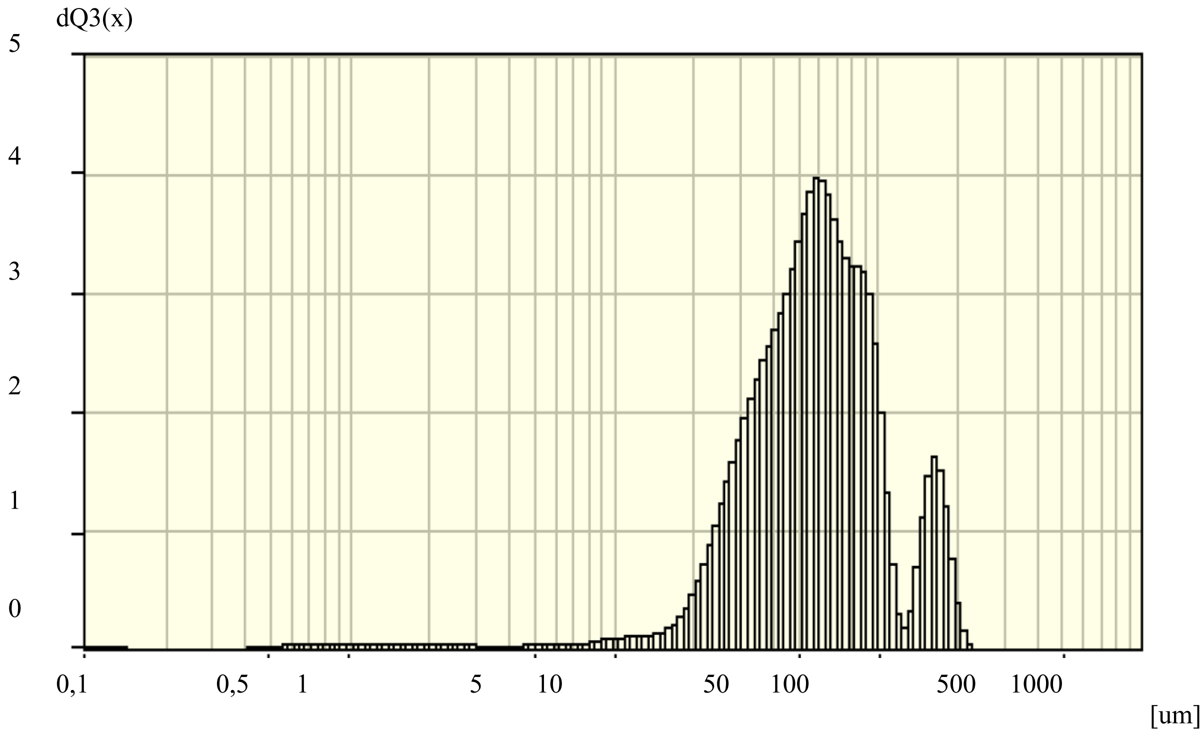

Fig. 2. Graphical results of the dispersed analysis of dust particles

The results are as follows: the dust contains about 90% of fine and medium-dispersed dust with a size of less than 100 microns. Particles of this kind are dangerous to human health; there is a risk of pneumoconiosis and silicosis.

The second stage of the experiment was aimed at detailing the dispersed composition of dust; it was carried out by X-ray spectral microanalysis [7].

X-ray phase analysis is the most promising method and is characterized by reliability and speed of obtaining results, based not on the comparison with available samples, but on the analysis of the crystal structure of the substance. The advantages of this type of analysis are non-infringement of the integrity of the part, assessment of phases in the mixture, tolerance to the volume of the object under study.

The data obtained by the X-ray spectral analysis show that dust has a shape that can be conditionally considered spherical. When settling, dust particles of this shape rotate and occupy a position at which they exert the greatest resistance to air. The shape of the sphere contributes to settling in inertial-type dust collectors and in the atmosphere. Particles smaller than 10 microns settle for a longer time, the presence of such particles in the air indicates the need to install a more efficient air purification system.

X-ray spectral analysis on the Bruker S8 Tiger wave X-ray fluorescence spectrometer at the Center for Collective Use of Scientific Equipment of VSU made it possible to obtain a more accurate number of elements in the sample. In order to refine the emission to standard concentrations equal to the maximum permissible concentrations of harmful substances in the air of the working area (MPCw.a.), it is proposed to supplement the existing dust collection system with a "wet" stage.

The main reason for the occurrence of strong noise is the peculiarities of the technological process in which aerodynamic noise occurs. To reduce noise of this kind, it is necessary to use techniques to improve the aerodynamic characteristics of the equipment.

The authors' proposal is to reduce the level of noise pollution by selecting soundproof and sound-absorbing parts of the body of shot blasting equipment.

The experimental studies of the absorption coefficients of a large number of cladding materials in the octave bands of the sound frequency spectrum, presented in [9], helped to choose the most effective combination of structural, sound-absorbing and vibration-damping materials. Methods of calculating the acoustic characteristics of materials and equipment helped to determine the optimal parameters of the components of production machines.

One of the authors' proposals is to maintain the thickness of the ferrous metal wall in the shot blasting chamber equal to 3 mm (Fig. 1, pos. 12), on which a layer of glued rubber with a thickness of 10 mm is applied (Fig. 1, pos. 10), which gives additional sound insulation of the walls of the chamber. On the inner surface of the chamber, it is necessary to apply sound-absorbing materials with a thickness of 30 mm, which are products that consist of superfine basalt fibers with a diameter of 1-3 microns, bonded together in the form of a canvas in a shell of glass fabric (Fig. 1, pos. 12). The sound absorption coefficient of the presented materials in the medium-high frequency range is from 0.5 to 0.9. Table 3 presents the sound insulation characteristics of the material made of superfine basalt fibers.

Table 3

Sound insulation characteristics of the material made of superfine basalt fibers

Material density – ρ = 15 kg/m^3. Material thickness – 30 mm. The size of the gap between the material and the insulating wall – 0 mm			
Frequency range, Hz	100–300	400–900	1200–1700
Normal sound absorption coefficient	0.05–0.15	0.22–0.75	0.85–0.93

The preliminary calculation of noise reduction at the operator's workplace when using the proposed measures showed that it was impossible to achieve the requirements of sanitary standards.

The results of experimental data on noise pollution do not meet the expected requirements. Carrying out a set of measures allowed reducing the noise level by 8-10 dB, which is not a safe value. To reduce the noise level more seriously, it is necessary to resort to installing a remote control system and sealing the equipment. [10].

The authors' proposal also consists in installing noise-proof structures and fencing in the areas with the most intense noise. This will help to form sound protection and significantly increase dissipation [11].

The recommended measures do not allow achieving the standard values of noise characteristics. Since making changes to the design of the shot blasting chamber is technically unrealizable, the use of personal protective equipment — a helmet with headphones is considered [12].

The authors offer comprehensive recommendations to reduce the level of dust and noise at the operator's workplace, which will consistently solve the problem of creating safe working conditions [12].

Conclusions. A comprehensive analysis of noise impact on foundry workers is described and the ways to optimize the working conditions of operators of shot blasting grinding plants are studied:

1. The unfavorable areas with the highest level of noise pollution have been identified — shake-out tables and shot blasting areas.

2. Granulometric analysis of the samples showed that dust with a size of less than 100 microns makes up 90% of its total volume.

3. It is established that in the shot blasting areas of the foundry, there is an excess of the normative values of the noise level by 4-18 dB.

4. A technical solution has been proposed to reduce the noise level for a standard shot blasting chamber — applying a two-layer coating on its inner surface consisting of a vibration damping material, which is a layer of glued rubber with a thickness of 10 mm and a sound-absorbing material made of super-thin basalt fibers made according to a flat scheme (cloth), which does not provide normative values of the noise level, but gives a significant decrease in it.

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V. Ya. Manokhin — scientific supervision, formulation of the basic concept, goals and objectives of the study; L. D. Drozdova — analysis of the research results, formulation of the conclusions; E. I. Golovina — performance of the experiment, analysis of the research results, formulation of the conclusions; D. A. Sokolov — preparation and formatting of the text of the article, work with literature.

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Assessment of the fire hazard level of buildings (structures) in operation, taking into account the functional fire hazard class for 2017-2020

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Introduction. The article analyzes the methods of assessing the fire hazard level of operated buildings (structures). The indicator "the proportion of people injured in fires from the total number of people injured in fires" is proposed to assess the fire hazard level of operated buildings (structures).

Problem Statement. To assess the fire hazard level of operated buildings (structures), various indicators are used that do not take into account the number of people present at the facility during the fire, but are dependent on this value. The calculation of the indicator "the proportion of people injured in fires from the total number of people injured in fires" as an additional one allows us to estimate the magnitude of fire hazard factors at facilities without taking into account the number of people who were at the protection facility during the fire.

Theoretical Part. As the basic information in the study, the statistics of fires and their consequences for 2017-2020 at operated facilities grouped by functional fire hazard classes were used. The indicators used in the calculation are the number of fires, the number of people killed and the number of injured people.

Conclusions. The indicator "the proportion of people injured in fires from the total number of people injured in fires" evaluates the probability of survival of people caught in the zone of exposure to fire hazards that lead to injury or death of a person, and characterizes the magnitude of fire hazard factors. Large values of this indicator may indicate a low level of fire hazard — the damage to health does not lead to the death of victims. The calculations of this and other indicators for objects of protection by functional fire hazard classes based on statistical data on fires and their social consequences are given. The high level of fire hazard in single-family residential buildings, agricultural buildings and cultural and leisure institutions is shown.

Keywords**:** fire, object of protection, functional fire hazard class, death, injury.

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Introduction. Many scientific studies have been devoted to the problem of fire hazard assessment of operated buildings (structures) [1–4]. At the same time, approaches to such an assessment often differ. It is proposed to use the following indicators: "the risk for a person to die in a fire" [1, 2]; "the proportion of dead and injured people for a group of hazardous objects similar in types of economic activity", calculated as the average number of injured people per object per year [3]; an indicator based on the Dow-Jones approach [4] et al. However, it is not always possible to accurately estimate the number of people who are at the hazardous object during a fire. In addition, biased estimates are calculations of the average number of people killed per 1 object per a year or per 1 fire, because they do not take into account the total number of people who are at the hazardous object during the fire, at the same time, the estimates under consideration depend on the total number of people.

In 2020, the number of planned and unscheduled fire safety inspections of hazardous facilities decreased by 66% [5]. This is due to several factors: firstly, changes in control and supervisory activities, enshrined in Federal Law No. 248-FZ of 31.07.2020 "On State Control (Supervision) and Municipal Control in the Russian Federation", which establishes a new procedure for the organization and implementation of state and municipal control. Secondly, the adoption by the Government of the Russian Federation of a number of resolutions related to the pandemic, including the extension of the moratorium on scheduled inspections of small and medium-sized businesses and the restriction of unscheduled inspections in the conditions of the spread of COVID-19. The purpose of these studies is to identify the hazardous objects that have the maximum level of fire danger.

Problem Statement. Based on the statistics of fires and their consequences for 2017-2020 [6-9, 10], the research provides the fire hazard assessment of operated buildings (structures) grouped by the level of such hazard in accordance with Article 32 of Federal Law No. 123-FZ of 22.07.2008 "Technical Regulations on fire safety requirements". Data on the statistics of fires and their consequences are given in Table 1.

Table 1

Statistical data on the number of fires and injured and dead people for 2017-2020

Functional fire hazard class	Number of fires	Number of people	
		dead	injured
Ф1.1	889	32	62
Ф1.2	1446	56	140
Ф1.3	119665	9713	14478
Ф1.4	173086	17555	10031
Ф2.1	528	65	86
Ф3.1	10961	44	165
Ф3.2	2563	14	84
Ф 3.4	488	11	21
Ф3.5	1136	10	38
Ф3.6	9627	86	158
Ф4.1	776	2	21
Ф4.3	3552	40	102
Ф5.1	13059	244	527
Ф5.2	30616	521	792
Ф5.3	8091	185	154

The following indicators were calculated for each group of hazardous objects differing in the class of functional fire hazard:

— the number of people killed in fires per 1 fire;

— the number of victims (dead and injured) in fires per 1 fire;

— the proportion of injured people from the amount of people affected by fires.

Theoretical Part. Figure 1 shows the distribution of fires by groups of hazardous objects corresponding to functional fire hazard classes. Most of the fires in 2017-2020 occurred in single-family residential buildings (46%), multi-apartment residential buildings (32%) and objects of functional fire hazard class Ф5.2 (warehouse buildings, etc.). Figures 2, 3 reflect the consequences of fires at various facilities.

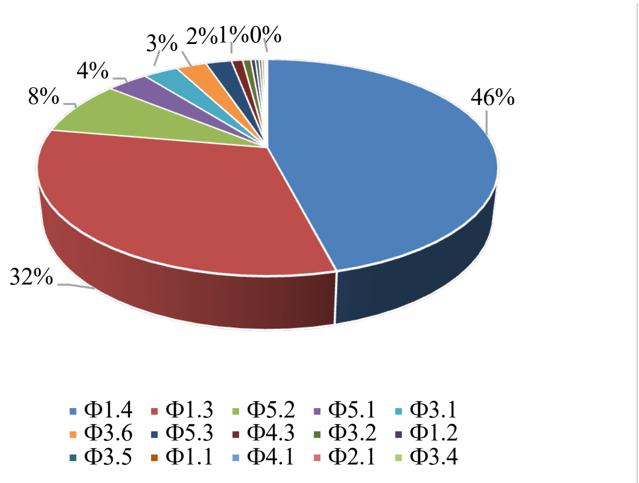

Fig. 1. Distribution of fires by functional hazard classes

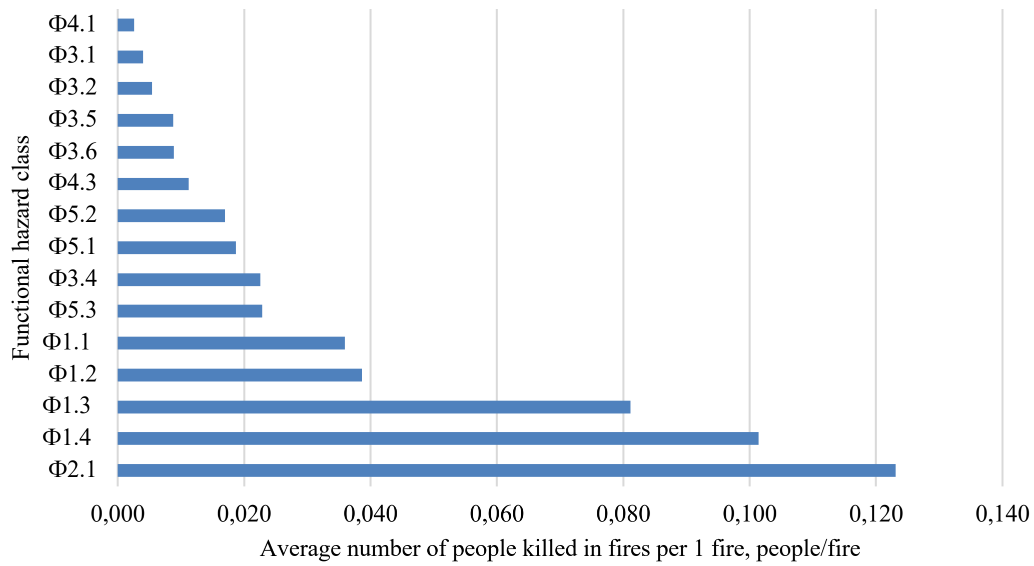

Fig. 2. Distribution of the number of people killed in fires per 1 fire by groups of hazardous objects

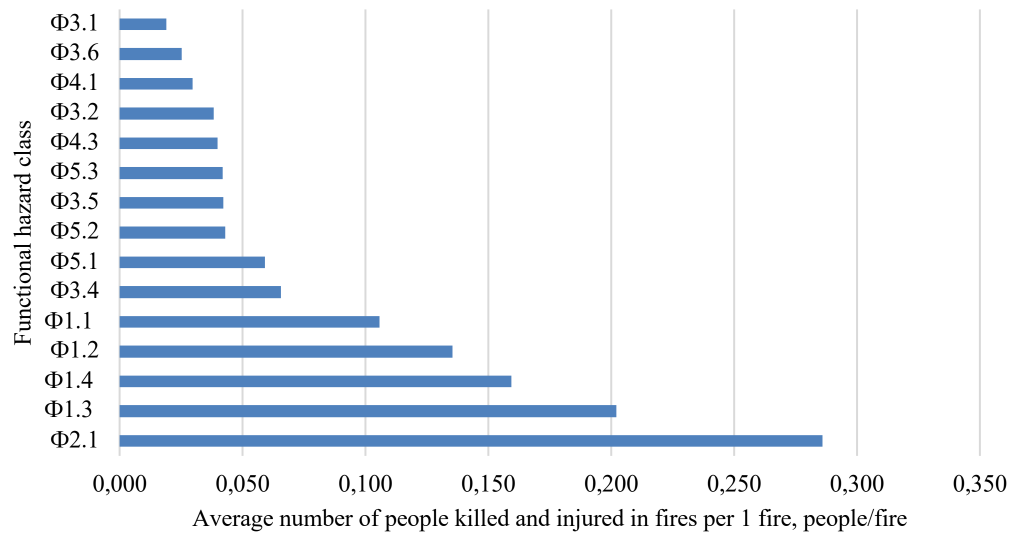

Fig. 3. Distribution of the number of victims (dead and injured) in fires of people per 1 fire by groups of hazardous objects

The maximum negative effect from fires was recorded at objects of functional hazard class Ф2.1 (cultural and leisure institutions, etc.). This indicator is also high in single-family and multi-apartment residential buildings and at objects of class Ф1.2 (hotels, dormitories, etc.). However, such values of the considered indicators can be associated with both a high level of fire danger of hazardous facilities and a large number of people who are at the facilities during a fire.

