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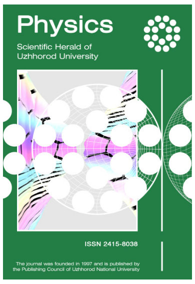

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Isothermal Transformations in High-Strength Cast Iron

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Abstract

Relevance. The technological process of manufacturing parts from high-strength cast irons is simpler and more economical than the process of manufacturing parts from steel. Cast irons are less sensitive to stress concentrators and strike loads. Spheroidal graphite cast irons can achieve DI 70 grades even in the cast state. Through hardening heat treatment or additional alloying, it is possible to produce cast irons of higher strength (grades DI 80 and above). As the strength properties of cast irons increase, disadvantages in the form of low ductility and plasticity become increasingly apparent. These problems can be compensated by providing an ausferritic, bainite or bainite-austenitic structure of the metal matrix of cast irons. A good solution is to obtain cast irons with a complex structure of the bainite-ausferrite type. In this regard, the relevance of this work is due to the fact that, in the practice of modern mechanical engineering, high-strength cast irons are increasingly used.

Purpose. The purpose of this work is to study and obtain the bainite structure due to isothermal hardening. To achieve which specific features of isothermal transformation in high-strength cast iron with spheroidal graphite have been considered.

Methods. This research was based on a theoretical method (analysis, synthesis, concretization, generalization, modeling), and empirical methods (study of research experimental works of scientists and their experience in this or similar field with the application of similar designs and study by experienced specialists).

Results. The possibility and efficiency of obtaining the bainite structure in economically alloyed nickel, copper and molybdenum, in the amounts, respectively, of 1.0; 0.5 and 0.5%, of cast irons using continuous cooling in air has been established.

Conclusions. The results and conclusions formulated on their basis can be used in the future as an effective scientific basis for studying the prospects of application of isothermal hardening of alloyed and unalloyed high-strength spheroidal graphite cast irons

Keywords: ausferritic cast iron, isothermal hardening, spheroidal graphite cast iron, bainite, austenitization

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Introduction

With the creation of eco-friendly technologies, including resource-saving technologies, the development of mechanical engineering is gaining a rapid pace. Such technologies make it possible to significantly increase the performance as well as the mechanical properties of castings, thereby reducing their metal consumption and dimensional accuracy. After high-strength cast iron with spheroidal graphite shape isothermal hardening, it becomes the optimal material for manufacturing parts used in abrasive and shock-abrasive wear conditions. In alloyed cast irons the processes of structure formation are characterized by increased sensitivity to kinetic factors. Castings from high quality cast irons, form a cast structure. This is primarily due to the crystallization process and the occurrence of conditions that determine the nature of the primary phases formed. After all, the nature of distribution, shape and number of phases depends on the chemical composition, factors of iron production in metallurgy. In the melt, under conditions of deep supercooling and oversaturation with carbon, the “nucleation” (i.e. inclusion) of graphite occurs. In turn, during eutectic crystallization of high-strength cast iron, the graphite phase develops around austenite and produces an equiaxed form of eutectic graphite inclusions. This is mainly due to the course of diffusion processes. Stress concentrators to some extent accelerate the nucleation and development of cracks, which is fraught with the destruction of the part. Such inclusions can occur in castings made of alloyed high-strength cast irons, due to the high chemical activity of the alloying elements. Casting defects or any other nonmetallic inclusions other than concentrators can also occur.

In order to obtain homogeneous austenite, the castings are heated to the critical region and held to form homogenization, which is the first stage of heat treatment. Considering the initial structure of the iron base and its chemical composition, the austenitizing temperature and holding time are selected. Ferrit, which is in large quantities in the initial matrix structure, does not allow at hardening temperatures to achieve the desired saturation (at 0.6-0.7% carbon, C) of austenite, as reported in two papers by J. Hernando et al. [1; 2], where the microstructure of austenite was investigated. As a result, the austenite is less resistant and the start of its decomposition in isothermal conditions decreases in the data of the incubation period. In order to dissolve carbides and homogenize austenite, provided there are free carbides or cementite at least in small amounts, it is necessary to increase the dwell time and quenching temperature. H. Hu et al. [3] reported that the decomposition of austenite during isothermal hardening accelerates with complete dissolution of carbides, other particles and stabilization of austenite, which can be achieved with prolonged holding time in the range of 950°C and above. However, significant heating during austenitization can lead to an increase in the austenitic grain, which implies a decrease in ductile properties. But at the same time, there is an enrichment of residual austenite and a decrease in the diffusion time. For example, in the work of S. Hasan et al. [4] reported that the amount of spherical graphite and the degree of spherules, affect the properties of bainite cast iron, the increase in the number of inclusions as a result gives a uniform fine-grained structure of the input iron, and consequently an increase in its mechanical abilities.

