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by

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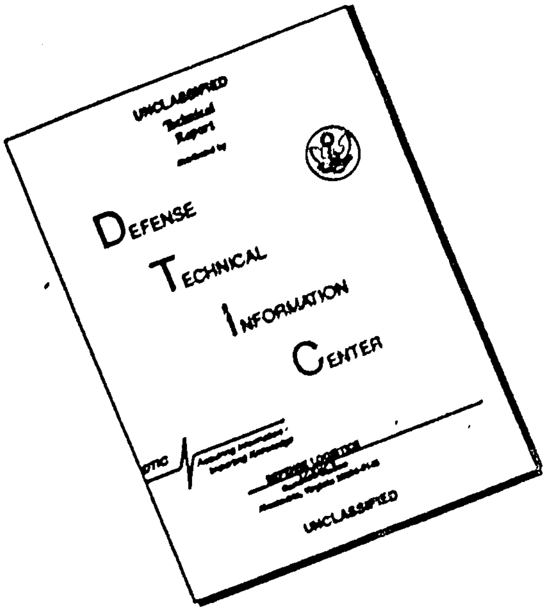

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ANTIFRICTION AND WEAR-RESISTANT CAST IRONS USED IN MACHINE CONSTRUCTION

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The pearlitic cast irons are antifriction cast irons: gray, inoculated, high-strengh modular or spheroidal, and malleable (alloyed and nonalloyed). The ferrite content must not exceed 15% [1-3]. These cast irons should have a considerable quantity of graphite. The steel base of the cast iron can consist of ferrite, cementite, pearlite, and phosphide eutectic. Ferrite, a soft structural component, has low wear resistance [4-6].

Alloyed aluminum (up to 0.5%) and copper (up to 2.0%) can increase the antifriction properties of ferritic cast iron [7]. Cementite has considerable hardness, makes the cast iron brittle, and causes significant shaft wear. There can be no free cementite in antifriction cast iron.

Pearlite, a eutectoid, is a mechanical mixture of ferrite and cementite and, as mentioned above, is the base of antifriction cast iron.

The phosphide eutectic, the solid structural component, plays a dual role in cast iron during wear. While absorbing a considerable load (having high natural wear resistance), it reduces wear; if it is removed or breaks off, wear considerably increases. The behavior of the phosphide eutectic during wear is obviously determined by the strength of its deposit in the steel base of the cast iron, as well as by the character and amount of friction. If the deposit strength of the phosphide is sufficiently great and it is not removed during friction, it obviously counteracts wear. For this reason it is recommended that the phosphide eutectic be obtained in the form of a lattice in the pearlite or pearlite-sorbite base of the cast iron [4]. The phosphide eutectic solidifies after the evolution of other structural elements and is located between the grains of the metallic base of the cast iron, forming a closed lattice when the phosphorus content is 0.6-0.8%. Since the phosphide eutectic is very brittle, it increases the brittleness of the cast iron.

References [4, 8-12] established the fact that there is increased wear resistance in cast irons when they contain a phosphide eutectic. On the other hand, references [3-13] recommend a minimum amount of phosphide eutectic in antifriction cast iron and a uniform distribution of it in pulverized form.

The graphite in cast irons has a great effect on the strength, the antifriction properties, and the wear resistance. On the other hand, it disrupts the continuity of the metallic base, contributes to the breakoff of metal particles during wear, yet is a lubricating material and fills the rough places of the friction surface, spreads out on them, increases the actual area of contact, reduces specific pressure, and serves as a lubricant counteracting wear. During liquid and boundary friction graphite contributes to the adsorption of the lubricant on the working surfaces, increasing the antifriction properties.

Various antifriction cast irons [2, 3] SChTs1 and SChTs2, which are cupola pearlite low-alloyed cast irons with a normal graphite content, have been suggested. These brands are used at specific pressures of no more than 100 kgf/cm^2 and slip rates of no more than 5 m/s if the product of specific pressure times rate is no more than 18 $kgf\ m/cm^2\ s$. (SChTs1 differs from SChTs2 by the presence of copper and aluminum.)

Cast irons Ts5 and B belong to this same type. These brands are used at specific pressures of no more than 60 kgf/cm^2 (Ts5) and no more than 160 kgf/cm^2 (B); slip rate must be no greater than 3 m/s for Ts5 cast iron and no greater than 5 m/s for brand B under the conditionsthat the product of specific pressure times rate does not exceed 15 kgf m/cm^2 s for Ū5 cast iron and 40 kgf m/cm^2 s for B cast iron.

It is recommended that cast irons SChTs1, SChTs2, and B be used under loads without impacts or jerks for operation in steam with shafts having an HB hardness no less than 300 kgf/mm^2.

A softer cast iron, Ts5, is recommended for work with shafts of less hardness.