To assess the fire hazard of operated buildings (structures), it is proposed to use the indicator "the proportion of people injured in fires from the total number of people injured in fires" as an additional indicator. This indicator evaluates the probability of survival of people exposed to fire hazards that lead to injury or death of a person, and characterizes the magnitude of fire hazard factors. Large values of this indicator may indicate a low level of fire danger, when damage to health does not lead to the death of victims. Figure 4 shows the ratio of the proportion of people injured in fires from the total number of victims of fires by groups of hazardous objects corresponding to functional hazard classes.

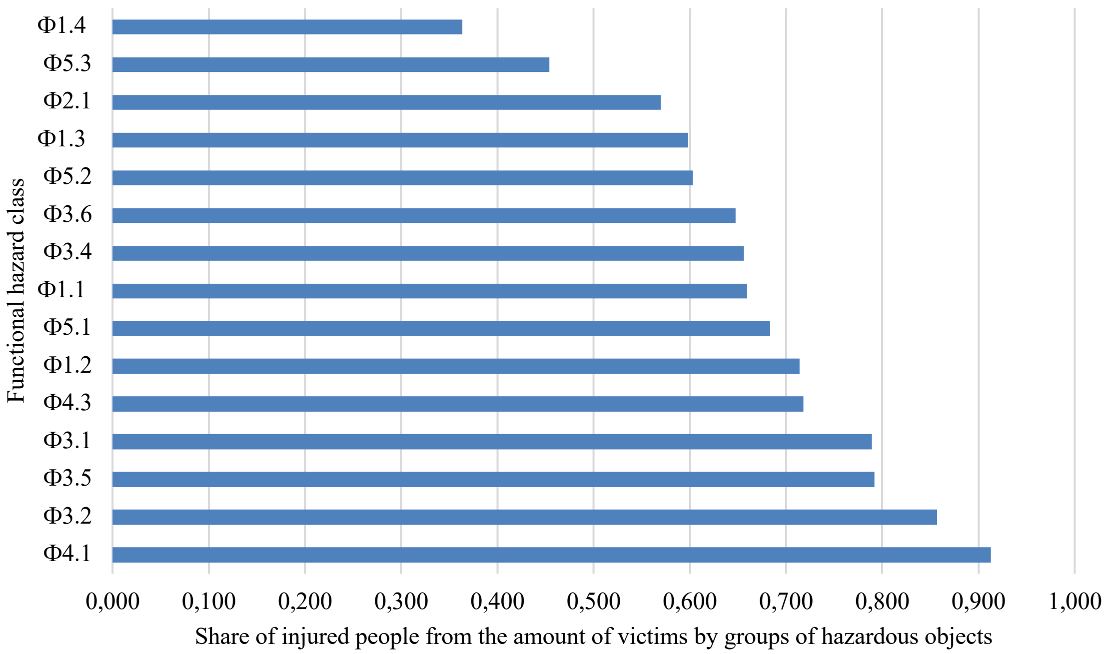

Fig. 4. The proportion of injured people from the amount of victims by groups of hazardous objects

As it can be seen from Figure 4, the highest level of fire hazard is recorded in single-family residential buildings. It should be noted that the biggest amount of fires occurred at these facilities (Fig. 1). However, if the indicator "average number of deaths per 1 object per year" is used, we get an estimate of 2.4·10-5 people/object /year, whereas for apartment buildings a similar estimate is 9.0·10-5 people /object/year. The calculated data obtained confirm the conclusion that it is incorrect to use this indicator to assess the level of fire danger of operated buildings (structures) without taking into account the number of people who are at the hazardous object during the fire. The proposed indicator "the proportion of people injured in fires from the total number of people injured in fires" does not depend on taking into account the number of people who are at the hazardous object during a fire, and seems to be more optimal for assessing the magnitude of the fire hazard of buildings (structures) in operation. It should be noted that low values of this indicator were obtained for agricultural buildings (Ф5.3), as well as cultural and leisure institutions (Ф2.1). Let us mention that other methods of assessing the fire hazard of operated buildings (structures) do not record a high level of fire hazard of agricultural buildings.

Conclusions. The indicators of fire hazard assessment of operated buildings (structures) classified according to the level of fire hazard in accordance with Article 32 of Federal Law No. 123-FZ dated 22.07.2008 "Technical Regulations on Fire Safety Requirements" are analyzed. A new indicator for such an assessment is proposed. The high level of fire hazard in single-family residential buildings, agricultural buildings and cultural and leisure institutions is shown. It is necessary to develop new forms of organization and implementation of state and municipal control, taking into account the high risks of fire hazard of hazardous objects of the selected categories.

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Claimed contributorship

V. V. Kharin — scientific supervision, analysis of the research results, correction of the conclusions, revision of the text; E. V. Bobrinev — formulation of the main idea and concept of the study, review of publications on the topic of the article, participation in the collection and processing of material, analysis of the research results, participation in writing the text of the manuscript; A. A. Kondashov — development of the purpose and objectives of the study, calculations, analysis and interpretation of data, formulation of the conclusions, participation in writing the text of the manuscript; E. Yu. Udavtsova — development of the research design, preparation of literature, participation in the collection and processing of material, participation in writing the text of the manuscript; T. A. Shavyrina — participation in writing the text of the manuscript, editing the text, making the final version of the article.

MACHINE BUILDING

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Research on the effectiveness of aluminum passive safety elements in cars based on computer simulation

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Introduction. The research of energy-absorbing element made of aluminum alloy, which is part of the passive safety system of a racing car, is carried out in the article. Designing and testing of the energy absorbing element was performed within the framework of the technical regulations of the international student engineering competition Formula SAE. Formula SAE is an engineering competition of student teams organized by the Society of Automotive Engineers (SAE).

The design and analysis of the dynamic performance of the research object were performed in the computer-aided design system (CAD) ANSYS® Workbench SpaceClaim and ANSYS Explicit Dynamics.

Problem Statement. The task of this research is to analyze the effectiveness of the use of aluminum alloy as the main material for the manufacture of the energy-absorbing element of the passive safety system of the car.

Theoretical Part. Eleven structures of different shapes (structures) made of aluminum alloy 6063 were developed as promising models of energy-absorbing elements. A simulation crash test (frontal impact) was carried out, as a result of which it was possible to study the flow of deformation in the structure, to find the main zones of stress and load. This study of energy-absorbing elements can be used to justify the choice of material for the manufacture of passive car safety elements by car manufacturers and machine builders.

Conclusions. The result of the research is a simulated process of destruction (or deformation) of the energy-absorbing element responsible for the absorption of energy in case of a frontal impact. The dependence of the manufacturing material and the shape of the energy absorbing element on the qualitative and quantitative characteristics of the passive car safety system has been investigated. Loads and stresses appearing in the structure of energy absorbing element have been studied. The efficiency of using aluminum alloy in promising car passive safety elements has been proved. Simulations of crash-tests showed that the use of progressive materials of construction elements of passive safety of vehicles, namely, aluminum alloys in an optimized (as a result of modeling) performance allows you to achieve high levels of protection of the pilot and passengers of the vehicle.

The analysis of the absorbed energy value distribution allows revealing the direction for further improvement of the car passive safety systems. The influence of energy absorbing element manufacturing material on the processes occurring during frontal impact has been established. A universal technology of crash-testing (modeling of impact processes) of an energy absorbing element with a rigid obstacle has been developed in Ansys software. The percentage ratio (redistribution) of energy absorbed by frontal elements of passive safety of the car has been investigated.

Keywords: energy absorbing element, aluminum alloy, deformation, efficiency, crash test, vehicle passive safety system.

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Introduction. The car is the most common land transport in the world as of 2022. Thus, in the Russian Federation, road transport occupies 61.6% of the total volume of passenger traffic (Fig. 1) [1].

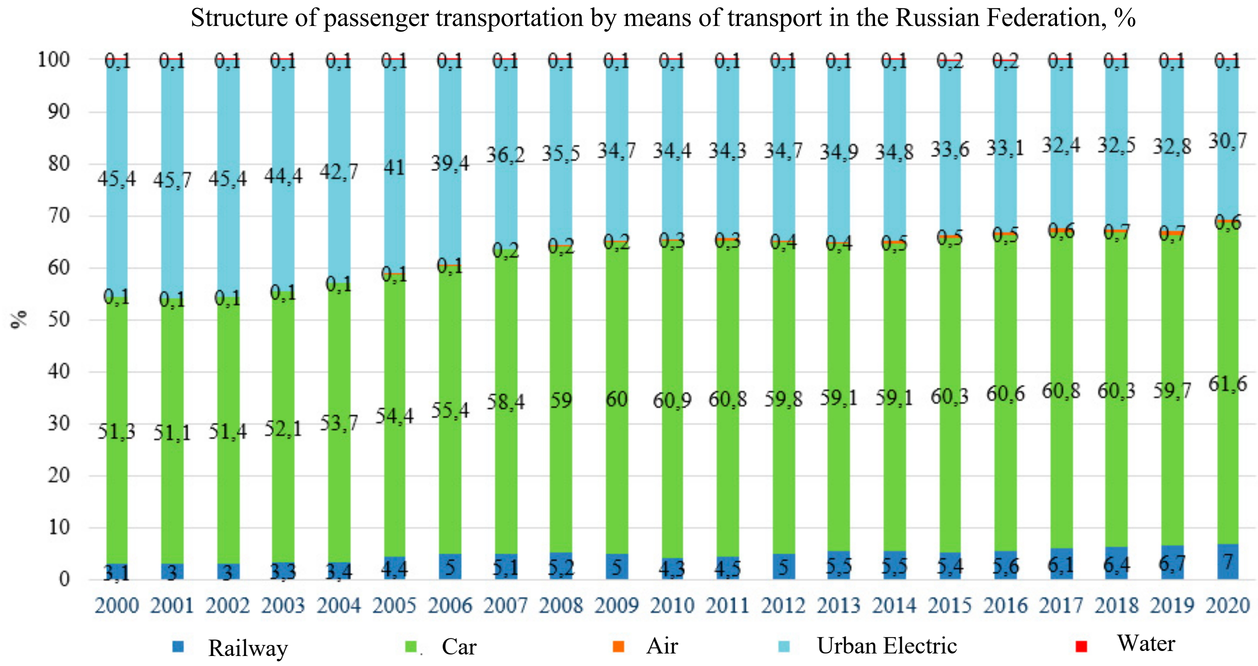


Fig. 1. Structure of passenger transportation by means of transport in the Russian Federation (in percentage terms from 2000 to 2020)

The main structural material in mechanical engineering is steel. However, with the development of technology in the automotive industry, new priority areas of development have emerged: reduction of fuel consumption, reduction of CO_2 emissions, improvement of vehicle safety, use of a fully electric or hybrid power sections in the car [2]. A tool for solving priority tasks in the machine-building industry is the use of aluminum alloys in the construction of a car [3]. As of 2021, aluminum consumption in mechanical engineering accounted for more than 10% of the total aluminum production in the world. The key factors of the increased demand for aluminum in mechanical engineering is an increase in the production of cars, as well as the number of their components and assemblies made of aluminum. Thus, the share of aluminum in the total weight of the car has grown from an average of 35 (1970s) to 152 kilograms (2021), and by 2025 the share of aluminum may reach 270 kilograms [4].

Use of aluminum in the automotive industry allows us to achieve the following results: reduce the weight of the car, increase the load capacity, reduce fuel consumption (and, as a result, carbon dioxide emissions), improve acceleration and braking dynamics, increase vehicle safety, since aluminum has better energy absorption characteristics than steel.

The ability of aluminum alloys to absorb shocks is 2-3 times higher than that of steel, and this has accelerated their introduction into the automotive industry. For example, in Tesla cars, a three-level passive car safety system made of aluminum alloys is installed. The first level of protection is an aluminum bump on the bottom of the Tesla Model S, made in the form of a hollow aluminum bar of a special shape, which throws objects lying on the road that have fallen under the car up, directing the main blow to the area of the front trunk, thereby protecting the battery compartment and maintaining the controllability of the car. The second level of protection is an eight-millimeter impenetrable plate made of aluminum-titanium alloy, which protects the battery compartment from damage. The third level of protection is a shield made of die-cast aluminum, which dissipates the impact energy and, if the obstacle is solid and stationary, lifts the car above it [5].

The use of aluminum as the main material in the manufacture of the car body became widespread in 2021. This is due to the fact that deformations in aluminum structures are localized in compact zones, preventing other parts of the body from deforming, thereby maintaining maximum safety of the part of the car where the passengers are. A promising direction for car manufacturers is also the creation of closed-cycle production facilities in which scrap aluminum parts of recycled cars will serve as raw materials for the manufacture of spare parts for new vehicles.

The relevance of research in the field of passive vehicle safety is due to the complexity and insufficient knowledge of testing methods and virtual simulation of dynamic crash tests of passive vehicle safety elements.

It is the passive car safety systems made of aluminum that have become the subject of research, the results of which are presented in this article.

Problem Statement. The initial objective of the study was to analyze the effectiveness of the use of aluminum in the car passive safety elements.

As an instrumental research method, modeling of the passive safety device of a racing car — an energy-absorbing element made of aluminum alloy and its further testing for energy-absorbing properties during frontal impact was used (Fig. 2) [6].

Fig. 2. Design of a racing car designed according to the FSAE regulations, with an energy-absorbing element (indicated in green)

As initial data for solid-state computer modeling and energy-absorbing element research, technical requirements for the research object from the technical regulations of the Formula SAE project were adopted.

The requirements of the FSAE technical regulations:

— according to paragraph T2.18.2, the energy-absorbing element must be installed in front of the front partition of the car frame, have dimensions of at least 100 mm in height and 200 mm in width at a distance of at least 200 mm from the front partition along the axis of the frame, securely fixed to the front partition (using glue, welding or bolted connection);

— according to paragraph T2.18.3, a protective plate made of aluminum with a thickness of 4 mm or of structural steel with a thickness of 1.5 mm must be integrated on all vehicles;

— according to paragraph T2.20.1, the energy-absorbing element is tested using a hard frontal impact (at an angle of 90 degrees) at a vehicle speed of 7 m/s. As a result of the energy-absorbing element tests, the total amount of absorbed energy should be at least 7,350 J, and the maximum overload should not exceed 40 g [7].

The results of the study can be applied by machine-building enterprises when choosing and justifying the effectiveness of using aluminum as the main material for passive car safety elements.