The size of graphite inclusions directly affects the rate of reaching the equilibrium state of cast iron, the larger they are, the longer it takes to reach this state, and, in turn, the rate of dissolution of these inclusions, is a diffusion process. Using the diagrams of isothermal transformation of supercooled austenite, and taking into account the chemical composition of cast iron, determine the holding time and the choice of cooling rate to the temperature of isothermal transformation. The duration of isothermal soaking and temperature, have the greatest influence on the structure of the metal base and, in particular, on its formation. Isothermal soaking determines the dispersity of the matrix as well as the completeness of the decomposition of austenite. The structure and phase composition of austenite decomposition products are quite complex. The shape of bainite changes with decreasing temperature, from porous (upper bainite), to needle-like (lower bainite). Always when quenching to bainite, the structure contains residual austenite. As the isothermal holding temperature increases, the residual austenite content will increase. The impact toughness and ductility have a fairly wide range of changes depending on the duration of holding during isothermal processing, but the strength properties are not greatly affected. Austenite cannot turn into bainite if there is insufficient holding time and upon further cooling, it turns into martensite, which has low ductility but high strength. Generally, because of the high silica content, carbide formation usually does not occur. In the work of M. Soliman & H. Palkowski [5] investigated the properties of martensitic-ferritic steels, where the results show that the ideal combination of ductility and strength characteristics, it is considered the complete transformation of austenite into bainite and the absence of martensite in the base.

Materials and Methods

This research, fundamentally studied work was based on a qualitative, reliable combination of proven theoretical methods (analysis, synthesis, concretization, generalization, modeling), and empirical methods (study of research experimental works of scientists and their experience in this or similar field with the application of similar designs and study by experienced specialists). The theoretical basis of this scientific work is mainly thematic studies consisting of scientific, research and review scientific articles, which include experimental methods and descriptions of experiments. Analyses, statistics and other types of works of researchers, taken from official sources with reliable information, aimed at the study of a large number of problematic issues that may appear during the application of the highlighted methods related to isothermal hardening of cast iron with spheroidal graphite.

At the first stage of scientific research its basic theoretical basis was prepared, on the analysis of which the basis for further conclusions is built. At this stage of scientific research the search and analysis of various reliable sources of information was performed. A large number of information resources devoted to increasing the strength of cast iron with spheroidal graphite using isothermal processes were reviewed and filtered. The collected data were reviewed and systematized for a simplified, quick and qualitative understanding of the information. A systematic analysis of the work and evaluation of tmethods of obtaining bainite structure in cast irons with spheroidal graphite was made and other ways of increasing the strength grade of cast irons were investigated. The main questions that can be effectively and qualitatively solved with the help of practical use of modern methods and technologies are outlined.

At the second stage, authors solved the problem of determining the possibility of obtaining the bainite structure in nickel, copper, and molybdenum-alloyed ductile cast irons using continuous cooling in air. Heating temperatures from 870 to 930°C were chosen. The results also show microphotographs for each temperature interval.

At the next stage of scientific research, an analytical comparison and in-depth study of the materials of the studied works was performed. Most of them included analyses, theoretical information and descriptions of the experience of various methods of improving the quality of cast irons and steels. Experiments by scientists on the topics of austenitization and martensitization of metals, as well as the production of nanobainite steels, their advantages and peculiarities, were analyzed in detail. The peculiarities of bainite transformation in graphitized cast irons, study of structure, mechanical and operational properties of cast irons were studied. The conclusions obtained as a result of research works were analyzed, specified and verified.

At the last stage, materials were completed, theoretical and practical conclusions were specified, and the data obtained were generalized, checked, and systematized. The results and conclusions formulated on their basis can be used in the future as an effective scientific basis for studying the prospects of application of isothermal hardening of alloyed and unalloyed high-strength cast irons with spheroidal graphite.

Results

This study considers the peculiarities of isothermal transformation in high-strength cast iron with spheroidal graphite. The possibility and efficiency of obtaining bainite structure in economically – alloyed with nickel, copper and molybdenum high-strength cast irons with spheroidal graphite cast in a metal mold by continuous cooling in air has been established. According to the standard technology, some parts of shut-off devices, including the slide valve, made of 40X steel, should be subjected to extensive hardening or normalization followed by nitriding to ensure high wear resistance and durability. This treatment is not suitable for cast iron. It is dangerous to subject cast iron parts to bulk hardening because of the possibility of cracking. Nitriding is also inadvisable because of the considerable duration of the process and the brittleness of the resulting layer. High durability of parts made of economically alloyed cast iron can be ensured by obtaining bainite structure in it by means of isothermal treatment or by some other method. It is known that a material with such a structure is not inferior to nitrided cast iron in terms of wear resistance, because the highest wear resistance belongs to cast irons with a bottom bainite structure, while the strength of isothermally hardened cast irons is at a high level.