Cast iron Ts5 contains chromium and nickel, while cast iron B is chromium, nickel, titanium, and copper. Cast iron B is worn and wears shafts 15-20% less than pearlitic cast irons. Pearlitic cast irons, containing 0.8-1.8% copper, [14] have been used in friction nodes of electrical traveling cranes (bearings for the transmission), loading machinery for open-hearth furnaces, slab shears, boring machines and lathes (support nuts), and other machinery.

The conditions governing the application of copper cast iron as antifriction material were the same as those for the cast irons SChTs1 and SChTs2.

Wear of parts of spindle nodes [15] with bearings of titanium-copper cast iron was not only no more than, but frequently less than, bronze. Two-year tests showed that titanium-copper cast iron can fully replace bronze in spindle bearings for wet spinning of flax, with the compulsory maintenance of an enlarged clearance, high-grade installation, and proper cleaning and lubricating of nodes. This cast iron contained 0.6-1.0% copper and 0.1-0.15% titanium.

In making piston rings by the individual method [12, 16], cast iron containing 0.4-0.45% molybdenum is used. Instead of expensive molybdenum, we can introduce 0.45% copper and 0.1% titanium. Molybdenum, chromium, copper, and titanium increase the thermal stability of the ring and, therefore, preserve the brittleness of the cast iron even at elevated temperatures.

In reference [17] titanium-copper cast iron containing 0.35-0.50% copper and 0.08-0.15% titanium was recommended for casting cylinder blocks of engines. Antifriction cast iron containing copper also operates well under the action of water and steam. The favorable effect of copper on the antifriction properties of cast irons was noted in references [10, 12, 19, 20].

In connection with this, special copper antifriction cast iron containing up to 2.0% copper was developed [20]. For bearings working with abundant lubrication, at low specific pressures and rates, soft antifriction cast irons with a ferrite base and a phosphide eutectic in the form of a lattice are used [8, 19, 20]. Antifriction porous cast iron was proposed [21, 22] as a substitute for bronze Br OTsS6-6-3 and Br OTsS5-5-5, as well as aluminum bronze. This cast iron is obtained by introducing lead and potash into the liquid metal and contains 0.5-1% phosphorus and 0.5-1% lead.

The heat treatment of antifriction porous cast iron (APC) depends upon what kind of microstructure the specifications require. In order to obtain pearlite structure (ferrite no more than 15%) APC is normalized, while to obtain ferrite-pearlite structure it is annealed. APC with pearlite or pearlite-ferrite structure has a hardness of HB-120 kgf/mm^2. In reference [22] it is mentioned that this cast iron has a pore diameter of 0.75-1.5 mm and a tensile strength of 40-50 kgf/mm^2.

With low values for hardness and the presence of pores there is some doubt concerning the amount of tensile strength. In such a cast iron tensile strength should be considerably lower than indicated in the reference. In addition, it is not clear how to achieve a specific quantity and size of pore. A pore diameter of 0.75-1.5 mm is represented as large enough. Also doubtful are the antifriction properties of this material and the areas of application indicated (bushings for rollers on the S-80 tractor, main bearings of the ZIL-150 and ZIL-5 automobile, bushings on metal-cutting machines, carrier bushings for sliding blocks on forging machines). In addition to these deficiencies, APC must have very low impact toughness.

In references [23, 24] antifriction and wear-resistant sulfur cast iron is described. This cast iron [23] was obtained by ferrous-sulfide treatment of ordinary SCh21-40 cast iron in liquid state at 1400°C. Ingots were subjected to normalization: heating up to 1050°C, holding 1-1.5 hours, and air cooling. After heat treatment, the cast iron had a fine-grain pearlite base and annealing graphite, which was distinguished around the sulfide inclusions as crystallization centers; the sulfides which formed in the cast iron (sulfur content was below 0.86%) had no effect on the decrease in mechanical properties after normalization. In addition, a 45-57% increase in the strength of the cast iron was observed. This was connected with the peculiarities of graphite structure after normalization and the fine-grain pearlite base.

With dry friction the wear of sulfur cast iron was 25-30% less than magnesium. The coefficient of friction during dry friction for sulfur cast iron based on steel was 0.350-0.401 and for magnesium and ordinary gray cast iron 0.450-0.500.

Metallographic studies of thin surface layers of sulfur cast iron [24] subjected to wear have shown that, as a result of friction, sulfide inclusions substantially change their form and character; we observe their deformation, pulverization, and the formation of dispersed crystalline inclusions oriented in the direction of the friction. When tempered steel slips along sulfur cast iron without lubrication, there is a high content of sulfur in the products of the wear during this friction. It is suggested that the dispersed inclusions of sulfides and sulfo-oxides forming in the surface layers have a positive effect on run-in, antiseizing properties, and wear-resistance of sulfur cast iron. These inclusions possibly play the role of fine grinding powder. Along with high antiseizing properties, the high quality of the friction surface attained during wearing in has a considerable effect on the performance and the durability of the friction pair. The roughness of a friction surface of sulfur cast iron during friction without a lubricant was in the 8th class and above, while with ordinary cast iron it did not exceed the 6th class during tests under the same conditions.