Theoretical Part. To solve this problem, aluminum alloy 6063 (AW-6063) was chosen as the material for manufacturing the energy-absorbing element, the chemical composition of which is presented in Table 1 [8].

Table 1

Chemical composition of aluminum 6063

Chemical composition of alloy 6063 according to EN 573-3 standards									
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other elements	
0.2–0.6	0.35	0.1	0.1	0.45–0.9	0.1	0.1	0.1	0.05	0.15

Aluminum 6063 is an aluminum alloy with magnesium and silicon as alloying elements. The standard of its composition control is supported by the Aluminum Association. It usually has good mechanical properties, is amenable to heat treatment and welding. Aluminum 6063 is the most common alloy used for the manufacture of profiles with a fixed cross-section (extrusion) of aluminum. It allows you to form complex shapes with very smooth surfaces suitable for anodizing. Aluminum 6063 is an aluminum alloy of increased ductility and corrosion resistance. The corrosion resistance of this alloy is high: it is not prone to stress corrosion cracking, regardless of the condition of the material. It is suitable for automated assembly operations because it is well welded by arc welding in an inert gas environment.

Table 2 provides the mechanical properties of aluminum 6063.

Table 2

Mechanical properties of aluminum 6063

Specific gravity	2690 kg/m^3 (2.69 g/cm^3 at 20° C)
Tensile strength (temporary tear resistance), min., Rm, MPa	240
Yield strength, min., Rp0,2 в N/mm^2	215
Elongation, min., %	11
Brinell hardness, HB max.	78
Tensile modulus of elasticity, MPa	68300
Shear modulus of elasticity, MPa	25800
Compressive modulus of elasticity, MPa	69700
Coefficient of thermal expansion, μm/m–C	23.4
Poisson's ratio	0.33

Figure 3 provides the arrangement of aluminum 6063 in the grid of other aluminum alloys depending on the percentage of Si (silicon) and Mg (magnesium).

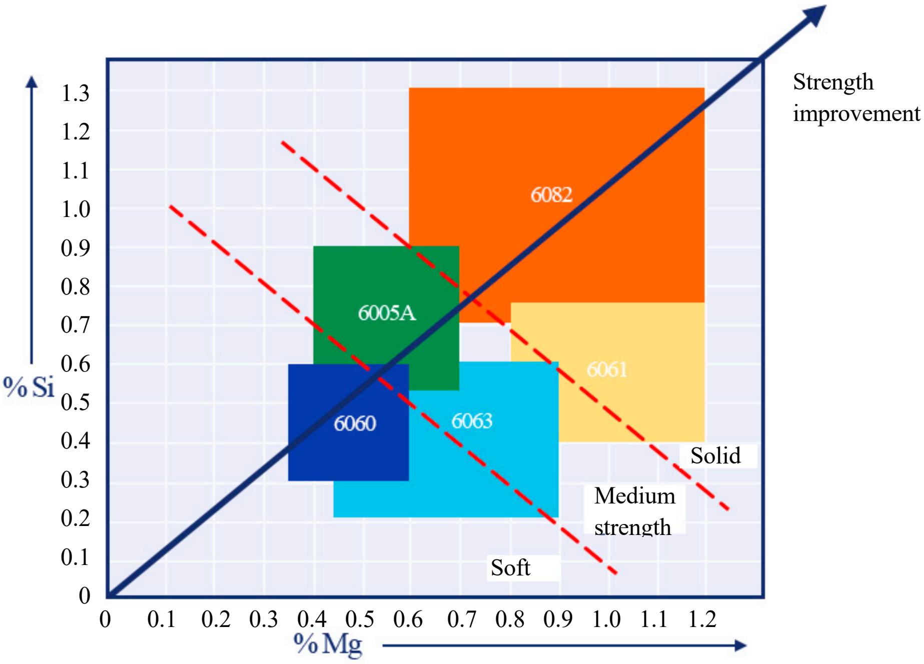


Fig. 3. Grid arrangement of aluminum alloys depending on the percentage of silicon and magnesium

Thus, we can draw a preliminary conclusion that aluminum alloy 6063 has mechanical properties that allow it to be used in passive safety elements production that require sufficient strength from the material and the ability to control deformation under calculated loads.

The Ansys SpaceClaim (CAD) software was used to model the structures of energy-absorbing elements. The shape and structural arrangement of the energy-absorbing element were chosen based on the capacity of the energy-absorbing device for structural deformation of the aluminum alloy during the manufacture of the energy-absorbing element.

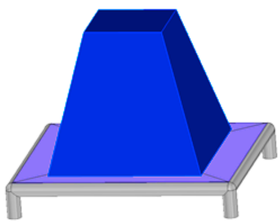
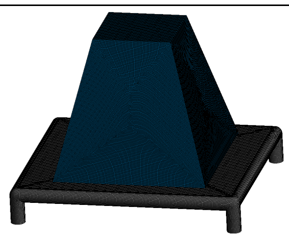
As promising models of energy-absorbing elements made of aluminum, the models of structures were developed, which are presented in Table 3. The Automatic method in Ansys Explicit Dynamics with a set element size of 2 mm was chosen as a method for constructing a finite-difference grid [9].

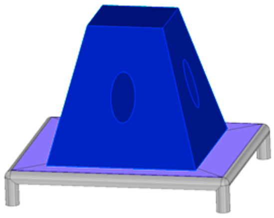
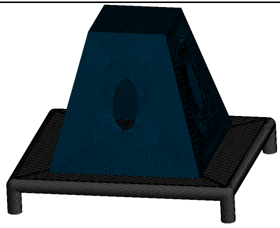
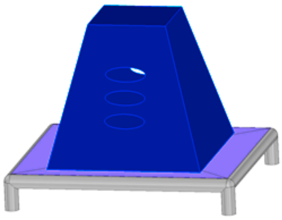
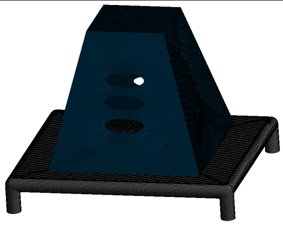
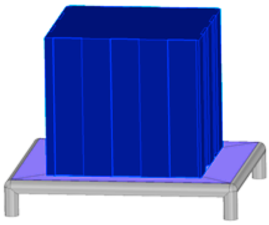
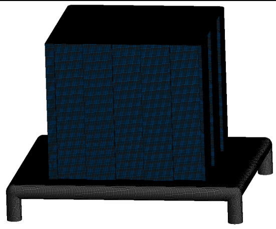
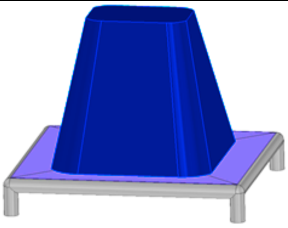
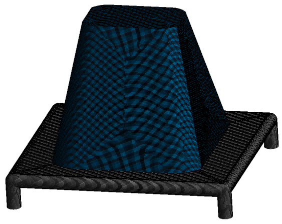
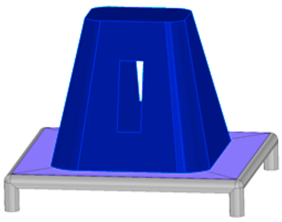
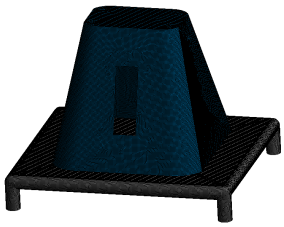
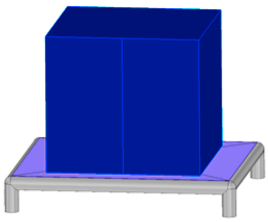
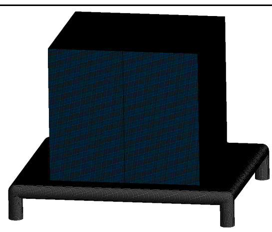
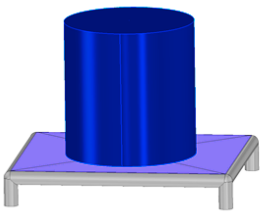
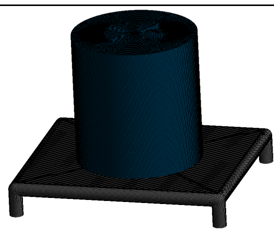
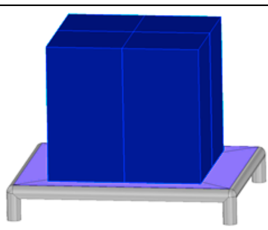
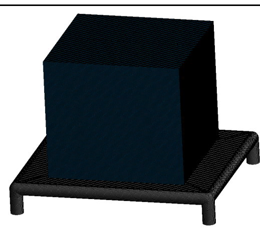
The choice of the size of the grid elements is due to the design of the model of energy-absorbing elements, as well as the ability to conduct an accurate study of the distribution of loads in the energy-absorbing elements at the time of collision [10].

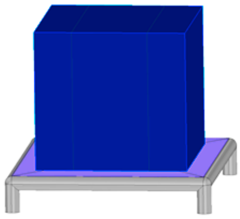
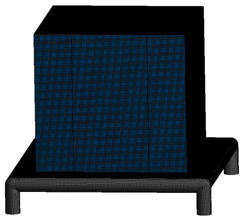
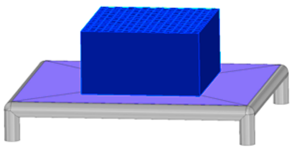
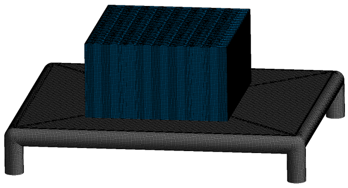
The number of nodes and grid elements of the developed models of energy-absorbing elements is also presented in Table 3.

Table 3

Promising models of energy-absorbing elements made of aluminum 6063 and their finite element grid

No	Structural Name	3D model	Finite Element Grid	Grid Characteristic
1	Energy absorbing element in the form of a truncated pyramid			Statistics Nodes 145685 Elements 145167

No	Structural Name	3D model	Finite Element Grid	Grid Characteristic
2	Energy-absorbing element in the form of a truncated pyramid with four manufacturing holes			Statistics Nodes 142751 Elements 142056
3	Energy-absorbing element in the form of a truncated pyramid with six manufacturing holes			Statistics Nodes 143989 Elements 143265
4	Rectangular energy absorbing element made of aluminum shape			Statistics Nodes 186165 Elements 185276
5	Energy absorbing element in the form of a smoothed truncated pyramid			Statistics Nodes 141020 Elements 140456
6	Energy absorbing element in the form of a smoothed truncated pyramid with two manufacturing rectangular holes			Statistics Nodes 138789 Elements 138065
7	Two-section energy-absorbing element			Statistics Nodes 185729 Elements 184826
8	Energy absorbing element of cylindrical shape			Statistics Nodes 149332 Elements 149022
9	Energy-absorbing element of a four-section design			Statistics Nodes 211941 Elements 211065

No	Structural Name	3D model	Finite Element Grid	Grid Characteristic
10	Energy-absorbing element of a three-section design			**Statistics** Nodes 212056 Elements 211035
11	Energy absorbing element made of aluminum honeycomb			**Statistics** Nodes 465640 Elements 366902

In the process of research, development and calculations of energy-absorbing elements, it is necessary to take into account the fact that the finite element method (FEM) is an approximate method, the accuracy of which depends on assumptions related to the type of element and the size of the grid. In the structural elements of an energy-absorbing element, where stress and strain changes occur by an order of magnitude or more, a denser grid is required. In elements subject to almost constant stress, with a minimal difference in values, as well as in elements that do not require accurate research, a rare grid with a large element size is used. When forming a finite element grid (FE), both triangular and rectangular elements can be used simultaneously, while the grid is constructed without gaps between the elements (Fig. 4).

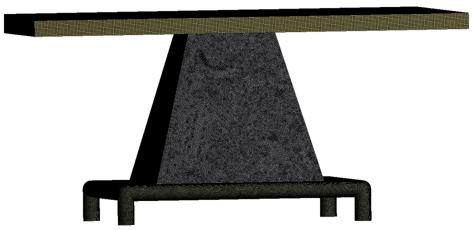


Fig. 4. Example of the grid of the FE model of an energy-absorbing element and a rigid obstacle

The dynamic study (crash test) was carried out using the Ansys Workbench software with the Explicit Dynamics dynamic analysis software package installed (Fig. 5).

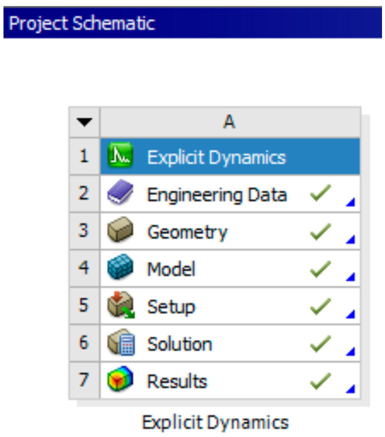


Fig. 5. Structure of the Ansys Dynamic Research project

The dynamic research project consists of the following main elements (stages):

− Engineering Data — a database of materials in which you can both select and configure ready-made materials, and add your own;

− Geometry — an environment for the development of models, structures, surfaces, allows you to upload a ready-made model to a project or develop it from scratch;

− Model — a system that combines geometry, selected materials, coordinate system, connections in the assembly, the grid of the FE model and the settings for conducting research (Setup). This section allows you to select the area of dynamic research and immediately display the results in graphically interactive form after the calculations are completed;

− Solution — calculations are included in the Model subsection, can be extrapolated to other analysis systems;

− Results — the results of calculations performed on the studied indicators (deformations, stresses, changes in speed, displacement, etc.).

All data on the material are entered in the Engineering Data section (Fig. 6).

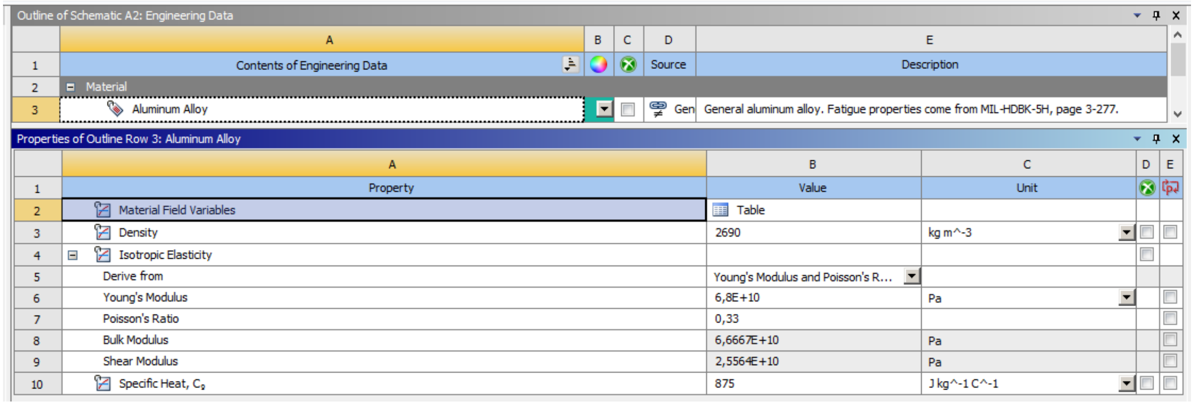


Fig. 6. The card of the aluminum alloy 6063 (AW-6063) material in Ansys Engineering Data

The speed of calculation by the software and the requirements for the developer's equipment depend on the choice of the design method. The model of the energy-absorbing element should be located close to the virtual obstacle (at an angle of 90 degrees), this allows for timely receipt of the necessary information and data on the processes occurring during the collision during the calculation (Fig. 7).