Many works are currently devoted to the study of methods for obtaining bainite iron. For example, one of them is the creation of a bainite matrix in cast iron. However, this method is complicated, requires the use of significant complex alloying additives and does not guarantee a homogeneous structure due to liquation and micro-liquation of the elements in the cast iron that develop during crystallization. For ductile cast irons, this method is even more unacceptable, since they must necessarily undergo graphitizing annealing. Therefore, isothermal hardening is a more expedient method for these conditions for obtaining the bainite structure in cast iron. It makes it possible to form bainite without pearlite inclusions and structurally free ferrite. It makes it possible to form bainite without pearlite inclusions and structurally free ferrite. At the same time this method requires special equipment and additional production area for placing hardening tubs, the use of scarce alkalis as hardening media. The complexity of the method also consists in the difficulty of ensuring the temperature constancy of the tubs, which is associated with high energy costs.

For cast irons, especially those alloyed with nickel, copper and molybdenum, in amounts of 1.0; 0.5 and 0.5%, respectively, it seems possible to obtain a bainite metal base during continuous cooling. The alloying additives should help to increase the stability of austenite in the pearlitic area. It is necessary to check whether it is possible to obtain the bainite structure in cast iron alloyed with nickel, copper and molybdenum under conditions of continuous cooling, what sizes of additives are required in this case, how homogeneous is the resulting structure and what level of properties can be ensured as a result of such treatment. After all, the presence of structural heterogeneity, as well as differences in the ratio of phases in the matrix can significantly affect the mechanical properties of the alloys under study. It is necessary to assess the degree of influence of these factors on the level of guaranteed properties of cast irons. Therefore, this work solved the problem of establishing the possibility of obtaining the bainite structure in nickel-, copper-, and molybdenum-doped ductile cast irons using continuous cooling in air.

Such a treatment can be performed with heating above and beyond. It does not seem to make sense to conduct heating in the intercritical region, since this can lead to strengthening the already strongly developed heterogeneity in the iron matrix. In addition, it is important to ensure the stability of pre-cooled austenite in the area of pearlitic decomposition, and this will be more fully achieved after heating higher. For this reason, heating temperatures from 870 to 930°C were chosen for the study. The heat treatment uses tightly controlled temperature modulation to improve certain wanted characteristics of the metals, such as performance and durability. Isothermal hardening is a heat treatment process designed for the treatment of metals with medium to high carbon content. The main purpose of isothermal hardening is to reduce deformation while increasing the strength and toughness of the metal. This is done by heating the product until the metal becomes austenitic and then hardening to precise temperatures and leaving it there for intervals of time.

Alloyed and, for comparison, unalloyed spheroidal graphite high-strength cast irons were subjected to isothermal hardening. The structure of bainite depending on the temperature of isothermal aging was studied on unalloyed cast iron samples. At the same time, the aim was to establish the connection between the initial structure of the matrix and the rate and completeness of the bainite transformation. The last is important in the development of production technology. The austenitizing temperature was 910°C, which is 50°C higher for the alloy under study. The holding time was 15 min, isotherm temperatures: 350, 400 and 450°C. During hardening, ferritic and pearlitic iron samples were subjected to the same heating in the furnace and simultaneously transferred to the tub. Exposures in the tub ranged from 30 s to 20 h. After isothermal soaking the samples were cooled in water. At low dwellings in the tub the cast iron acquired high hardness. This was due to the presence of a significant amount of martensite formed during precooling of the samples from the isothermal temperature in water. The bainite transformation in ferrite cast iron develops slower in the beginning than in pearlitic cast iron, as evidenced by their high hardness. The results obtained are shown in Table 1.

Table 1. Hardness of ductile iron with nodular graphite after isothermal quenching

Isothermal hardening temperature, ^{0}C														
450					400					350				
Cooling time of cast iron ($\tau_{isot.}$)														
30s	50s	100s	16m	2h	60s	90s	10m	16m	2h	90s	120s	10m	16m	2h
Initial structure of cast iron (hardness, HB):														
pearlitic														
512	444	340	321	–	–	387	375	321	–	425	402	364	351	351
ferritic														
512	512	512	–	248	496	496	283	241	187	532	512	340	283	–

Source: [6]

The bainite transformation starts to develop intensively in cast irons with a ferritic initial structure after more than 10 minutes of holding. At temperatures of 400 and 350°C it practically ends in 15-16 minutes, the obtained microphotographs are shown in Figure 1. Cooling in the tub at 350°C leads to the formation of the lower bainite (Figs. 1; 2), at 400 and 450°C to the upper bainite. In the structure of the samples treated at 450°C, with dwell times of more than 16 min. In Figures 3-5 it can be clearly seaw the small isolations of carbides.