A sufficiently deep sulfurized layer can be obtained by surface alloying of an ingot of sulfur directly in the foundry mold [25]. The essence of this process lies in the application of a layer containing sulfur compounds or simply sulfur on the dry surface of the foundry mold or core. When the mold is filled with metal, the sulfur is melted and the metal is enriched with it to a considerable depth by diffusion. Sulfurization of bevel and root pinions for runners increased their lifetime from 2-2.5 months to 1 year and more, while the service life of dumpers was increased from 3-4 to 8-10 days.

Sulfurized bushings of the TE1 diesel locomotive from nonalloyed SCh15-32 cast iron were 2-2.5 more wear-resistant than commercial bushings from low-alloy cast iron.

Wear-resistance tests on a TsNII MPS machine with reciprocating motion imitating the work of the bushings and on an MI machine show that sulfurization of cast iron and steel increases their antifriction properties and wear resistance. The high properties of the sulfurized cast irons and steels are explained by the formation in their structure of interlayers and rosettes of soft sulfides, which make a lubricant on the surface of friction.

Antifriction antimonous cast iron, obtained by alloying gray cast iron SCh15-32, SCh18-36, and others, with a small amount of antimony introduced directly into the ladle under the metal stream, is described in reference [26]. This cast iron contains 0.3-0.65% antimony, does not require heat treatment, and has good casting properties. Antimony increases the hardness of pearlite and the phosphide eutectic. With optimal antimony content the transverse strength limit is reduced 5-30%, while hardness increases 6-23%.

The antifriction properties of antimonous cast iron were tested on the AYe-5 end-friction machine with boundary lubrication and friction without lubrication. Cast iron containing 0.32-0.64% antimony had the lowest coefficient of friction and wear for the coupled pairs.

Extended operational tests on parts from machines made of this cast iron showed that in many cases it can successfully replace bronze.

In another work [27] it is noted that during seizing tests the samples seized the supports after the first few seconds regardless of the amount of antimony. However, after sulfocyanogenation of the cast irons containing antimony, the samples and the supports operating as a pair with them had no surface damage. The ability of the cast iron after sulfocyanogenation to resist seizing with an antimony content of more than 0.05% is explained by the formation of the compound Sb_2S_3 with a lamellar hexagonal crystalline lattice and very low hardness – 2 on the Mohs scale. The low melting point of Sb_2S_3 (550°C) contributes to the easy disruption of seizing points; soft flakes of Sb_2S_3 are contained in the wear products. The advisability of sulfocyanogenation of antimonous cast iron is confirmed by a test and successful operation of approximately 200 different machine parts made instead of bronze.

In this same work it is correctly noted that data on the properties of cast iron containing antimony are insufficient and contradictory. Recommendations concerning the optimal amount of antimony are not connected with the cross section of the castings and with the possible variations in the composition of the cast iron. There are considerable contradictions concerning the increase in wear resistance of cast irons. No consideration is given to the amount of wear of a steel sample which, when operating in a pair with antimonous cast iron, was two times greater than with Br CF-10-1, 8 times greater than with Br OTsS5-5-5, and 50 times greater than with Babbit B-83. Naturally it is not sufficient to evaluate the usefulness of antifriction material only with respect to its wear without taking into account the wear of the coupled steel parts.

Good antifriction properties, high wear resistance and heat resistance up to 600°C are noted in reference [12] for cast irons alloyed with nickel, chromium, and copper.

Such cast irons are used for ball-and-socket joints of outlets, cases for automobile engines, and in refrigerators since they are not cold-short alloys.

Wear-resistance studies on various cast irons in the machines of Savin and Amsler [28] made it possible to establish the high wear resistance of nickel-molybdenum cast iron, particularly with a "needle" structure for the metallic base, and high-strength cast iron with spheroidal graphite, which considerably exceeds the wear resistance of ordinary gray and inoculated cast irons. Antifriction pearlite malleable cast iron is considered a precursor of higher-quality and more wear-resistant, high-strength pearlite cast iron with a more compact form of graphite inclusions.

Hardening by high-frequency current increases the wear resistance of all cast irons except nickel-molybdenum cast iron with a "needle" structure. The alloying of cast iron, which has a considerable effect on wear resistance in the test state, has a comparatively small effect in the case of surface hardening.

The wear resistance of a hardened layer of cast iron which has been cold-treated, in spite of the increase in hardness, does not increase, but actually decreases in the majority of cases. With heat treatment inoculated and high-strength cast irons can achieve a wear resistance as good as the wear resistance of chilled cast iron. By the introduction of molybdenum into the cast iron for piston rings, it was possible to achieve stable and high mechanical properties and increase the wear resistance of the metal several times [29]. Subsequently it was possible to replace molybdenum, which is an expensive element, with chromium, copper, and titanium. Introduced into the mixture were titanium-copper cast irons and chromium with an additive of ferrochromium. The wear resistance of these rings was even somewhat higher than it was with chromium-molybdenum cast iron.