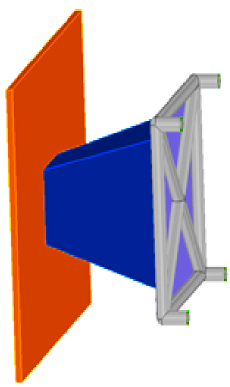
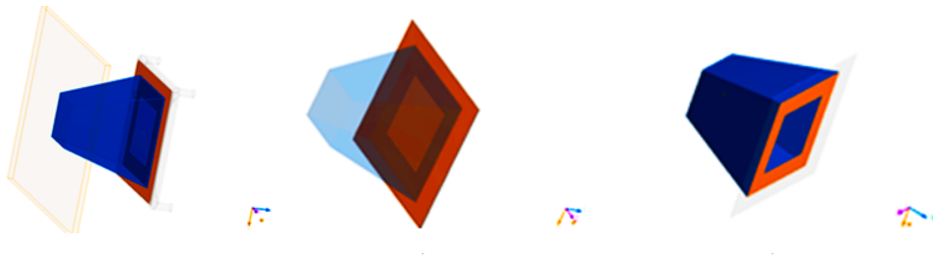


Fig. 7. An example of the location of an energy-absorbing element in front of a rigid obstacle

After installing materials for all components of the assembly, the connections (contacts) between the assembly nodes are configured (Fig. 8). The contacts of the components are configured in the Connection subsection. Thus, a prerequisite for a correct study is the absence of a connection (contact) of an energy-absorbing element with an obstacle, since these objects are not connected in real conditions. During the study, the following connections (contacts) of the components were established:

− car frame — front platform;

− front platform — energy-absorbing element.



a) *b*) *c*)

Fig. 8. An example of installing contacts between an energy-absorbing element and a front platform mounted on a car frame: a) general view of contacts in the design model of energy-absorbing elements; b) contact between the car frame and the front platform; c) contact between the energy-absorbing element and the front platform

After creating a grid and installing contacts in the assembly, restrictions are formed in the model and the speed of movement of the assembly of the front part of the car is set (Fig. 9). During modeling, the contour and the rear wall of the obstacle are fixed, and restrictions are introduced in the displacement of the car frame. The impact velocity of the energy-absorbing element on a rigid obstacle is assumed to be 7 m/s, according to the Formula SAE technical regulations (Fixed Support, Displacement, Velocity functions are used for these operations).

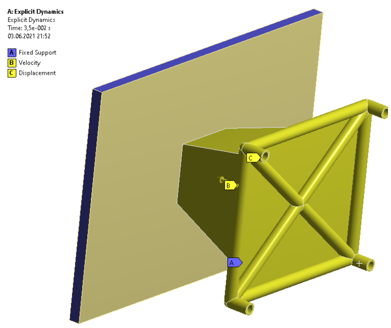
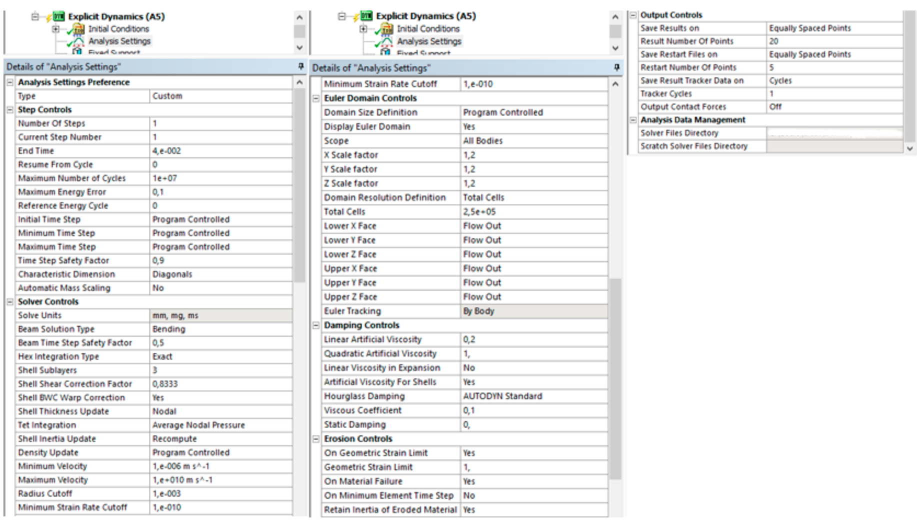


Fig. 9. Adjustment of movements of the test sample of the energy absorbing element for the crash test

At the last technological stage, the parameters of the dynamic test are configured using the Analysis Setting module; and the necessary indicators for calculation are selected (Fig. 10).



Explicit Dynamics (A5)
Initial Conditions
Analysis Settings

Details of "Analysis Settings"

Analysis Settings Preference	
Type	Custom
Step Controls	
Number Of Steps	1
Current Step Number	1
End Time	4,e-002
Resume From Cycle	0
Maximum Number of Cycles	1e+07
Maximum Energy Error	0,1
Reference Energy Cycle	0
Initial Time Step	Program Controlled
Minimum Time Step	Program Controlled
Maximum Time Step	Program Controlled
Time Step Safety Factor	0,9
Characteristic Dimension	Diagonals
Automatic Mass Scaling	No
Solver Controls	
Solve Units	mm, mg, ms
Beam Solution Type	Bending
Beam Time Step Safety Factor	0,5
Hex Integration Type	Exact
Shell Sublayers	3
Shell Shear Correction Factor	0,8333
Shell BWC Warp Correction	Yes
Shell Thickness Update	Nodal
Tet Integration	Average Nodal Pressure
Shell Inertia Update	Recompute
Density Update	Program Controlled
Minimum Velocity	1,e-006 m s^-1
Maximum Velocity	1,e+010 m s^-1
Radius Cutoff	1,e-003
Minimum Strain Rate Cutoff	1,e-010

Explicit Dynamics (A5)
Initial Conditions
Analysis Settings

Details of "Analysis Settings"

Minimum Strain Rate Cutoff	1,e-010
Euler Domain Controls	
Domain Size Definition	Program Controlled
Display Euler Domain	Yes
Scope	All Bodies
X Scale factor	1,2
Y Scale factor	1,2
Z Scale factor	1,2
Domain Resolution Definition	Total Cells
Total Cells	2,5e+05
Lower X Face	Flow Out
Lower Y Face	Flow Out
Lower Z Face	Flow Out
Upper X Face	Flow Out
Upper Y Face	Flow Out
Upper Z Face	Flow Out
Euler Tracking	By Body
Damping Controls	
Linear Artificial Viscosity	0,2
Quadratic Artificial Viscosity	1,
Linear Viscosity in Expansion	No
Artificial Viscosity For Shells	Yes
Hourglass Damping	AUTODYN Standard
Viscous Coefficient	0,1
Static Damping	0,
Erosion Controls	
On Geometric Strain Limit	Yes
Geometric Strain Limit	1,
On Material Failure	Yes
On Minimum Element Time Step	No
Retain Inertia of Eroded Material	Yes

Output Controls	
Save Results on	Equally Spaced Points
Result Number Of Points	20
Save Restart Files on	Equally Spaced Points
Restart Number Of Points	5
Save Result Tracker Data on	Cycles
Tracker Cycles	1
Output Contact Forces	Off
Analysis Data Management	
Solver Files Directory	
Scratch Solver Files Directory	

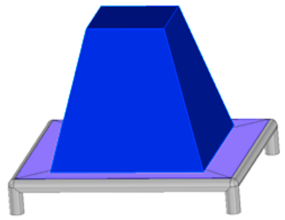
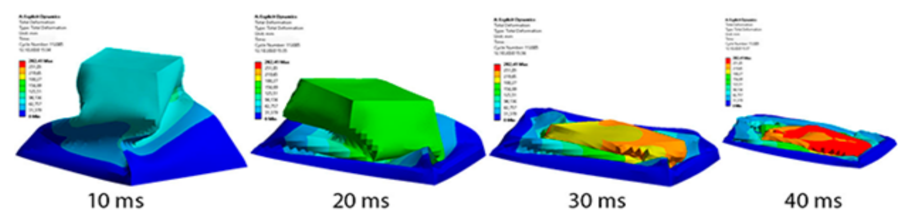
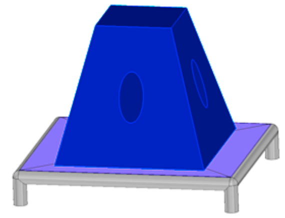
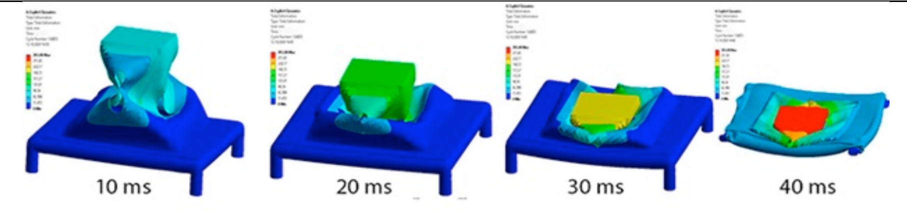
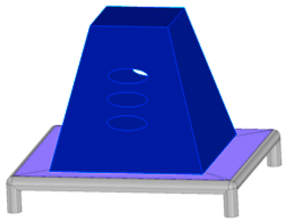
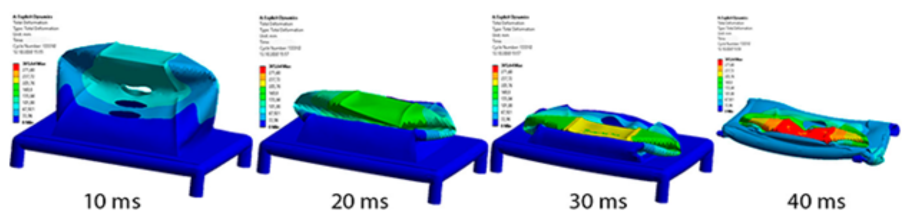
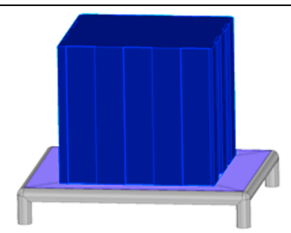
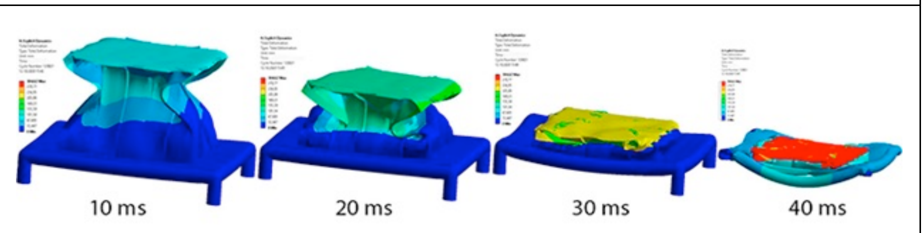
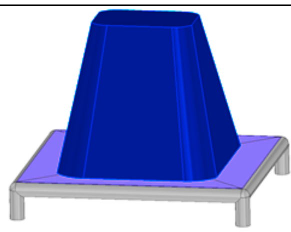
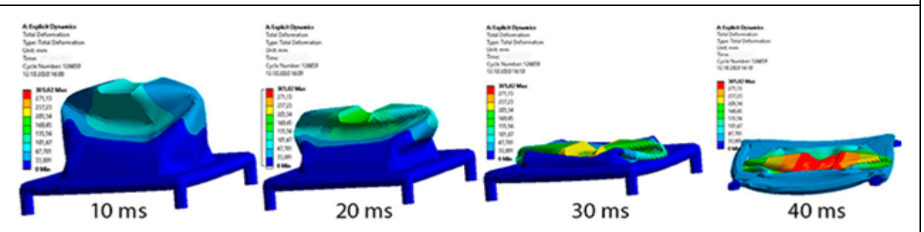
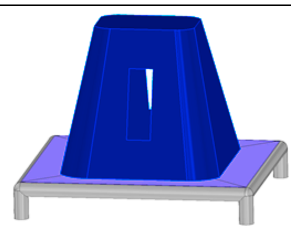
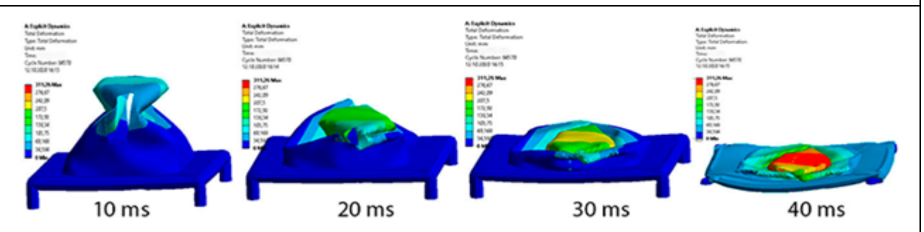
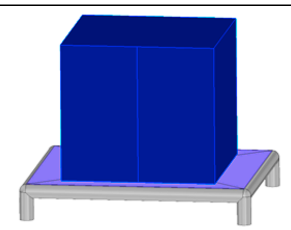
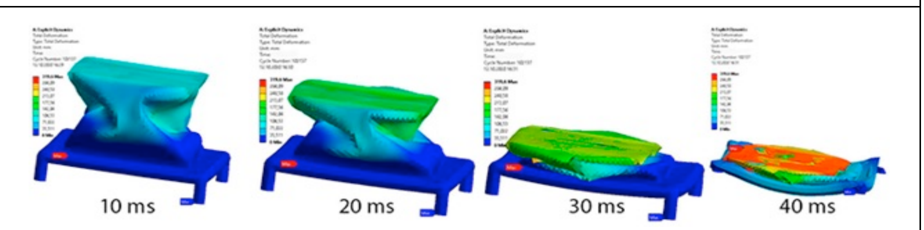
Fig. 10. Setting the parameters of the Analysis Setting dynamic test

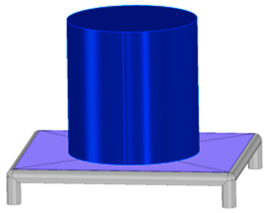
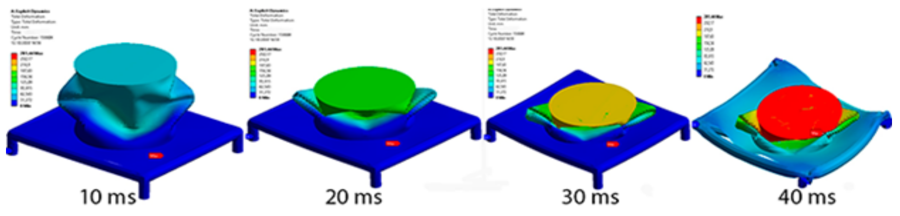
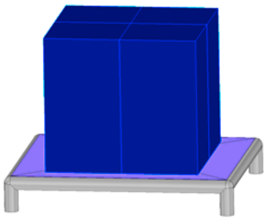
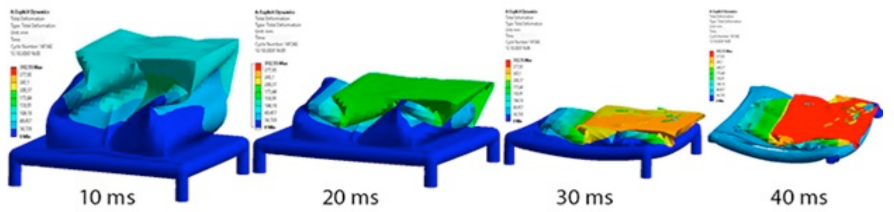
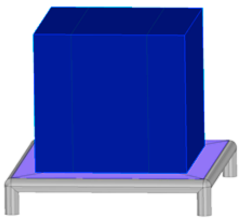
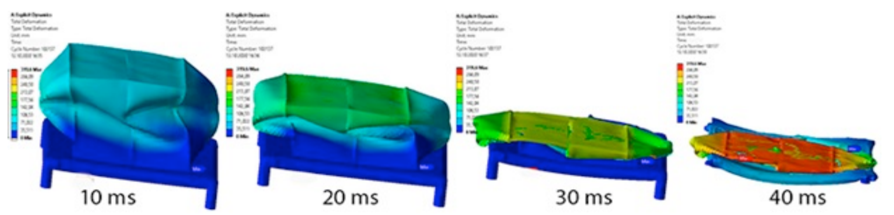
In the settings, it is recommended to set the End Time to no more than 50 ms (0.05 s), since on average, in 40 milliseconds, the impact is completely absorbed and the subsequent rebound of the car occurs. With a simulation time of 40 milliseconds, an average of 126,000-150,000 calculation operations-cycles are performed.