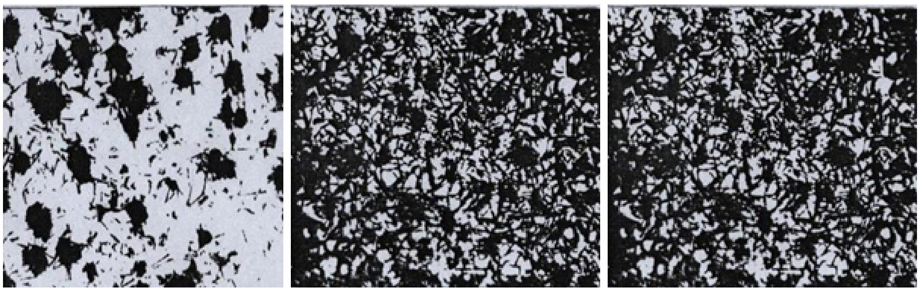

Figure 1. Microphotographs of bainite formation

Source: [6]

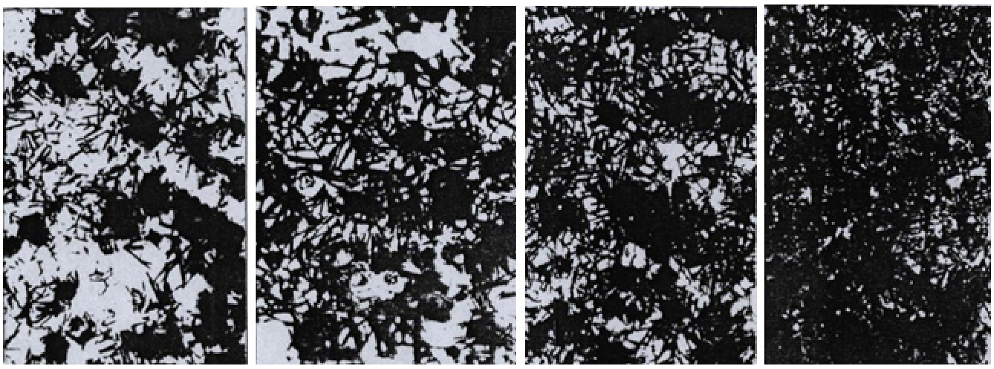

Figure 2. Micrographs of bainite formation

Source: [6]

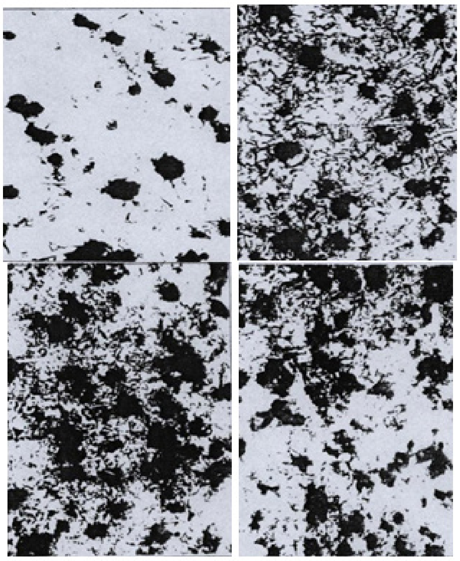

Figure 3. Microphotographs of carbide isolation

Source: [6]

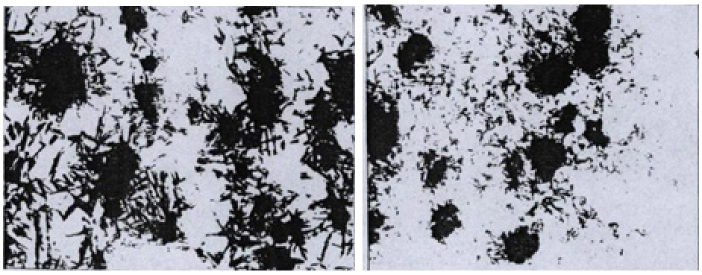

Figure 4. Microphotographs of carbide isolation

Source: [6]

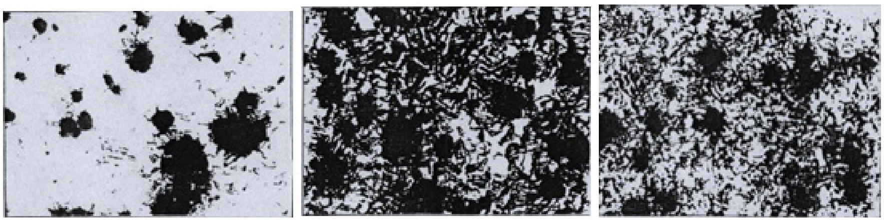

Figure 5. Microphotographs of carbide isolation

Source: [6]

The isothermal hardening process hardens medium- and high-carbon iron alloys, as well as carbon steel, by heating the metal to a temperature that breaks down its crystal structure until it becomes austenitic. Once the work becomes austenitic, the processes of martensitization or austenitization diverge into martensitization and austenitization.