Pearlite and pearlite-ferrite malleable cast irons [30-35] are antifriction and wear-resistant materials in many cases of friction.

In reference [30] we are told that pearlite-ferrite malleable cast iron (pearlite 50-80%) works completely satisfactorily at specific pressure up to 300 kgf/cm^2, slip rates up to 2-3 m/s and semiliquid friction, with products of specific pressure times rate up to 250-200 kgf m/cm^{2}s, and under conditions of variable-sign impact loading. This cast iron showed considerable advantages as compared with bronze of the type Br OS5-10 and Br A-10, as well as the aluminum alloy alcusin (less wear of bearings and connected shafts).

An increase in pearlite content in the structure of malleable cast iron causes an increase in the wear of the coupled steel part.

In reference [31] it is indicated that the best structure for pearlite-ferrite malleable cast iron is a structure containing 50-70% pearlite with a hardness of HB-149-170 kgf/mm^2. This cast iron must be lubricated just as bronze and its use is not recommended for work during friction without lubrication or with insufficient lubrication.

In a pair with moist steel shafts a pearlite content within 60-70% is permissible (HB = 167-178 kgf/mm^2), while in a pair with steel hardened shafts pearlite can be 90-100% (HB = 197-217 kgf/mm^2) [32]. In this work it is noted that the good antifriction properties of pearlite-ferrite malleable cast irons do not depend upon the method of preparing them. It is impossible, of course, to agree with this claim. Manganese-titanium malleable cast iron [33], containing 1.0-2.0% manganese, 0.05% chromium, and 0.05-0.12% titanium with spheroidized pearlite structure was used as an antifriction and wear-resistant material (journals of pressure cast molds, bearings of reducing gears in mixers, push-rods of tunnel annealing furnaces operating with lubrication, links in chains of overhead conveyers, aerator blades, rollers of plate transporters, blades of vibrators and crushing chamber, blades of runners operating without lubrication).

The wear resistance of parts made from this cast iron was higher than those from normalized steel 45 and stannic bronze.

On the basis of operational tests it has been concluded that manganese-titanium malleable cast iron with spheroidized pearlite is, in a number of cases, a completely satisfactory substitute for nonferrous metals. The least wear occurs in pearlite magnesium-titanium malleable cast iron during sliding friction without lubrication and with lubrication with a content of 1.5-2.0% manganese and 0.1-0.15% titanium in the cast iron [34].

Based on studies presented in this work, we have concluded that it is possible to use manganese-titanium pearlite malleable cast iron as a substitute for bronze in the manufacture of bearings and as a substitute for carbon steel in the manufacture of chain links; aerator blades; bottoms and blades for runners; rollers for plate, overhead, and pouring conveyers; etc.

In reference [35] it was found that malleable cast irons alloyed with manganese from 1.0-2.25% and titanium from 0.05-0.15% can be substitutes for antifriction nonferrous alloys and carbon structural steel. Inoculated pearlite malleable cast iron [36] during tests in laboratories, without any lubrication or with insufficient lubrication, was 20-25 times more wear-resistant than ordinary gray cast iron and 12-15 times moreso than inoculated gray cast iron.

Wear in inoculated malleable cast iron was the same, and in some cases 2-5 times less, than bronze. Operational tests on journals of this cast iron installed in various machines, hydropresses, etc., confirmed its high wear resistance. Journals of ordinary stannic bronze, as a rule, work no more than 12 months, and those from aluminum-iron bronze (Br AZh9-4) no more than 6 months. After replacing them with cast iron journals, service life increased to 18-30 months. Inoculated pearlite malleable cast iron also found use as a material for cold-pressing, bending, flanking, drawing, and compound dyes.

Comparative tests of inoculated cast iron (with an additive of silicocalcium and ferrosilicon) for wear resistance during reciprocating motion in the laboratory and in operation [37] showed its advantage over uninoculated cast iron.

At a specific pressure of 20.0 kgf/cm^2 inoculated cast iron were 25% less than high-quality pearlite cast iron. Based on the tests made, recommendations are given concerning the use of inoculated cast iron for machine casting of mountings, drums for automatic machines, lathed chucks, etc.

In addition, this cast iron can be used in place of bronze and steel. At low specific pressures (less than 10 kgf/cm^2 or, when there is good lubrication, less than 30 kgf/cm^2) the advantages of inoculated cast iron are scarcely noticeable; however, as the pressure grows and the operating conditions of the friction node generally worsen, the advantages of this type of cast iron increase [38].

The inoculation of cast iron with ferrosilicon [39] considerably improves wear resistance.

A small increase of alloying elements in a cast iron (nickel and chromium) noticeably increases wear resistance.