In order to find the most promising structural solutions for energy-absorbing aluminum alloy elements and their further analysis, crash tests were conducted with readings in the range from 0 to 40 milliseconds. Table 4T provides the results of the tests.

Table 4

Deformations of energy-absorbing elements at four time points after the impact (10-20-30-40 milliseconds)

№	3D Model	Deformation of the energy-absorbing element
1		
2		
3		
4		
5		
6		
7		

№	3D Model	Deformation of the energy-absorbing element
8		
9		
10		

Based on the results of computer modeling for further analysis and selection of promising designs of energy-absorbing elements, summary graphs of deformation and effectively absorbed energy were formed (Fig. 11, 12).

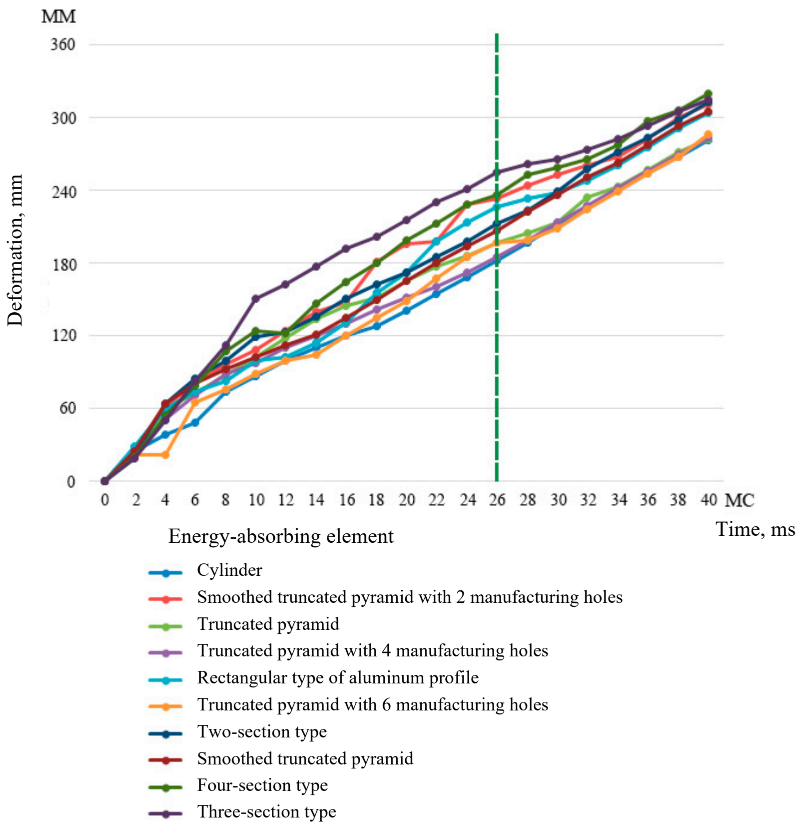


Fig. 11. Diagram of deformation of energy-absorbing elements in the time range of 0-40 milliseconds

The green line in Figure 11 limits the zone from 0 to 26 milliseconds. During this time range, the most effective deformation (Effective Plastic Strain) of the energy-absorbing element occurred, during which it did not deform or experienced minor displacements of the space frame of the car.

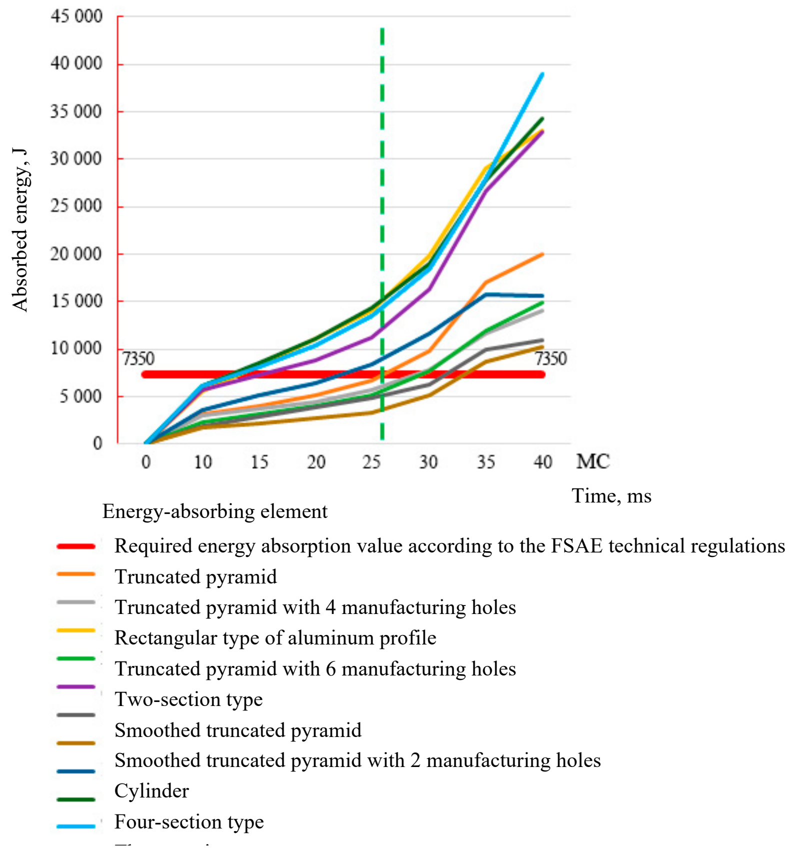
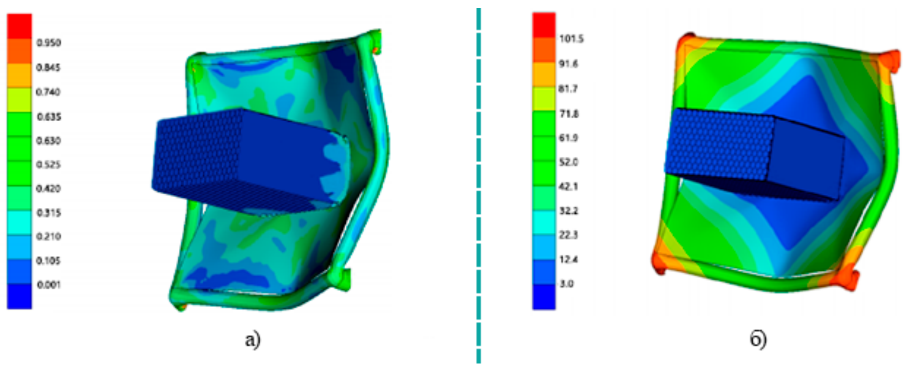


Fig. 12. Diagram of absorbed energy (J) by energy-absorbing elements in the time range of 0-40 milliseconds

The green line in Figure 12 also limits the zone from 0 to 26 milliseconds. In this time range, the energy-absorbing element absorbed the incoming energy by its own deformation without serious damage to the remaining elements of the car. The upper value of this time range (26 milliseconds) is the time during which an aluminum alloy energy-absorbing element is able to effectively absorb a shock, with a properly calculated design, this happens without significant overloads.

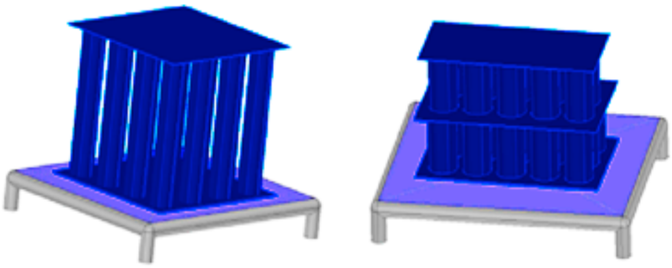
The calculation results showed that the design of the energy-absorbing element made of aluminum honeycomb does not meet the safety requirements of the Formula SAE technical regulations. The rigidity of this design turned out to be too large, which caused premature deformation of the front plate and frame of the car, and the resulting overloads > 20 g do not allow the use of this passive safety element in the Formula SAE car (Fig. 13).



a) *b)*

Fig. 13. Stresses and deformations in an energy-absorbing element made of aluminum honeycomb: a) stresses in an energy-absorbing element made of aluminum honeycomb (hPa); b) deformation in an energy-absorbing element made of aluminum honeycomb (mm)

Additionally, energy-absorbing multi-component elements with cylindrical structures were investigated, but they turned out to be absolutely ineffective (Fig. 14). The high rigidity of the structure did not allow absorbing the impact in sufficient quantity due to the deformation of the energy-absorbing element, therefore, the use of these structures in a car made according to the Formula SAE regulations is out of the question.



a) *b*)

Fig. 14. Multi-component energy-absorbing elements: a) a single-level energy-absorbing element with 16 cylinders; b) a two-level energy-absorbing element with 15 cylinders on the first and 10 cylinders on the second level

For further analysis of the problem, a gradation of energy-absorbing elements is made according to their efficiency, which is built on aggregate qualities (Fig. 15). They include the ability to absorb a sufficient amount of incoming energy, to absorb the impact without exceeding the permissible overload indicators, the ability to deform without premature destruction or displacement of the energy-absorbing element.

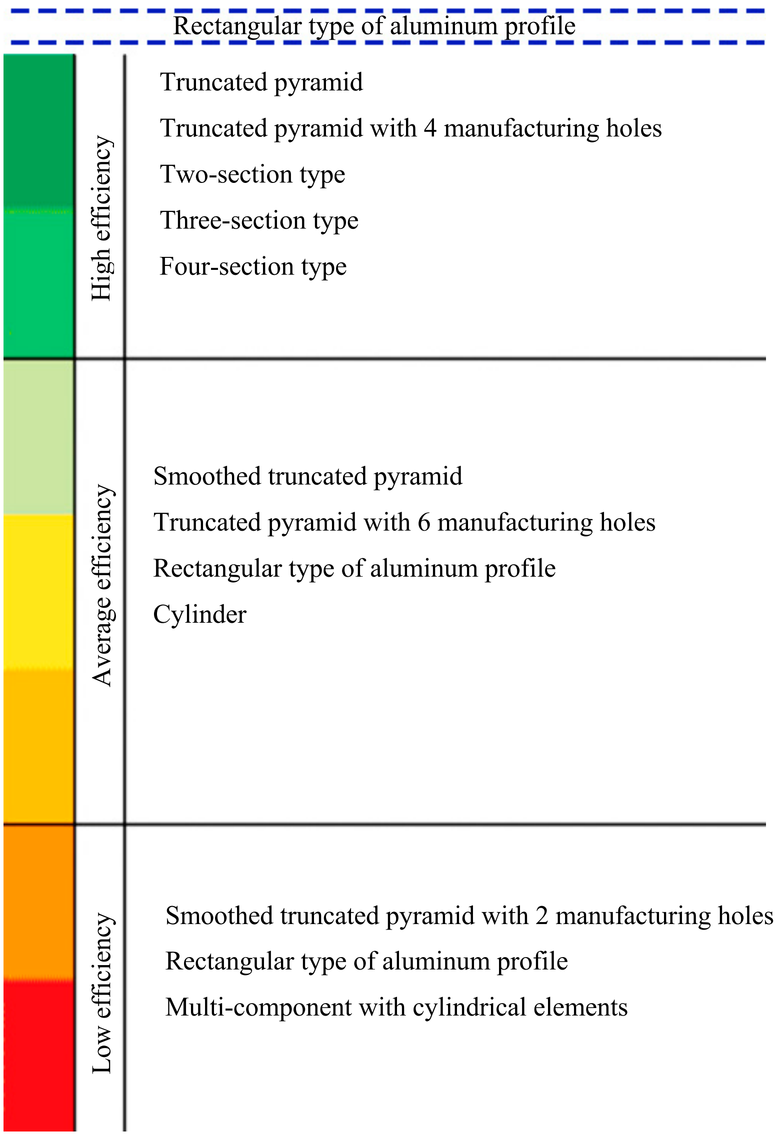


Fig. 15. Gradation of energy-absorbing elements by efficiency

Further research was carried out only for energy-absorbing elements of the "high efficiency" category. The data for the graphs were formed from a control point located at the center of the intersection of the front pipes of the space safety frame of the car (Fig. 1 6).

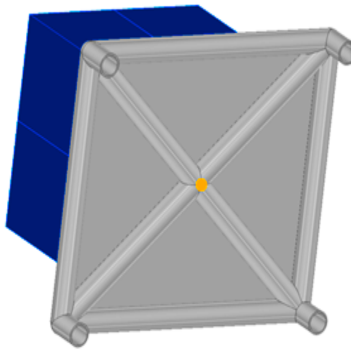


Fig. 16. The control point (indicated in yellow) on the structure of the energy-absorbing element

Figures 17 and 18 show the graphs of movement, speed and acceleration for the control point of effective design options for energy-absorbing elements.

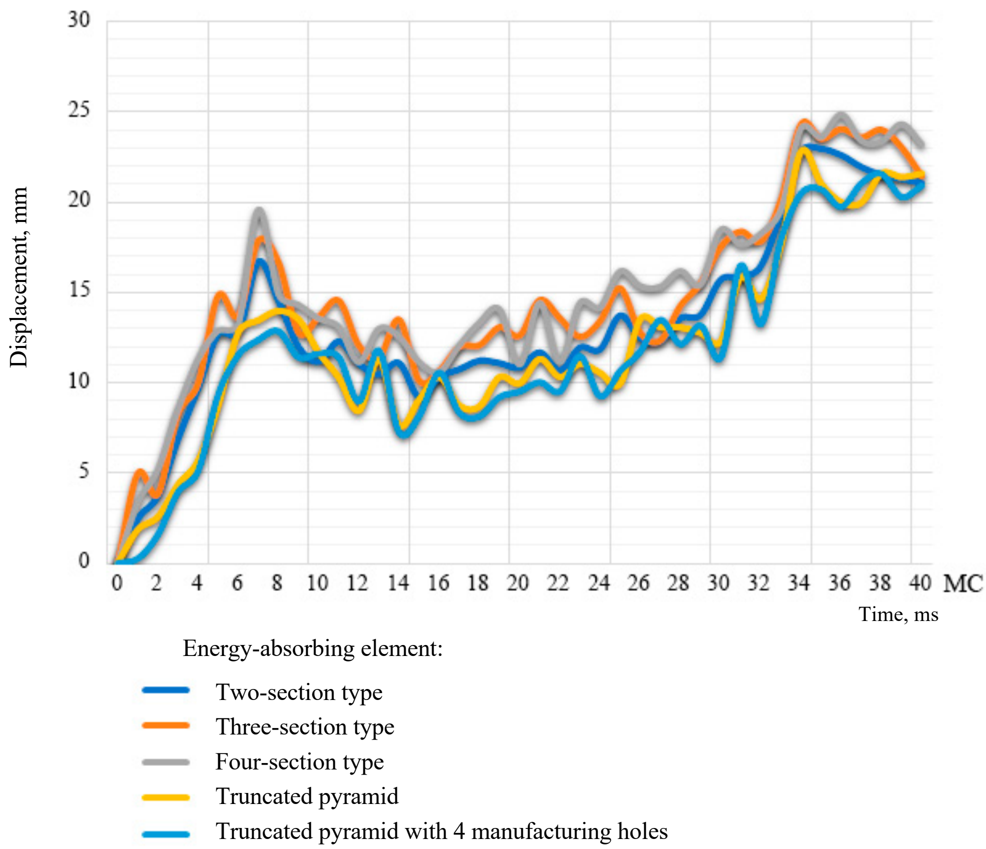


Fig. 17. Graph of the dependence of the movement of the energy-absorbing structure on time (the results are obtained from the control point in Fig. 16)

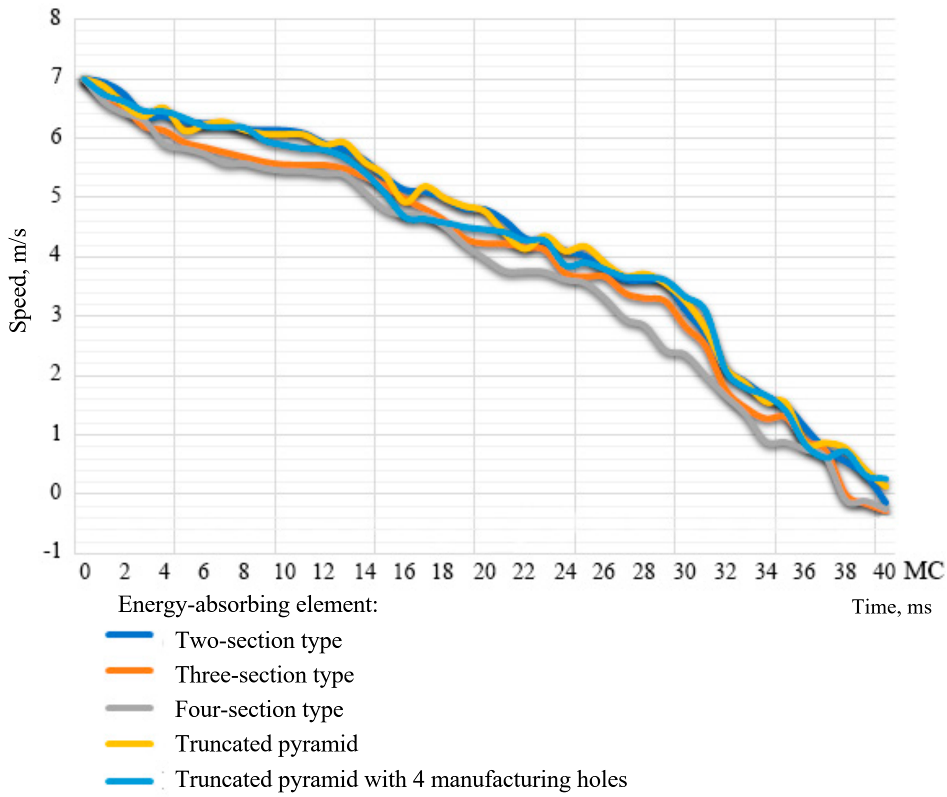


Fig. 18. Graph of the dependence of the deceleration rate of the energy-absorbing structure on time (the results are obtained from the control point in Fig. 16)

During the simulation, the main stress concentration zones were identified (Fig. 19). Thus, it was found that the intersection (center) of the diagonal pipes of the space frame, the corner elements of the frontal part of the car frame, the perimeter of the plate to which the energy-absorbing element is attached, in places of structural bends and fasteners of the energy-absorbing element, are subjected to the main loads.