Martensitization:

– to prevent austenite from turning into bainite or pearlite, this piece is quickly and successively hardened;

– having reached a homogeneous temperature of the material in front of the initial temperature of formation of martenite, the transition to the last step follows;

– air cooling to room temperature.

Austenitizing:

– having converted to austenite, the next step is to harden this piece to a temperature just above the temperature at which bainite begins to form;

– to turn austenite into bainite, the part must be kept at the required temperature for a while;

– finally, the piece is air-cooled or hardened in water.

Austenitizing and martensitizing have a wide range of advantages for many industries. The main ones are:

– increased strength. The crystalline structure of martensite or bainite, after isothermal hardening significantly hardens the metals, unlike untreated metals.

– impact strength. Where untreated metals can tear or crack, austenitic components are likely to withstand impact while retaining their shape. Hardened metals have this property because of their exceptionally strong crystalline structure.

– reductionn of distortion. They show less deformation compared to untreated steel because of the ductility acquired during the hardening process. For thin components, which need to maintain their dimensions during and after treatment in this way, this is a particularly useful property.

The main differences between austenitic and martensitic hardening:

1. Achievable hardness:

– martensitization – Rockwell hardness up to c65;

– austenitizing – Rockwell hardness up to c35-54.

2. Physical properties:

– martensitization – high strength, good impact toughness;

– austenitization – high strength, highest impact toughness.

3. Distortion control:

– martensitization – very good;

– austenitizing – excellent.

For example, a carburized gear wheel with a required Rockwell hardness of c 61-62 that is outside the austenitic tempering range should be subjected to martensitic tempering. A lawn mower blade requiring a Rockwell hardness of 46-48 should be austenitized to give it greater hardness to resist dents in use. Austempering is a special type of heat treatment in which austenite is converted to lower bainite. Generally, in conventional heat treatment, the austenitic structure turns into pearlitic or martensitic structure during continuous cooling methods. The process proceeds as follows: Heating the steel above the austenitizing temperature, hardening in a tub (usually a salt tank) at a constant temperature above the temperature of the particular steel (200-400°C), waiting in the tub until the bainite transformation is complete and finally cooling the steel part to room temperature with air or any other preferred method. In the literature, the austenitizing process is sometimes referred to as isothermal hardening or because of the isothermal heating mode of the process.

Tempering tubs play a crucial role in the austenitic tempering process, since maintaining the same temperature for a period of time is the basis of this heat treatment. However, because of the relatively high tub temperatures, oils are not a suitable hardening medium for this process. Instead, various molten salts are used in these tubs. Salt tub furnaces are pot-type furnaces that contain mixtures of salts with low melting points that are heated/melted by a pair of electrodes. They can also be used for numerous heat treatment processes such as liquid carburizing, cyaniding, liquid nitriding, martensitic tempering and austenitic tempering. It is not as eco-friendly due to the formation of gaseous products in the process, but it provides efficient and consistent heating of metal parts.

There are many variations in the chemical composition of the salt tub. In general, the use of molten salt tubs with nitrate/nitrite is common practice for the austenitic tempering heat treatment process. If we heat steel or cast iron until its constituents are converted to solution, then harden to 1200°F and hold at that temperature long enough, we will cause that microstructure to turn into the softest microstructure, perlite. If instead we had cooled this austenite to 600°F before aging, we would have avoided the pearlite transformation and instead created a much harder microstructure, bainite. Finally, if we cool this metal billet quickly and sufficiently, the formation of both pearlite and bainite would be eliminated, turning into the hardest structure, martensite. The studies conducted and the results obtained have established that the initial structure of the metallic base of ductile cast irons has a significant influence on the kinetic parameters of the bainite transformation. In the ferritic initial matrix the transformation proceeds faster and more completely than in the pearlitic one. However, the incubation period in ferritic cast iron is longer.

Discussion

With its good tribological properties and low cost, cast iron is a fairly current material, but the lack of the required mechanical properties leads to the fact that its main areas of application have become those in which the combination of heat and material wear plays a key role, for example in piston ring and liner cylinder systems. To reduce weight and save energy, it is necessary to improve the tribological and mechanical properties of cast iron, which, in turn, can be achieved by improving its microstructure, for which many studies have been conducted to improve its microstructure. With excellent thermal conductivity and an excellent endurance limit, compacted graphite cast iron is an excellent substitute for gray cast iron, for example in piston rings or cylinder liners. Thanks to the coral-like morphology of the graphite particles between ductile and nodular forms, such an excellent combination of tribological, physical and mechanical properties has been achieved in compacted graphite cast iron.