Operational tests on parts cast from alloyed inoculated high-strength cast iron and before heat treatment (sleeves of the valve chamber lining in the S-252 concrete pump) showed high wear resistance, metal hardness, and, at the same time, ductility.

Reference [40] indicates the possibility of widespread use of inoculated ferrosilicon alloyed cast iron as antifriction material in place of expensive bronze and other nonferrous alloys, particularly for parts working under high loads.

The wear resistance of inoculated cast iron [41] is 4 times greater than ordinary gray cast iron and approximately 3.5 times greater than steel pearlitic cast iron.

Tests for wear were carried out by abrasion from a rotating disk. In the test for wear from reciprocating motion without lubrication [38] the wear resistance of inoculated cast iron was approximately 2.7 times greater than for uninoculated cast iron. The wear resistance and good antifriction properties of inoculated cast iron [41] are explained by a combination of the following:

"a) the flake form of graphite which adsorbs the lubricant well and by the soft-lubricating action of this graphite when there is no lubricating layer between the working surfaces (for example, upon starting and stopping);

b) the pearlite structure of the basic metallic mass in which there are no crumbling inclusions of ferrite and hard brittle structurally free inclusions of cementite and a ternary phosphide eutectic acting as an abrasive during wear." (page 30).

Data are presented on the good antifriction properties and high wear resistance of high-strength cast irons with spheroidal graphite [42-45, 47-72].

Reference [42] discusses the high wear resistance of large parts from high-strength cast iron. The wear resistance of this cast iron in a cast state is greater by a factor of 2.5-3.5 than inoculated cast iron [43].

As a result of wear tests on a Savin machine [44] (abrasion by a revolving disk of hard alloy with lubrication and cooling by a 0.5% solution of potassium chromate in water), the considerably higher wear resistance of high-strength cast iron than St3 and inoculated cast iron SChM35 was also established. A successful test is noted on the use of high-strength cast iron in agricultural machinery construction [45].

Tests in laboratory conditions, verified by operational tests, have established the high wear resistance and good antifriction properties of high-strength cast iron with and without lubrication (reduced wear of coupled part, low coefficient of friction) as compared with cast irons of other types, including the best of them – malleable cast iron [46].

Cast iron with spheroidal graphite combines the specific properties of cast iron and the high strength of steel [47, 48]. Cast iron with spheroidal graphite virtually removes strength limitations existing in antifriction cast iron with flake graphite. In addition, the possibility of controlling the structure of the metallic base with heat treatment is important as it enables the selection of a specific structure depending upon the operating conditions [49].

In wear tests [50] on the MI machine using the friction of a roller of tempered steel along the test material without lubrication, it was established that pearlite cast iron with spheroidal graphite has a higher wear resistance than bronze Br OTsS5-5-5, Br AZh9-4, and malleable cast iron.

Increasing the ferrite content in cast iron with spheroidal graphite above 15% leads to a reduction in wear resistance; the wear of a bearing, in this case, considerably exceeds the wear of bronze bearings and bearings from SChTs2 cast iron with a purely pearlite metallic base, as well as those from titanium-manganese malleable cast iron. According to the wear of the roller, the materials were arranged in the following sequence (based on increase in roller wear): bronze, cast iron with spheroidal graphite with pearlite structure, titanium-manganese malleable cast iron, cast iron with flake graphite brand SChTs2, and, finally, pearlite-ferrite cast iron (with ferrite content 20-45%) with spheroidal graphite.

The highest coefficient of friction corresponded to pearlite cast iron with flake graphite, and the lowest to cast iron with spheroidal graphite with a pearlite structure. The coefficient of friction for bronze was only half as great as the studied cast irons.

It requires considerably more time for cast irons to wear in than for bronze.

In tests on the ATS-5 machine (with a soft-adjusting bearing) cast iron with spheroidal graphite has better wear-in characteristics than cast iron with flake graphite or with graphite in the form of temper carbon.

Maximum loads in the wear-in period for the majority of tested cast irons differ only slightly from loads sustainable by bronze.

Almost all tested cast irons withstood the maximum load taken for the wear-in regime at 120 kgf/cm^2. Total load capacity was greatest in bearings of bronze Br OTsS5-5-5. Then (in descending order) followed bronze AZh9-4 and the cast irons: type SChTs2 and cast iron with spheroidal graphite. In tests on the MI friction machine without lubrication [51] the coefficient of friction for various pairs was 0.15-0.60 and during friction with lubrication was 0.02-0.06, i.e., in the first case 5-10 times greater than in the second.

Cast iron with spheroidal graphite [52] has high wear resistance during friction without lubrication, which, in certain cases, exceeds the wear resistance of heat-treated steel.

Tests on the wear resistance of cast iron with spheroidal graphite without lubrication during reciprocating motion [53] showed that the wear resistance of this cast iron with a pearlite structure is 2-3 times greater than that of hardened steel.