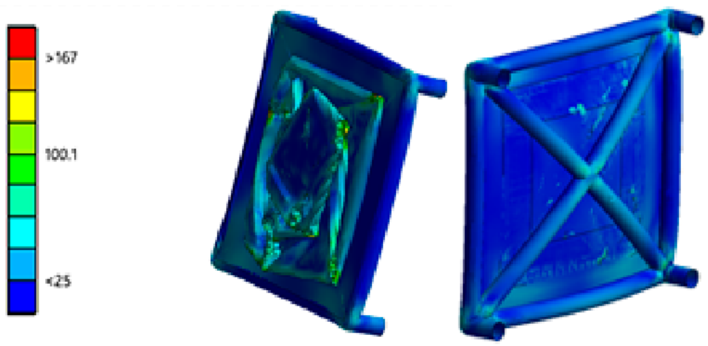


Fig. 19. Places of intense concentration of accumulated stresses (hPa)

Based on computer simulation, it can be concluded that all the presented energy-absorbing elements from the "high efficiency" category can be used as a passive safety system of a racing car. The category of effective energy-absorbing elements has a well-predicted deformation in case of a frontal impact. Additionally, several structures were tested with a frontal impact with 40% overlap, which is considered the most difficult testing of the existing safety elements (Fig. 20) [11].

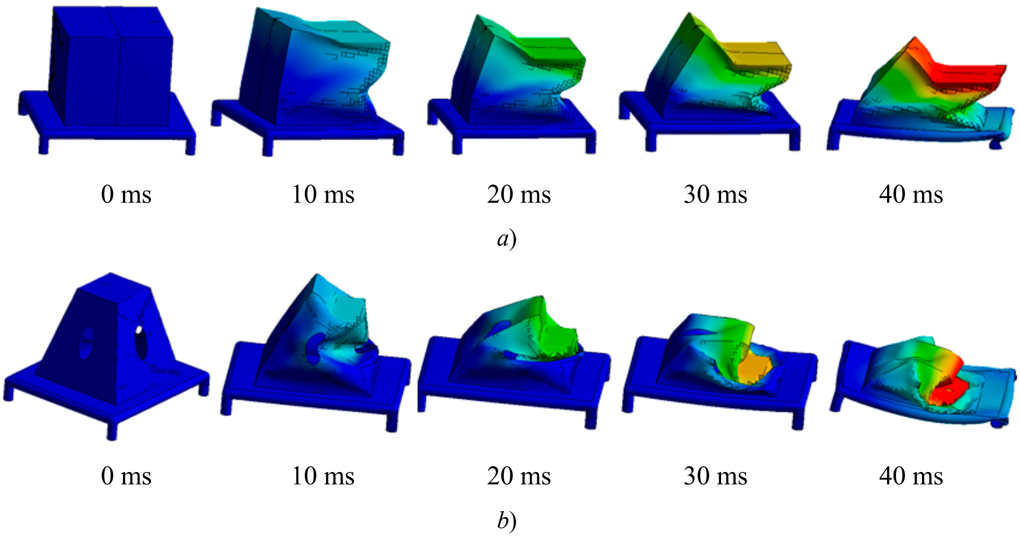


Fig. 20. Crash test of energy-absorbing elements with 40% overlap:
a) EAE of a two-section type; b) EAE of a truncated pyramid with four manufacturing holes

Testing of an energy-absorbing element with a 40% overlap is considered successful if the structure of the element was not prematurely destroyed in the collision and its stability on the front plate was preserved. As a result of testing by a crash test with a 40% overlap of the tested samples of energy-absorbing elements made of aluminum, it can be concluded that the malleability of the material allows it to withstand deformations in the structure without destruction, shifts and with the maximum possible distribution (in case of partial contact of the energy-absorbing element and the obstacle) of stresses and loads throughout the structure of the specified element.

Energy-absorbing elements from the "high efficiency" category are stable during experimental crash tests: the structural displacement relative to the horizontal axis is not significant and meets the requirements of the FSAE technical regulations. Energy absorption and overload also comply with the FSAE technical regulations.

Having analyzed the data obtained on inefficient designs of energy-absorbing elements, the proportional distribution of absorbed energy by individual structural elements of the car should be noted. When an energy-absorbing element of low efficiency (for example, made of aluminum honeycombs or a multi-component one) is hit, the required amount of energy (7350 J) is not absorbed, while the largest amount of the absorbed energy is taken by the front partition of the car or the support plate. The plate to which the energy absorbing element is attached is the second most important level of absorption of incoming energy. The rest of the energy is absorbed by the car frame. Energy-absorbing elements in case of insufficient or excessive structural rigidity absorb only 15-35% of the required energy, which is unacceptable for use as the main deformable element. The percentage of absorbed energy when struck by the structural elements of the car is given in Table 5.

Table 5

Percentage of the absorbed energy by the structural elements of the car

Name of the car structural element	High efficiency	Medium efficiency	Low efficiency
1	2	3	4
Energy-absorbing element	65–100 %	35–65 %	15–35 %
Front plate	5–15 %	15–25 %	20–35 %
Car frame	5–15 %	10–25 %	15–45 %

The presented energy-absorbing elements (with the exception of low-efficiency ones according to the gradation table for the efficiency of energy-absorbing elements) in terms of total absorbed energy meet the requirements of the FSAE technical regulations. However, it is always possible to improve the design of the energy-absorbing element due to structural changes and adjustments to the composition of the aluminum alloy.

It is known from scientific publications that energy-absorbing elements of a conical or a truncated pyramid shape are more effective than others in controlling the process of energy absorption when a car collides with a rigid obstacle (Fig. 21) [12].

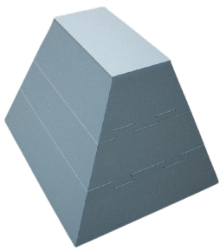


Fig. 21. Model of an energy-absorbing element with a grooved fastening system fixed with an Impax adhesive base

It was also found that the design features of energy-absorbing elements (manufacturing holes, profile bends, and so on) make it possible to control not only the deformation process, but also the geometric stability of the structure. During the analysis of the deformation of energy-absorbing elements with elliptical (or other shape) manufacturing holes, it was found that they effectively redistribute the deformation energy throughout the structure during the collision of the car with an obstacle.

In cases of insufficient rigidity of the structure of energy-absorbing elements, either its premature destruction occurs, or a slight absorption of energy with a significant displacement of the entire structure. Therefore, the developers of passive safety systems, in particular energy-absorbing elements, should take into account the possible redistribution of energy between the elements of the safety system. Thus, by changing the structural shape, size and material of manufacture of the energy-absorbing element, it is possible to redistribute energy in the collision process.

When designing passive safety elements, including energy-absorbing elements of the car, it is necessary to take into account the strong influence of the shape and size of the structure on its stability in deformation. In the process of the development of an effective energy-absorbing element, it is necessary to achieve deformation of the structure along its entire axial length.

Conclusions. The results of the study of various designs of energy-absorbing elements indicate that the distribution of stresses and deformations in them depends on the shape, size and material of EAE. When modeling and further testing energy-absorbing elements, it is necessary to achieve the deformation of the structure along its entire length.

It is established that the loss of stability of the structure of the energy-absorbing element leads to an increase in its deformation, which entails the destruction of the test sample.

Based on the simulation of the behavior of the developed variants of the designs of energy-absorbing elements during a frontal impact, it is established that:

− for rigid (non-deformable) energy-absorbing elements, the deformation is determined by the movement of the front wall of the car;

− for energy-absorbing elements of low and medium rigidity, the main part of the displacement (deformation) during impact occurs due to the deformation of the energy-absorbing element;

− the analysis of the stresses of typical structures of energy-absorbing elements that occur when hitting a rigid obstacle showed that the main zones of maximum stress concentration are located in the middle of the pipes of the frontal part of the car frame, at the attachment points of the front plate, as well as at the places of bending of the wall of the energy-absorbing element;

− the greatest drop in vehicle speed is observed at the moment of the beginning of deformation of the front plate, when the deformation of the energy-absorbing element itself is no longer sufficient. As a rule, this is a period of time from 30 to 40 milliseconds.

The analysis of the deformation of the energy-absorbing element, the front wall and the frame allowed us to establish the connectivity of all structural elements of a racing car in the field of passive safety. With excessive incoming kinetic energy, each structural element distributes and absorbs a certain percentage of energy.

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Formation of structural features of powder materials during cooling after heat treatment

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Introduction. Recently, sintered materials and products made of them have been increasingly used in powder metallurgy. In this regard, the issue of obtaining sintered products with high performance properties is acute. To achieve such properties, the materials are subjected to heat treatment. This procedure significantly affects their structure and mechanical properties. In production, sintered materials are most often subjected to subsequent hardening and tempering, as a result of which their equilibrium structure is established, grain growth stops, and strength characteristics improve.

The article discusses the problems that arise in the formation of the qualitative structure of dispersed-hardened alloys as a result of their heat treatment.

Problem Statement. The objective of this work is to study the phase changes in the process of cooling of powder steels and alloys in order to determine the modes of their heat treatment in order to form optimal conditions for the martensitic transformation of austenite.

Theoretical Part. Phase transformations in powder steels occur in the temperature range at which their structures are rearranged, and as a result, the properties of the material change. The main factors affecting the phase transformations are the chemical composition of the alloy, the structure imperfection and the size of the grains. Changes in the structure and properties of alloys are considered in comparison with compact materials. Heat treatment significantly affects the phase and structural characteristics of powder materials, which are related to the mechanical characteristics of the alloys themselves.

Conclusions. The conducted studies have shown that with an increase in the heterogeneity of the solid solution of steels, the temperature of the beginning of the martensitic transformation increased. A decrease in the temperature of the martensitic transformation with an increase in the degree of homogeneity of the solid solution occurs due to its enrichment with carbon and other alloying elements (chromium, molybdenum). With an increase in the percentage of carbon, an increase in the porosity of samples, the starting point of martensitic transformation also decreases. The temperature of the beginning of the martensitic transformation is not affected by carbides that are with austenite. These conclusions will help us to evaluate the mechanical properties of materials, as well as to develop recommendations for the practical application of heat treatment in the manufacture of products of complex shape.

Keywords: powder steels, heat treatment, phase transformations, martensite, austenite

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Introduction. Modern technologies — three-dimensional printing, injection molding, spark plasma sintering — have become an incentive for a new round of development of powder metallurgy. This also applies to the production of powders with specified properties, the emergence of new methods for evaluating the properties of powders and powder mixtures, as well as the development of complex techniques for evaluating the properties of the resulting powder materials.

The most widespread type of powder metallurgy products are materials and structural products that are used in various components and mechanisms of machines. These parts, depending on the chosen material and technology, can have high hardness, strength, wear resistance, heat resistance and special properties.

Unfortunately, the structural features of sintered powder alloys do not allow the parameters and modes of conventional heat treatment of cast and forged steels to be applied to them. Therefore, there is a problem: how and by what means to improve the mechanical and operational properties of such alloys? It can be solved after a thorough study of the structural transformations of sintered powder alloys.

Problem Statement. One of the ways to solve this problem is the study of phase transformations of powder steels proposed by the authors to determine the rational modes of their heat treatment, to identify the effect of free carbon on the temperature shift of phase transformations during cooling. The cooling process of powder steels and alloys is the main process in heat treatment. At the same time, it should be emphasized that the fundamental processes of formation of sintered alloys are the structure formation of the material and the creation of qualitative bonds between alloy particles on the existing and newly formed contact surfaces. The value of the properties of powder alloys is largely regulated by the density of the material. When high densities are achieved by various methods of deformation, their properties may exceed those of compact materials of similar composition. This can be attributed to their high uniformity and fine-grain structure, as well as the absence of anisotropy. Such materials have a wide range of physical, mechanical and operational properties.

Theoretical Part. Heat treatment of powder steels is an effective way to improve their mechanical properties and increase wear resistance. In the practice of heat treatment of steel, transformations occur spontaneously when external conditions (temperature, pressure) change, and transformations occur in the direction of decreasing free energy. It should be noted that the equilibrium temperature A_1, being a thermodynamic parameter of the system, does not depend on the initial structure and the rate of heating or cooling of the alloy. At the same time, this temperature is a function of the alloy composition, so it is difficult to determine it unambiguously for powder steels characterized by unequal carbon content and alloying elements in the structure and volume [1–3].

Under the conditions of phase equilibrium, the transformation of austenite into perlite can begin only below temperature A_1. The transformation consists in the rearrangement of the gamma-alpha lattice and the diffusion redistribution of the carbon concentration between the phases. With an increase in the difference, the free energy increases and the formation of a critical austenite nucleus decreases. But the diffusion mobility of atoms also decreases, and therefore the transformation rate curve has a maximum at the degree of supercooling of 150°C. For compact carbon steels, this is about 550°C. For powdered porous steels, the cooling curves are shifted to the right and up, and it is the greater, the lower the diffusion saturation energy in absolute value is. With an increase in the free metal surface of the pores, the activation energy decreases, this leads to an increase in the size of the critical nucleus. An increase in the inhomogeneity of the solid solution and an increase in the defectiveness of metal particles lead to the same result.

With the increase in dispersed nonmetallic inclusions in steel and the growth of interparticle boundaries, the probability of heterogeneous nucleation of a new phase increases due to the higher contribution of the boundary interaction force to the free energy of nucleus formation. This also leads to an increase in the absolute value of energy and a decrease in the formation of a critical nucleus. Thus, the lower the absolute value of the compaction energy and the greater the force is, the more noticeable the transformation rate curves shift to the right and up.

Despite the high degree of alloying in powder steels, the incubation period turned out to be short. Already in the first minute of isothermal exposure, the decay of austenite was observed. In compact steels of similar composition, the incubation period was several minutes. Thus, the macro-micron homogeneity of the solid solution, as well as the density, contributed to a decrease in the stability of supercooled austenite. Figure 1 shows the dependences of the authentic transformation of sintered steels depending on the cooling rate at different porosity, as well as on the density of samples. The temperature was selected depending on the position of the starting point of transformation A_1.