Laser hardening techniques by V. Writzl et al. [7], addition of stabilizing pearlitic elements Y. Lyu [8], surface alloying by J.J. Feng et al. [9] and induction hardening by T. Slatter et al. [10], have become an excellent solution for improving the wear resistance of cast iron with compacted graphite. Another way to improve mechanical properties is through austenitic tempering heat treatment. Several studies have shown a significant effect of the microstructure on improving the wear resistance of compacted graphite iron (CGI) after hardening, especially felt differences in comparison with pearlitic metal matrix under dry sliding conditions A.R. Ghaderi et al. [11], R. Ghasemi et al. [12] studied the austenitic tempering parameters of CGI ferritic cast iron and noticed a strong influence of temperature on the microstructure: at 275°C less ausferrite transformation was observed, in turn, when austenitizing was performed at 375°C, the final ausferrite was large due to higher carbon diffusion rate. Also in these studies, the authors showed little effect of processing time, summarizing that only at times up to 120 minutes did hardness increase slightly due to the emergence of carbides.

Isothermal ductile iron is produced by heat treatment of ferritic ductile iron without the addition of costly alloying elements. In terms of efficiency and economy, isothermal ductile iron is an extremely suitable solution for the production of very large parts requiring a high level of static and fatigue strength, such as pump heads for hydraulic systems, knuckles and axle center housings. isothermal ductile iron has higher performance than nodular cast iron and is more affordable than austenitic ductile iron, the benefits of which we will be discussd next. As reported in Dg. Eiken et al. [13], the matrix structure of isothermal ductile iron consists mainly of ferrite and pearlite, two elements which, due to a different distribution compared to conventional ductile cast irons, increase the mechanical characteristics of the finished castings. Therefore, isothermal ductile iron is a worthy alternative. With machinability comparable to that of perlitic ductile irons commonly used in machine shops, isothermal ductile iron is also suitable for machining. It has a mixed ferrite-pearlite structure, which means that it can also be surface hardened only where necessary, thus increasing the wear resistance of the parts. The advantages of isothermal ductile iron include:

- lightness: the specific weight of isothermal ductile iron is 10% lower than that of steel, which allows vehicles to either increase their maximum load or reduce fuel consumption;
- complex shapes: thanks to the melting technology and excellent casting ability the material can be applied only where it is necessary;
- fatigue strength: comparable in characteristics to pearlitic ductile cast irons;
- economical: no alloying elements are required
- elasticity: even at temperatures below 0°C (down to -40°C) the material guarantees stable mechanical characteristics in very thick castings or parts with variable thicknesses.

Two well-known tempering methods use isothermal hardening and martensitization. These two processes have much in common, their main differences being in the temperatures to which they are hardened, the time they remain at those temperatures, and the end result. To fully understand these processes, it is worth using the C-shape curve. During heat treating, the microstructure of the workpiece is transformed to produce the desired properties. C-curves are important for the metallurgist to understand when certain transformations occur in the metal and at what temperatures. The austenitic metal is stronger, more ductile, more impact resistant, and less prone to deformation. As reported in M. Rahaman et al. [14], martensitization quickly and effectively quenches austenite to avoid the formation of pearlite or bainite, resulting in the hardest microstructure, martensite. Examples of the major benefits of the austenitizing process are higher ductility and toughness at high hardness values, lower internal stresses and improved fatigue properties. For example, in A.I. Belyakov et al. [15] the authors show a number of advantages that it has in comparison with conventional hardened and tempered steels. Austenitizing also cools quickly, but not as low as martensitic hardening, because perlite formation is avoided and the temperature is maintained in the hardening until the billet becomes completely bainite. Typically, this process is used to create thin, yet strong ductile iron or carbon steel components. Common austenitized components include:

– agricultural machinery components;
– automotive transmission gears;
– construction machinery components;
– cutting blades;
– weapon parts;
– clips;
– clips, seat belts in automobiles.

The material after martensitizing has the highest Rockwell rating of any hardening process. This process is used to give parts the properties of minimal deformation. For example, in large parts of the aircraft industry. Some typical hardened parts include: crankshafts; gears; parts of industrial equipment; helicopter props. Common materials with isothermal hardening include: carbon steels, iron and alloy steels. These materials are the most hardenable with these methods because of the large amount of carbon they contain, which facilitates the transformation at different temperatures.