In a stand test of plane motion without lubrication similar results were obtained. If the wear of gray cast iron is taken as 100%, then the wear of inoculated cast iron was 21.5% and of cast iron with spheroidal graphite was 5.2%.

In wear-resistance tests [54] on the Savin machine the wear of cast iron with spheroidal graphite was near (somewhat less than) the wear of inoculated cast iron with flake graphite brand SMCh-35. With this method of testing no difference was seen in the wear resistance of various high-strength cast irons.

In tests using the MVTU method (the test sample is clamped under a load to a revolving steel shaft with a hardened surface; tests are made without lubrication; wear is determined based on weight loss of sample) considerable advantages were noted for cast iron with spheroidal graphite as compared with ordinary gray and inoculated cast irons.

Very appreciable advantages have been established for pearlite high-strength cast irons over ferrite. The wear resistance of high-strength cast iron with spheroidal graphite in a test state is 2.5-3.5 times higher than the wear resistance of inoculated cast iron [43].

Reference [44] indicates that with the proper selection of composition and heat treatment, it is possible to obtain high-strength cast irons with high wear resistance under any operating conditions. In references [55, 56] the conclusion is reached that high-strength cast iron can be used in many areas of machine building and repair.

The stand test on the wear resistance of cast iron with spheroidal graphite during reciprocating motion with lubrication [53] revealed high wear resistance. The best wear resistance was shown by a pair consisting of high-strength cast iron with a pearlite structure and hardness of HB = 255 kgf/mm^2, followed by a pair consisting of pearlite cast iron with spheroidal graphite (bushing) and inoculated hardened cast iron (pin).

Tests on the Amsler machine with sliding friction and lubrication gave the same results. Pearlitic cast iron with spheroidal graphite in a pair with Babbit B-83 had the best results.

Under these conditions, the wear resistance of high-strength cast iron is higher than steel. Blades, levers, guide wheels, cross pieces, and pistons for the working wheels of turbines, which were formerly made from ZOL steel, are being made from high-strength cast iron with spheroidal graphite [52]. Also cast from it are diesel crankshafts; pistons, bushings, and other parts; all kinds of small parts such as impellers for methane torches, impellers for dust removers, parts for sporting guns and sewing machines; parts for corn combines which formerly were made from malleable cast iron (clutches, jointed square shafts with screw thread, turnstile box, sprocket wheels, thrust washer, etc.). Also made from this cast iron are crankshafts, wheels, and brake drums for automobiles, gear drives, piston rings, pistons, bushings, rollers, plowshares, dyes, etc.

GOST 1585-57 [52] specifies antifriction cast iron with spheroidal graphite of two brands: AVCh-1 designed for operating in a pair with a heat-treated (tempered or normalized) shaft and AVCh-2 designed for operating in a pair with a nonheat-treated shaft.

AVCh-1 differs from AVCh-2 by a copper content of 0.7% and a higher allowable amount of manganese.

Presented below are the maximum permissible operating conditions for parts from antifriction cast iron with spheroidal graphite.

Cast iron	Specific pressure in kgf/cm^2	Circular velocity in m/s	P in $kgf\ m/cm^2 s$
AVCh-1	5	5	25
AVCh-2	120	1.0	120.

The maximum operating conditions for antifriction cast iron with spheroidal graphite considerably exceed those for antifriction gray cast irons.

With good lubrication the wear resistance of high-strength cast iron is the same as for gray cast iron [57]. Under conditions of friction without lubrication high-strength cast iron is less wear-resistant than gray cast iron.

Crankshafts from high-strength cast iron with spheroidal graphite are no less wear-resistant and reliable than steel [42, 52, 58-63]. Crankshafts from magnesium cast irons are more durable than those from cerium [62]. Heat treatment can considerably improve their wear resistance [63]. Camshafts and push rods of tractor engines made from high-strength cast iron with spheroidal graphite and from gray cast iron with flake graphite with a troostite structure had greater wear resistance than those from medium-carbon and high-carbon steel [64].

Piston rings from high-strength cast iron have high wear resistance, strength, elasticity, and heat conductivity [65].

Spheroidal graphite chips off with a minimum disruption of the metallic base, which contributes to run-in during friction.

Elasticity of rings from high-strength cast iron with spheroidal graphite is considerably greater than in those of alloyed cast iron. Heat resistance of high-strength cast iron is higher than cast irons alloyed with chromium, nickel, and copper and somewhat lower than cast irons containing molybdenum.

Based on studies made, it has been concluded that high-strength cast iron with spheroidal graphite in a cast state is the best material for piston rings.

High-strength cast iron with spheroidal graphite is successfully used for engine pistons [66]. The durability of pistons from high-strength cast iron was 3-4 times greater than those from malleable cast iron with spheroidal graphite. This cast iron also indicated high wear resistance in bushings made from it [52].