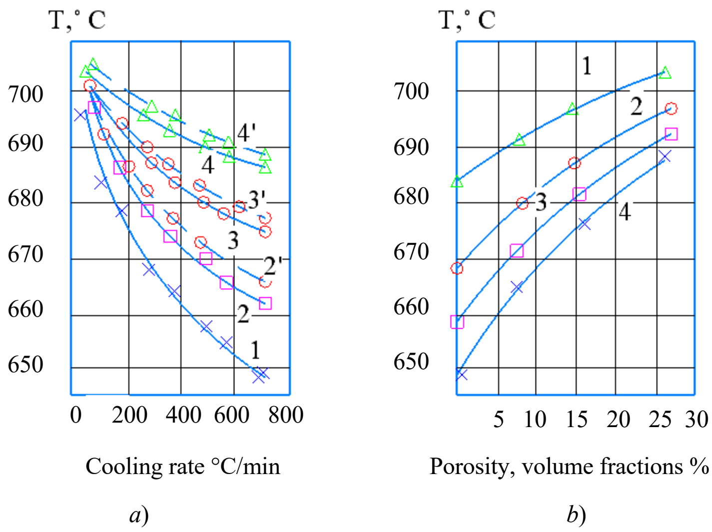

Fig. 1. Ratio of the linear dependence of the beginning points of martensitic transformation of Ar_1 dispersed-hardened alloys: a) on the maximum cooling (density – 1–0 %; 2 – 2′ – 5–10 %; 3 – 3′ – 12–15 % and 4 – 4′ – 20–30 %); b) on density (velocity after quenching – 1 – 120°C/min; 2 – 250-300°C/min; 3 – 400-500°C/min and 4 – 600-700°C/min); solid lines – data for samples made of PL alloy-PZH4M2+0.8% S, dashed lines – data for samples made of alloy PL-PZH4M+0.8 % C

The maximum conversion rate of austenite of porous powder steels is greater than that of compact ones. Consequently, the minimum stability of porous austenite will be observed at temperatures above 500°C. Therefore, the C-shaped curves of isothermal transformation of porous steel of eutectoid composition approach the ordinate axis and shift upwards.

In proeutectoid steel, isothermal decomposition of supercooled austenite begins with the release of ferrite, and in hypereutectoid steel — with the release of excess cementite. These transformations on the C-shaped diagram are marked with additional lines. The incubation period and the time of complete isothermal decomposition of austenite in proeutectoid compact steel is less than in eutectoid steel, in which austenite is more homogeneous and, consequently, more stable (Fig. 2).

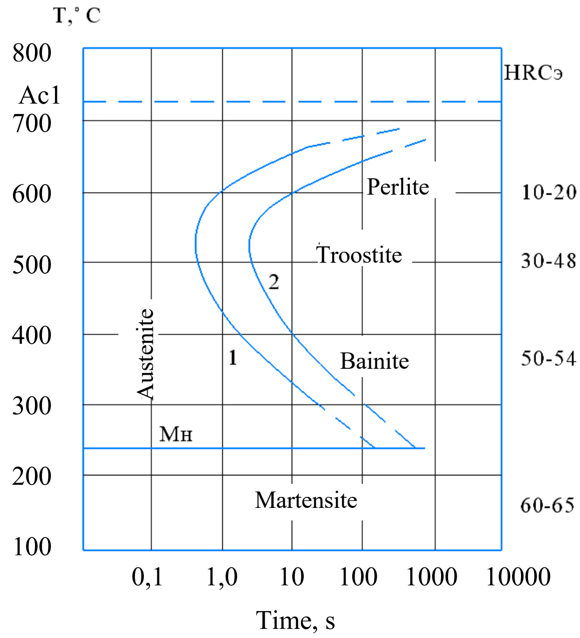

Fig. 2. Graph of the dependence of the transformation of austenite of eutectoid steel of sintered samples obtained by mechanical mixing from a charge of PL-PZH4M2+0.8% C

Austenite, supercooled to low temperatures, loses thermodynamic stability, but due to the fact that the diffusion mobility of carbon atoms is completely suppressed, the transformation cannot be carried out by the pearlite mechanism. The supersaturated solid solution of carbon in alpha-iron formed as a result of the diffusion-free transformation of austenite with the same concentration as that of the original austenite is called martensite. To obtain a martensitic structure, it is necessary to cool the obtained samples at a critical rate so that the time it is in the temperature range of the stable state of supercooled austenite is less than the duration of the incubation period of its decay. The minimum speed that meets these conditions is called the critical quenching rate. With a decrease in the stability of supercooled austenite and a shift of the C-shaped curve to the left, the critical quenching rate increases (Fig. 2).

Depending on the composition, density, carbon content and alloying elements, the degree of heterogeneity, the grain size of austenite and other structural features, various critical quenching rates are noted. They are greatly influenced by the degree of overheating of austenite. The higher the quenching rate is, the lower its critical rate is. The horizontal $M_н$ line on the C-shaped diagram shows the temperature of the beginning of the diffusion-free martensitic transformation (Fig. 2). For carbon steel samples considered by the authors, this temperature is about 250°C. Within 100 seconds, a martensitic transformation occurs, as a result of which various solid solutions are formed. In contrast to the pearlite transformation, the temperature of the beginning of the martensitic transformation does not depend on the cooling rate (in the range of speeds used for industrial hardening of steel). In order for the martensitic transformation to develop, it is necessary to continuously cool carbon powder steel in the range of temperatures under consideration [4-6].

With rapid cooling of carbon steels, austenite has time to cool down strongly, without suffering diffusion decomposition into a ferrite-cementite mixture. But austenite, starting from a certain temperature T_0, cannot exist, since its free energy at this temperature is higher than the free energy of a supersaturated solid solution of carbon in the alpha iron of martensite.

At the moment of transformation, martensite has the same composition with the original austenite and differs from it only by the type of crystal lattice. Martensite is a metastable phase, and therefore it is not on the "iron—carbon" diagram. Under equilibrium conditions, when the system has an absolute maximum of free energy, the steel structure is below point A_1 and consists of a mixture of two stable phases — ferrite (F) and cementite (C). Martensite has a higher free energy at all temperatures than perlite, so the diffusion-free transformation of austenite into martensite leads the system to a relative minimum of free energy. This means that the separation of iron carbides from a carbon-supersaturated ferrite solid solution is thermodynamically likely at any temperature, but at temperatures close to 20°C, the speed of this process is infinitely small.

Figure 3 shows the dependence of the beginning of the martensitic transformation for powder steels on density (porosity). For almost all materials, the dependence is linear, and with a decrease in density, the temperature of the martensitic transformation increases.

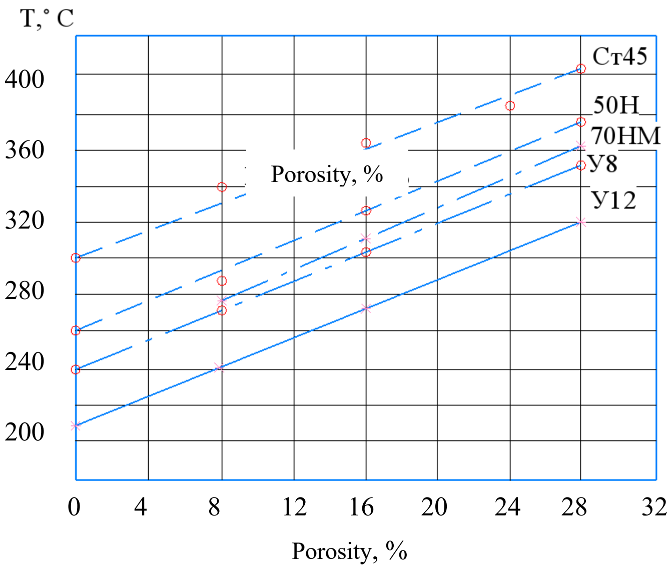

Fig. 3. Dependence of the density of powder steel samples on the temperature of martensitic transformation

The linear dependence of the critical points of martensitic transformation on the density of samples can be explained by the fact that the total density is proportional to the metal surface of the pores, with the growth of which the degree of influence of elastic interaction forces decreases [2, 7-8].

Experimental studies of the processes of diffusion-free transformation of porous austenite of sintered alloys confirm the strong influence of porosity on the shift of the temperature of the beginning of the martensitic transformation of carbon and alloy steels to the region of higher temperatures. As with compact steels, the temperature of martensitic transformation does not depend on the cooling rate and conditions of austenite transformation (isothermal or with continuous cooling), and with an increase in carbon, alloying elements in sintered alloys with the same density, it decreases. With an increase in the density of sintered samples, the incubation period decreases and the stability of austenite decreases. A further decrease in the density or an increase in the porosity of the samples leads to an increase in the $M_н$ temperature (Fig. 4).

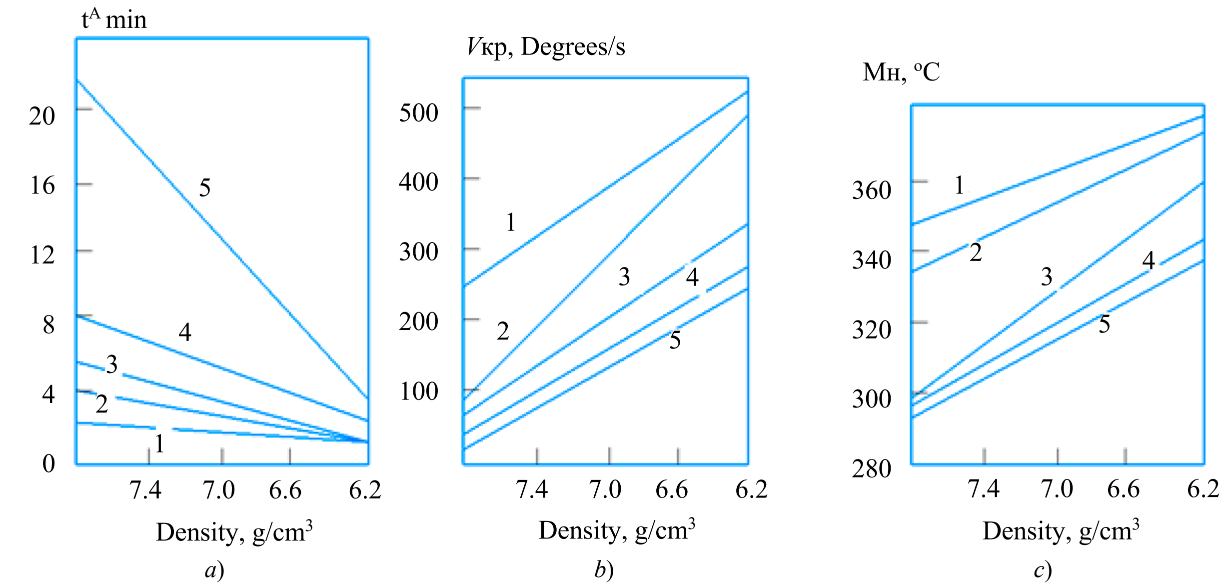

Fig. 4. Graphs of the dependence of the degree of τ^A_{min} (a), the cooling rate during quenching (b) and $M_н$ (c) on the density of alloys: 1 – PL-ZHGR-0.5; 2 – PL-ZHGR-0.5X; 3 –PL-ZHGR-0.5 KhN; 4 – PL-ZHGR-0,5N2M; 5 – PL-ZHGR-0.5

Conclusions. The use of heat treatment of alloys allows them to obtain higher strength and plastic properties than cast steels. This requires preliminary comprehensive theoretical and experimental studies. This will solve the problem of creating new alloys through the use of rational heat treatment modes.

With an increase in the heterogeneity of the solid solution of the steels under consideration, the critical points A_1 and A_3, as well as the temperature of the beginning of the martensitic transformation shift to the region of higher temperatures. This nature of critical points shift is explained by the fact that the areas of micro-heterogeneity, being ready centers of crystallization, are the most likely places of heterogeneous origin of martensite nuclei. Indeed, heterogeneous nucleation of martensite is associated with special nucleation centers located on the microparticles of the initial phase [8-9]. Such centers may be packaging defects that occur during the coupling of dislocations, various micro-heterogeneities. The decrease in the temperature of the martensitic transformation with an increase in the degree of homogeneity of the solid solution can also be explained primarily by its enrichment with carbon and other alloying elements (chromium, molybdenum).

The paper shows that with an increase in the percentage of carbon and porosity of samples, the starting point of martensitic transformation decreases. Even for compact steels, the carbon content in austenite is not always the same, either because of its uneven distribution, or because carbon is part of the carbide phases [2, 6, 10].

Carbides with austenite do not affect the temperature of the beginning of the martensitic transformation. With an increase in the quenching temperature and an increase in the holding time, when carbides dissolve in austenite, the concentration of carbon and alloying elements in it increases or equalizes, the $M_н$ point must necessarily decrease.

With an increase in the homogeneity of austenite, the composition of the solid solution also changes, which has a decisive effect on the quenching temperature and the $M_н$ point.

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M. S. Egorov — formulation of the basic concept, goals and objectives of the study, calculations, preparation of the text, formulation of the conclusions; R. V. Egorova, G. G. Tsordanidi — scientific supervision, analysis of the research results, revision of the text, correction of the conclusions.

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Determination of mechanical properties of sintered dispersion-strengthened iron-based alloys depending on sintering conditions

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Introduction. The problem of creating new sintered materials is now in the center of attention of the entire domestic community in the field of powder metallurgy. Today, when creating a new class of structural materials, first of all, it is worth paying attention to their strength properties. The article considers technological features in the formation of high-quality interparticle splicing of dispersion-strengthened materials. High-quality splicing is primarily determined by the mechanical properties of the alloys, which show the degree of its completeness during sintering. Depending on the density of the materials, the sintering temperature and the percentage of carbon that is introduced into the charge, the mechanical properties of the material also change. The determination of these properties is the main task of the research.

Problem Statement. To determine the strength and plastic characteristics of the materials under consideration, it is necessary to analyze how these characteristics are affected by free carbon introduced into the charge. Determination of mechanical properties will allow us to recommend an alloy with the best characteristics for further research.

Theoretical Part. As a theoretical description, the processes of sintering of dispersion-strengthened alloys, carbon homogenization, and the effect of compaction density and pressure on the mechanical properties of alloys are given.

Conclusions. The obtained mechanical properties show that the addition of 0.8% carbon is sufficient to achieve high strength characteristics. However, the addition of carbon by 20-30% reduces the plastic characteristics of the alloys. The results obtained in this work will help to recommend the material for the manufacture of products with high performance properties.

***Keywords*:** sintering, carbon, alloys, strength limits, yield strength, elongation, surface microstructure, fracture surface factography.

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Introduction. Among the list of powder materials, iron-based and steel-based alloys have the greatest use. When creating new structural materials, along with the requirements of improving quality, reliability and operational durability, the task of saving and replacing expensive and scarce alloying elements with less scarce and low-cost ones is put forward. This fact has served as an incentive for a new round of development of domestic metallurgy in the field of obtaining materials with specified properties, the development of methods for assessing their properties. Currently, there are a large number of nanoscale additives having different properties, and the same additive can be obtained by different methods and have different properties, shape and dimensions. Also of particular interest is the search for an answer to the question of how the introduction of nanoscale particles will affect the structure formation of alloys during various types of molding or deformation. The fundamental processes of the formation of hot-deformed alloys are the structure formation of the material and the creation of qualitative bonds between the powder particles.

The aim of the work is to determine the dependence of the pre-sintering parameters on the formation of the structure and properties of high-density dispersion-strengthened hydra metals. It is necessary to do this for the possibility of further effective use of heat treatment in order to improve the mechanical and operational properties of such alloys.

Problem Statement. To determine the strength and plastic characteristics of sintered materials, it is necessary to analyze how the free carbon introduced into the charge affects them. Knowledge of these mechanical properties will allow the authors to recommend an alloy with the best characteristics for further research.