A significant limitation of austenitic tempering heat treatment is that it can only be applied to relatively thin cuts because of the requirements for uniform heating and temperature. In addition, the austenitic-perlitic transformation of a particular alloy must be relatively slow and the bainite temperature must be within reasonable limits when considering the tempering process from an economic point of view, mainly the energy consumption during tempering. A study of the effect of deformation temperature on phase transformations and microstructure in nanostructured bainite steel indicates that deformed austenite with deformation 0.3 at 300°C demonstrates accelerated kinetics of bainite transformation. However, the amount of bainite in preformed austenite then decreases as the deformation temperature increases. In deformed austenite, a critical deformation temperature can be detected that determines the possibility of bainite transformation. In addition, the thickness of the bainite plate in deformed austenite decreases with decreasing ausforming temperature. The lower ausforming temperature contributes to the more severe phenomenon of cross-growth of bainite plates. For these reasons, low-carbon steels are not suitable unless they are carburized. Examples of alloys suitable for austenitic tempering include the following groups of alloys: Spring steels (e.g., 50CrV4), smooth medium/high carbon steels, chromium molybdenum steels (AISI 4140), tool steels (e.g., H13) and boron steels (e.g., 94B30). Hardening of cast iron. Austenitizing iron is a heat treatment process that produces an ausferritic matrix. This heat treatment process is usually carried out using these stages:

– the austenitizing of castings usually takes place at temperatures of 850-950°C for between 15 minutes and 2 hours, long enough to saturate the austenite with carbon;
– rapid hardening to avoid the formation of pearlite in a hot salt bath at 250-450°C (lower than pearlite but higher than the beginning of martensite);
– isothermal aging in a hot salt tub, for sufficient time (usually 0.5 to 3 hours) to obtain an ausferritic matrix, a combination of needle ferrite and high-carbon austenite.

The factors controlling the cooling process to room temperature after a given hardening time can vary depending on the required mechanical properties (different microstructure), so there are different types of austenitic iron. Here are the best known of them and their typical uses:

– high-strength cast iron with austenitic tempering;
– the best known and most used technique;
– hardened gray iron;
– used to make quieter parts (excellent damping effect);
– bearing shells;
– brake components;
– carbide austenitic ductile iron;
– wear resistance even higher than austenitic ductile iron;
– hammers;
– parts of threshing drums.

Advantages and applications of austenitic ductile iron:

– no tempering is required after hardening;
– lower strain rate than that of hardening and tempering (isothermal transformation);
– savings are achieved by machining before heat treatment;
– often, wear resistance and strength are also improved;
– for a given surface – increased wear resistance;
– increased ductility and impact resistance for the same hardness;
– density 10% less than that of steel;
– ductile cast iron from austenitic tempering provides higher strength-to-weight ratio;
– lower production costs for castings near a given shape (0.2-0.4% increase in volume);
– good machinability;
– higher damping capacity;
– good casting throwing ability.

Acetylene ductile iron has found successful applications in many industries, including construction, mining, agriculture, automotive, heavy truck and railroad. It is commonly used in applications where both strength and impact resistance are required at the same time. In order to make parts made of economically alloyed cast iron highly resistant to wear, they can be isothermally machined into it with a bainite structure. Material with such structure is just as wear resistant as nitrided material. It makes no sense to subject the material to nitriding itself because of the considerable duration of the process and the brittleness of the resulting layer. In the works of A.I. Belyakov et al. [15] & V. Dubrov [16] point out that the highest wear resistance is possessed by cast irons having a bottom bainite structure and the strength of isothermally hardened irons is at a high level. Isothermal hardening makes it possible to form bainite without pearlite inclusions and structurally free ferrite. At the same time this method requires special equipment and additional production area for placing hardening tubs, the use of scarce alkalis as hardening conditions. The complexity of the method also consists in the difficulty of ensuring constant temperature of the baths, which is associated with high energy costs. At low durations in the tub, cast iron acquires high hardness. This is caused by the presence of a large amount of martensite formed during the precooling of the samples from the isothermal temperature in water. The bainite transformation in ferrite cast irons is slower in the beginning than in pearlitic ones, as indicated by their high hardness. The bainite transformation begins to develop intensively in cast irons with a ferritic initial structure after more than 10 minutes of aging.

At the same time, in the work of J. He et al. [17] demonstrate that carbide-free nanobainitic steels have an excellent combination of high strength and toughness combined with inexpensive adaptability through low-temperature isothermal treatment. In a study by W. Gong et al. [18] reported that the key to obtaining steels with such properties is to reduce the martensitization initiation temperature, suppress the release of carbides and, therefore, create an optimal microstructure of nanosized plates of bainite ferrite, in sum with small layers of residual austenite. Such alloys have the advantage of controlling the number and size of phases by heat treatment compared to conventional high-strength steels, but are less common due to the expensive alloying elements present in the composition.