High-strength cast iron with spheroidal graphite satisfies to the fullest extent the high requirements imposed on roller material [67-69].

High-strength cast iron rollers 670 × 1380, installed on a continuous billet mill operated for 5 weeks between changes, while other rollers had to be replaced every 2 weeks; rollers of high-strength cast iron showed less wear [68].

A comparison of the results of the work of rollers made from ordinary and high-strength cast iron of varying hardness indicates that the advantage always falls to rollers of high-strength cast iron; the greater the difference in quality the lower the hardness of the working layer.

The service life of rollers with a hardness of HB = 200-280 kgf/mm^2 for reduction mills and cogging mills rose 1.5-2.5 times as compared with rollers of cast iron with flake graphite and more than 3 times as compared with steel.

Reference [52] deals with a further improvement in the quality of rollers brought about by alloying high-strength cast iron. Technological factors such as the preparation of charge, the melting mode, inoculation, and teeming, have a considerable effect on the quality of rollers [70-71].

A high ferritic oxide content in slag has an unfavorable effect on the structure of cast iron and noticeably reduces the quality and wear resistance of rollers [72].

Hard white cast iron alloyed with carbide-forming elements is usually used to operate under abrasive conditions [12, 73-80].

It has been found that by alloying white cast iron with boron, titanium, or both elements together with a certain content of carbon and silicon, a considerable increase in the strength of this cast iron during abrasive wear can be achieved. When white cast iron is alloyed only with boron, its hardness improves significantly while, at the same time, its strength, particularly viscous strength, is reduced. The additional alloying of such cast iron with titanium leads to improved strength properties while its hardness remains sufficiently high. The alloying of white cast iron with titanium only produces an insignificant increase in strength. White cast iron containing 0.3-0.5% boron is suitable for casting parts which are subjected to abrasive wear without impact loading. The deoxidation of this cast iron by ferrotitanium in the amount of 0.13-0.15% has a very favorable effect on its properties.

White cast iron containing 0.7-1.0% titanium can be used for making parts which are subjected to the action of intensive abrasive wear and impact loading. White cast iron containing 0.3-0.5% boron and 0.7-0.9% titanium is recommended for these same operating conditions.

Parts for power equipment, made from white cast iron with 0.3-0.5% boron, have operated effectively for several years. Their service life has been 3 times longer than parts made from rolled products and twice as long as parts from chilled cast iron.

Cylindrical corrugated armor plates of ball mills "Sh-16" were cast from white cast irons containing 0.3-0.5% boron and 0.7-0.9% titanium, as well as titanium alone in the amount of 0.7-1.0%, and mounted simultaneously with plates of austenitic manganese steel. Examination and measurement of the plates after 8079 hours of mill operation showed that wear in plates alloyed with boron and titanium was approximately one half as much as in those made of manganese steel.

In order to increase the wear resistance of cylinder bushings of reciprocating sump pumps, it was proposed [74] to cast them inside with boron cast iron containing 1% boron and nickel. Boron cast iron has a very high hardness, approximately HRC = 67-70. The service life of such bushings was increased by a factor of 9 when pumping water with sand.

Nickel-boron white cast iron [12] containing 3.5-4.5% nickel and 0.7-1.0% boron with a hardness of HRC = 58-62 has been used for buckets of pumps and other parts operating in an abrasive medium and also with limited lubrication.

Alloyed white cast iron [75] containing 1.8% boron and 3.7% nickel with a hardness of HRC = 63-64 has greater wear resistance than nitrided and cyanided steel bushings of drilling pumps intended for pumping the flushing liquid into the borehole during drilling. The flushing liquid is a clay solution. Intensive wear of the bushing-piston pair occurs, mainly on the abrasive layer.

Centrifugal pumps, which are widely used (for hydromechanization of time-consuming earth work, in the construction of hydroelectric stations, in transport and industrial construction, in agriculture, in the chemical industry, mining, metallurgy, in glass, silicate, and cement plants, and at power stations), are subject to severe wear [76].

The best structure for cast iron with respect to wear resistance in these conditions is carbide-martensitic, i.e., the structure of white cast iron containing 3.8-5.0% nickel and 1.6-2.6% chromium. Cast hardness is HB = 400-600 kgf/mm^2.

The carbon content must be no less than 3.0-3.6%. A decrease in carbon content below 2.5% causes a sharp decrease in wear resistance along with a drop in hardness.

Chrome cast iron containing 28.0-30.0% chromium and 2.0-3.0% nickel has high wear resistance under these conditions. Molybdenum in the amount of 1.0-1.5% and titanium in the amount of 0.5-1.0% improves the wear resistance of cast iron noticeably.

The rotary throwing of shot is widely used at the present time for cleaning pickup and scale from castings, forged pieces, and rolled products, as well as for surface hardening of parts. However, the intense wear of the parts, particularly of the blades, of the shot-throwing device is a major disadvantage, which complicates and raises the cost of these installations [77].