Theoretical Part. Sintering plays a major role in the formation of a complex of physical and mechanical properties of complex alloyed powder steels. In dispersion-strengthened alloys, during their sintering, a structure is formed that differs significantly from the structure of cast and forged materials. Sintered compacts are primarily porous products in which the number of pores can vary from 0.5–2 to 80-90%. Thus, for powder materials and alloys, porosity acts as a structural component. The shape of the pores, their size, morphology and volume content are determined by the physicochemical, mechanical and other properties of the products, as well as the scope of their application. When sintering, a special role is played by carbon, which is added to the composition of the charge in various ways. The percentage of carbon is selected based on what properties the products will have to have after the sintering. In our case, the amount of carbon was taken as a percentage of the total volume of the material and was 0.5 and 0.8%, respectively [1-3].

Sintering is quite an important operation in powder metallurgy, and the quality of the products obtained depends on the choice of its technological modes. It is advisable to consider two consecutive stages of the sintering process at once: the formation and growth of interparticle contacts (the initial, early stage of the process), as well as an increase in the density of the sintered body due to a decrease in the number and volume of pores (intermediate and late stages). In real conditions, both of these processes cannot be completely separated; they are intertwined and proceed mostly in parallel [2-6].

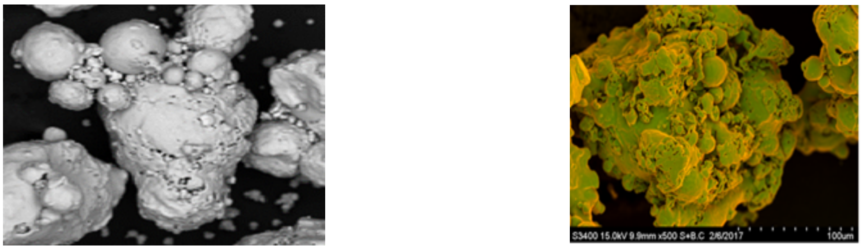
Since the homogenization process does not have time to fully occur during the sintering of steels obtained from the charge of components, this should entail the formation of an inhomogeneous structure. The presence of such a structure, along with porosity, makes the system non-equilibrium, which should have a specific effect on the nature of the processes occurring during heating and cooling of powder steels. The determining technological parameters of sintering of compacts are the temperature regime, the duration of sintering, the parameters of pretreatment of material particles by pressure, etc. In addition, it is necessary to take into account certain features inherent in the sintering processes of single-component and multicomponent materials. When sintering single-component materials, diffusion processes contribute to the compaction of bodies in most cases, and in multicomponent systems, a deceleration of the compaction process and even expansion of the sintered volume may occur due to uneven diffusion. A decrease in the free energy of a multicomponent system during sintering can occur not only as a result of a decrease in the surface and the number of pores, recrystallization and a reduction in the density of defects in the crystal structure, but also due to the formation of alloys. At the same time, the use of low-oxidized and finely dispersed alloy particles, the high sintering temperature before pressing and the maximum possible compaction of the compacts by pressure contribute to the process of alloy formation [7-10].

Analyzing the factors affecting the sintering process and, accordingly, the quality of the materials and products obtained from them, it is impossible not to take into account such an important parameter as the time factor.

The structure of powder steels affects not only the temperature, but also the kinetics of austenization. In conditions of high-speed heating, not only the temperature of the beginning of transformation decreases, but also the incubation period decreases, the temperature and time intervals of transformation increase. With an increase in porosity, the content of non-metallic inclusions, and an increase in the defectiveness of powder particles, these features of the austenization process are enhanced.

In order to obtain high-quality interparticle splicing, which characterizes high mechanical properties, it is necessary to achieve complete dissolution of carbon in the alloy charge.

In this work, modern powder mixtures of grades PL-N4D2M and PZHRV 2.200.26 produced by Severstal AO (Cherepovets) were used (Fig. 1).



a) *b*)

Fig. 1. X-ray diffraction analysis of alloy particles: a) PL-N4D2M alloy; b) PZHRV 2.200.26 alloy

Table 1 provides data on their chemical composition.

Table 1

Chemical composition of alloys

Alloy grade	Mass content of components, %									
	Mo	Ni	C	O	H	Cu	Si	Mn	P	S
PZHRV 2.200.26	–	–	0.09	0.14	–	–	0.014	0.087	0.012	0.005
PL-N4D2M	0.45–0.55	3.5–4.5	0.02	0.2	–	1.3–1.7	–	–	0.02	0.02

Chemical composition of the alloys was chosen based on the composition of alloying elements and the assessment of the influence of these elements on mechanical properties [11–14].

Results and Discussion. Let us consider the dependences of the mechanical properties of the PL-N4D2M alloy on the density of the manufactured samples and the amount of carbon introduced into the charge (Fig. 2). Sintering was carried out at a temperature of 1200°C for 30 minutes 0.5 and 0.8% carbon were added to the charge, respectively [15-18].

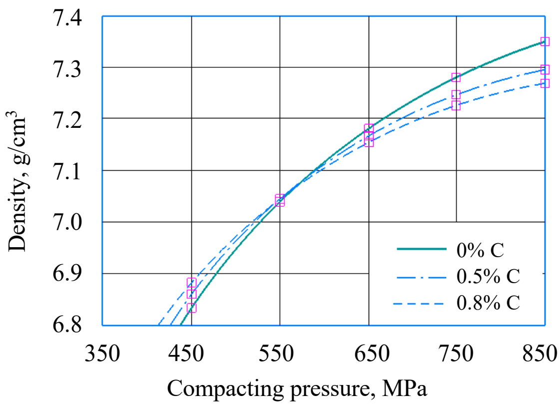


Fig. 2. Compaction of the PL-N4D2M alloy charge depending on the compacting pressure and the amount of introduced carbon

The stretching samples were made with different densities (from 6.7 to 7.6 g/cm³), with different carbon content and sintered in a dissociated ammonia medium for 30 minutes at a temperature of T = 1200°C. Figures 3-6 present the results of the experiments

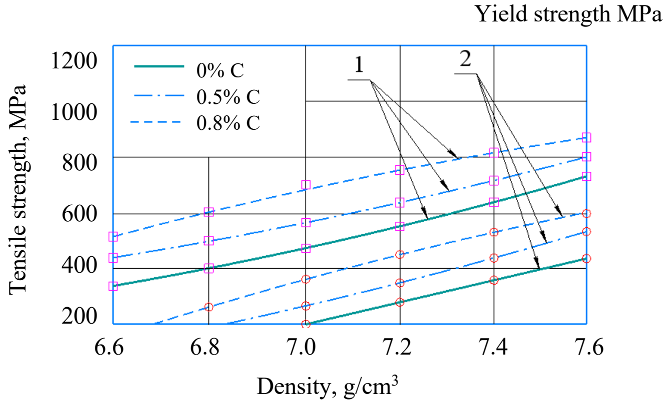


Fig. 3. Dependence of the tensile strength (straight lines 1) and yield strength (straight lines 2) on the density of samples during sintering at T = 1200°C for 30 minutes PL-N4D2M alloy (carbon content in the charge 0% C, 0.5% C, 0.6% C)

The results of the experiment: the tensile strength of the pure PL-N4D2M alloy shows a value of 750 MPa at a density of 7.6 g/cm³, and with the addition of carbon in an amount of 0.8%, the value increases to 900 MPa.

Next, we will determine the dependence of the hardness of the PL-H4D2M alloy on the density of the samples and the carbon content.

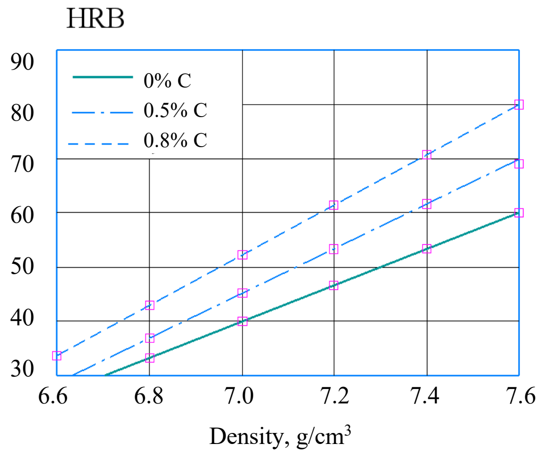


Fig. 4. Dependence of HRB hardness on sample density during sintering at T = 1200°C for 30 minutes of PL-H4D2M alloy (0% C, 0.5% C, 0.8% C)

Let us note the changes in the relative elongation of the samples at break depending on their density and the amount of carbon in the charge.

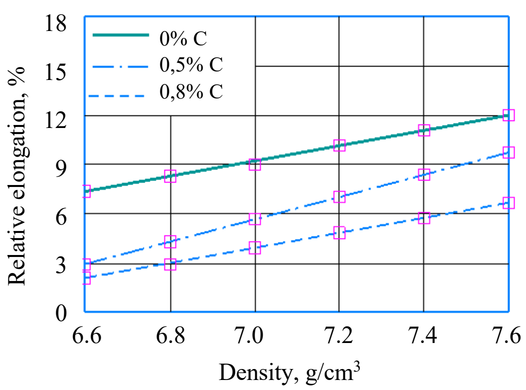


Fig. 5. Dependence of elongation in tension on the density of samples during sintering at T = 1200°C for 30 minutes of the PL-N4D2M alloy (0% C, 0.5% C, 0.8% C)

The data presented in Fig. 5 show that this alloy has better plastic tensile characteristics than the alloys of the Swedish company Höganäs.

The next step is to determine the dependence of the shrinkage of the samples on the density and the amount of carbon introduced into the charge.

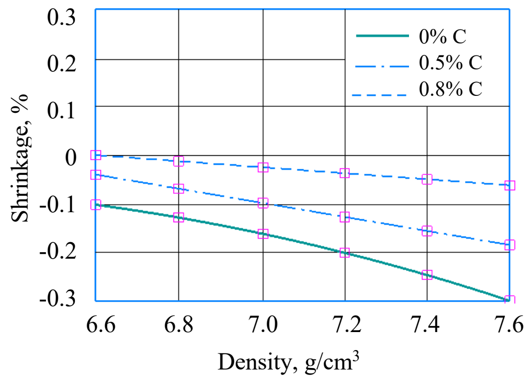


Fig. 6. Dependence of shrinkage on the density of samples during sintering at T = 1200°C for 30 minutes of the PL-N4D2M alloy (0% C, 0.5% C, 0.8% C)

Now let us analyze the dependence of the mechanical properties of the alloy grade PZHRV 2.200.26 on the density of the manufactured samples and the amount of carbon introduced into the charge (Fig. 7). Sintering was carried out at a temperature of 1100°C for 30 minutes. 0.5 and 0.8% carbon were added to the charge, respectively.

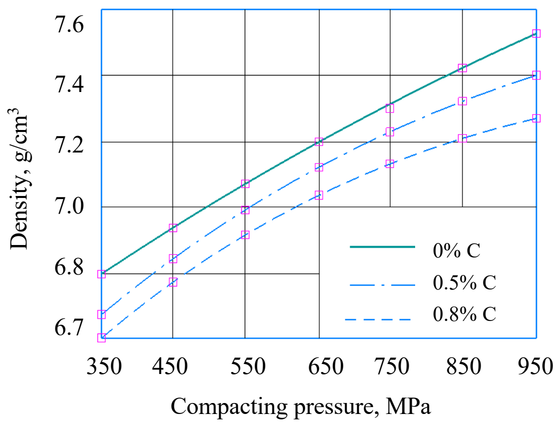


Fig. 7. Compaction of the charge of the PZHRV 2.200.26 alloy depending on the compacting pressure and the amount of carbon introduced

The stretching samples were made with different densities (from 6.7 to 7.6 g/cm^3), with different carbon content and sintered in a medium of dissociated ammonia for 30 minutes at a temperature of T = 1100°C.

The results of the experiments are shown in Fig. 8-10.

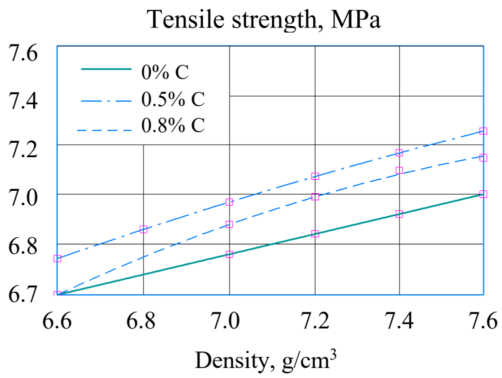


Fig. 8. Dependence of the tensile strength on the density of samples during sintering at T = 1100°C for 30 minutes of the PZHRV 2.200.26 alloy (carbon content in the charge 0% C, 0.5% C, 0.8% C)

Strength characteristics of this alloy are inferior to those of the PL-N4D2M alloy. So, at a density of 7.6 g/cm^3, the strength limit of pure PZHRV 2.200.26 alloy is only 200 MPa.

Next, let us consider the dependence of hardness on the density of samples and the carbon content for the PZHRV 2.200.26 alloy.

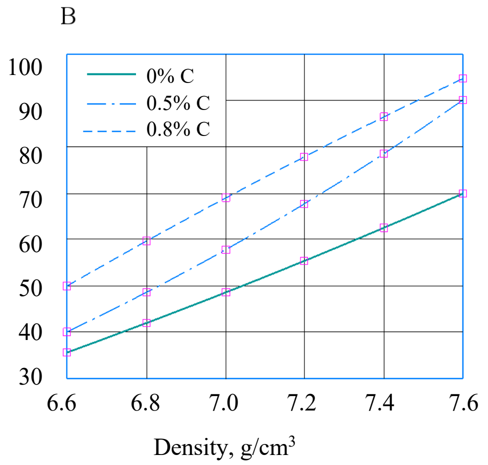


Fig. 9. Dependence of hardness of HRB on the density of samples during sintering at T = 1100°C for 30 minutes of the PZHRV 2.200.26 alloy (0% C, 0.5% C, 0.8% C)

Let us consider the change in the relative elongation of samples at break depending on their density and the amount of carbon in the charge.

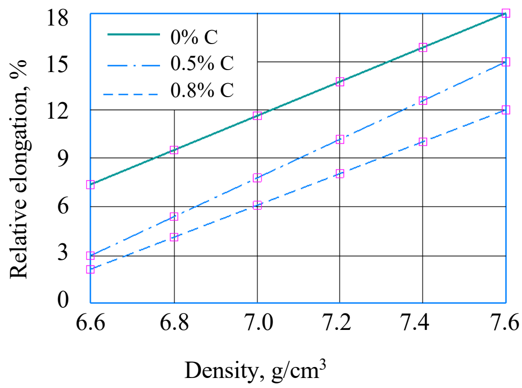


Fig. 10. Dependence of the elongation at tension on the density of samples during sintering at T = 1100°C for 30 minutes of the PZHRV 2.200.26 alloy (0% C, 0.5% C, 0.8% C)

The results presented in Fig. 10 show that this alloy has better plastic characteristics under tension than the alloy of the PL-N4D2M brand. With a carbon content of 0.8% in an alloy with a density of 7.6 g/cm^3, the elongation index is 12%.

Evaluation of the mechanical properties of alloys after sintering has showed that with an increase in the carbon introduced into the charge, the strength properties increase by 25-30% compared to pure alloys. An increase in density also strongly affects the strength and plastic properties of such materials [19-20].

Conclusions. Experimentally, the authors determined the dependences of the strength and plastic characteristics of sintered alloys on the density of samples, as well as on the carbon introduced into the charge. It has been established that sintering for 30 minutes for pure iron alloys is the minimum time at which carbon homogenization occurs in a metal matrix. The sintering temperature of 1,100°C for such materials is absolutely reasonable, and an increase in temperature will not matter to accelerate the sintering process. The paper shows strength properties of the alloys under consideration depending on the percentage of carbon in the initial charge. For the PL-N4D2M alloy, the optimal sintering temperature is 1,200°C, which is 100°C higher than the sintering temperature for iron alloys. The results obtained show that the best strength properties are achieved by sintering the PL-H4D2M alloy +0.8% C for 30 minutes at a temperature of 1200°C.

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Claimed contributorship

M. S. Egorov — formulation of the basic concept, goals and objectives of the study, calculations, preparation of the text, formulation of the conclusions, R. V. Egorova — scientific supervision, analysis of the research results, revision of the text, correction of the conclusions.