To properly design a nanobainite alloy, it is necessary to have an understanding of the effects of conventional alloying additives on the bainite transformation as well as the resulting properties. The main dependence of the kinetics of the bainite transformation is the stability of the austenitic and ferrite phases at temperature, during the transformation. Also, in the work of S. Hasan et al. [4] the strength of nanobainite alloy depends on the plate thickness of bainite ferrite and, in general, its amount, while its ductility will depend on the amount and stability of residual austenite in the microstructure. The rate of bainite transformation is significantly affected by the addition of martensite (0.29%) along with a moderately high percentage of aluminum (0.9%) by J. Tian et al. [19], M. Soliman & H. Palkowski [5] & W. Liu et al. [20]. Provision of high-strength structures of the metal matrix of cast iron is possible due to rational alloying and rationally chosen temperature-time parameters of the heat treatment regime. Nanobainitic carbide-free steels entail a combination of high strength and impact toughness combined with inexpensive adaptability by low-temperature isothermal treatment. Therefore, the creation of composite structures in high-strength cast irons with spheroidal graphite is an effective way to harden it, expanding the field of its application.

Conclusions

Therefore, continuous air cooling is an effective way of obtaining the bainite structure in economically alloyed ductile cast irons. The optimum mode of heat treatment providing rational structure and properties of ductile iron castings with nodular graphite for parts of stopper devices for oilfield equipment has been established. Consequently, the analysis of issues related to the structure formation of bainite iron shows that changes in the austenitizing temperature, the time of isothermal aging of castings, temperature and cooling rate contribute to a significant change in the physical and mechanical properties. In contrast to untreated cast irons, steels subjected to the isothermal process have a higher strength, and regardless of alloying, hardening provides the maximum strength value. The structural formation and kinetics of the bainite transformation in steels have been studied in detail and are well described in the fundamental literature. But, unfortunately, the details of austenization and transformation of the matrix into bainite, in cast irons with spheroidal graphite are not studied as qualitatively. Heating to a temperature that destroys the crystal structure of the metal, up to becoming austenitic, hardens carbon steel and other carbon-rich iron alloys.

The advantages of isothermal hardening are: increased strength (the crystal structure of martensite or bainite, after isothermal hardening, significantly hardens metals, unlike untreated ones), impact resistance (where untreated metals can tear or crack, austenitic components are likely to withstand the impact while maintaining their shape, metals with hardening have this property due to their extremely strong crystal structure). Reduced distortion (due to the plasticity acquired during the hardening process, this metal exhibits less deformation compared to untreated steel. For thin components that need to maintain their dimensions during and after treatment, this is a particularly useful property). Ensuring high-strength structures of the metal matrix of cast iron is possible due to rational alloying and rationally chosen temperature-time parameters of the heat treatment regime. The tasks for further research related to the study of nanobainite steels, which do not contain carbide, entail a combination of high strength and toughness in combination with inexpensive adaptability by low-temperature isothermal treatment. Therefore, the creation of composite structures in high-strength cast irons with spheroidal graphite is an effective way to harden it, expanding the field of its application.

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Ізотермічні перетворення у високоміцному чавуні

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Анотація

Актуальність. Технологічний процес виготовлення деталей з високоміцних чавунів простіший і економічніший, ніж процес виготовлення деталей із сталі. Чавуни менш чутливі до концентраторів напруг і ударних навантажень. Чавуни зі сфероїдним графітом можуть досягати марок DI 70 навіть у литому стані. Шляхом зміцнювальної термічної обробки або додаткового легування можна отримувати чавуни підвищеної міцності (марки DI 80 і вище). У міру підвищення міцнісних властивостей чавунів все більше виявляються недоліки у вигляді низької пластичності і пластичності. Ці проблеми можна компенсувати, забезпечивши аусферитну, бейнітну або бейнітно-аустенітну структуру металевої матриці чавунів. Хорошим рішенням є отримання чавунів зі складною структурою типу бейніт-аусферит. У зв'язку з цим актуальність даної роботи зумовлена тим, що в практиці сучасного машинобудування все ширше застосовуються високоміцні чавуни.

Мета. Метою даної роботи є дослідження та отримання структури бейніту за рахунок ізотермічного зміцнення. Для досягнення чого враховано особливості ізотермічного перетворення у високоміцному чавуні зі сфероїдальним графітом.

Методи. Дане дослідження ґрунтувалося на теоретичному методі (аналіз, синтез, конкретизація, узагальнення, моделювання) та емпіричному методі (вивчення дослідницько-експериментальних робіт вчених та їх досвіду в цій або подібній галузі із застосуванням подібних конструкцій та вивченням досвідченими фахівцями).

Результати. Доведено можливість та ефективність отримання бейнітної структури в економічно легованих нікелі, міді та молібдені в кількостях відповідно 1,0; Встановлено 0,5 і 0,5 % чавунів при постійному охолодженні на повітрі.

Висновки. Отримані результати та сформульовані на їх основі висновки можуть бути використані в майбутньому як ефективна наукова основа для вивчення перспектив застосування ізотермічного зміцнення легованих і нелегованих високоміцних чавунів із кулястим графітом

Ключові слова: аусферитний чавун, ізотермічне гартування, чавун з кулястим графітом, бейніт, аустенітизація