The wear-resistant alloys for the blades must have a hardness of approximately HB 600 kgf/mm^2, a yield point of 20 kg/mm^2, a shear strength limit of 70 kgf/mm^2, modulus of elasticity $E = 9000$ kgf/mm^2, a coefficient of recovery upon impact of 0.78, a coefficient of friction of approximately 0.2. The structure of alloys for blades must consist of a sufficiently strong and ductile base, pearlite and a thin lattice of carbide of high hardness. Fine inclusions of carbides in the base increase wear resistance to an even greater extent. There must be approximately 2% bound carbon in the alloy and 30% carbide phase.

Chromium alloys have higher wear resistance than alloys of other elements.

Boron intensifies the effect of chromium; however, when the content is greater than 0.3% the alloy becomes brittle. Oil hardening with subsequent tempering improves the wear resistance of alloys by approximately 30%.

Cast iron blades having the following chemical composition in (%) gave the best results under industrial conditions: C-2.0, Mn-0.53, Si-1.18, S-0.023, P-0.048, Cr-4.70, Ni-0.07, B-0.32, after hardening in oil from 1100°C and subsequent tempering at 200°C for two hours.

Tests on shot-cleaned blades coated with caprone with linings of shock-resistant glass and also cast blades of Silumin impregnated with powdered silicon carbide under the action of ultrasonics indicated their inadequacy in connection with intense wear after 5 minutes of operation. The linings of glass were broken by the impact of the shocks in the first moments of operation. The grinding bodies (balls and cylinders), cast from various cast irons in sand, in metal molds with fibration and the centrifugal method, were tested for strength, shock resistance, and impact fatigue on specially prepared drop hammers. In addition, wear-resistance tests were made on the Kh4-B machine [78, 79]. The best indices were attained with the centrifugal method of casting grinding bodies from unalloyed cast iron with low carbon and silicon content. Balls of low-carbon cast iron were tested for 2 years in industrial silicate plants and proved to have a higher wear resistance than steel by a factor of 3-4. These balls did not heat up while working in mills with a diameter of 2.2-2.5 m.

The abrasive wear resistance of working parts of grain cleaners, disks with pores, was improved by the introduction of tellurium into cast iron [80].

The following amounts of tellurium - 0.005%, 0.01%, 0.015% - were poured into a ladle with liquid cast iron at 1325-1350°C; casting began when the tellurium ceased giving off steam, approximately 30-60 s after it was poured into the cast iron.

The addition of 0.01% tellurium gave a uniform chill to a depth of 1.0-1.2 mm, while 0.15% tellurium gave a continuous chill. Surface purity of disks cast with tellurium added to the ladle was excellent and fully responded to the requirements in the specifications.

An attempt was made to increase the wear resistance of these parts by creating a chilled skin by surface microalloying with small quantities of tellurium. Surface chills of various depth were obtained; however, a surface purity for disks and cells which satisfied specifications was not achieved.

Tests on the abrasive wear resistance of various cast irons in the Kh4-B machine [81, 82] showed that white cast iron had the worst wear resistance. High-strength cast iron with spheroidal graphite, obtained after hardening the martensite structure, revealed comparatively high wear resistance. The least wear resistance was found in high-strength ferritic and pearlitic cast irons after annealing; their wear resistance is near the wear resistance of Armco iron.

The greatest wear resistance in castings was found in high-strength pearlitic cast irons; their wear resistance is near the wear resistance of annealed 412 steel and higher than inoculated cast irons. In some specimens of pearlitic high-strength cast iron wear resistance was lower.

With an increase in hardness the wear resistance of cast iron also increases; however, there are other factors affecting wear resistance which do not affect the hardness of the cast iron. The mechanical properties of cast iron are not connected directly with wear resistance.

The authors of this work note that the mechanical properties determined during tensile testing depend to a considerable extent upon the dimension and quantity of graphite separation, while wear resistance depends chiefly on the structure of basic metallic mass.

Tests made it possible to establish that the relative wear resistance of pearlitic high-strength cast iron increases as a result of hardening by approximately 50% and that the relative wear resistance of white cast iron is somewhat higher than hardened pearlitic high-strength cast iron. No substantial difference was found in the wear resistance of high-strength pearlitic cast irons and inoculated cast irons with the same structure (when comparing them as castings).

Cast irons with ferrite structure, obtained during casting or after annealing, have the lowest wear resistance.

In reference [83] the effect of cast iron structure on its abrasive wear was studied. A method of mutual grinding was used, which made it possible to observe the behavior of materials in the presence of an abrasive layer between working surfaces. The best results with respect to wear resistance were revealed in cast irons with a troostite-sorbite structure obtained by hardening and tempering at 400°C.

Wear resistance increases only when the hardness of the cast iron's metallic base increases. When the content of graphite is the same but the size of the graphite inclusions is larger, wear resistance is less.

Cast iron with spheroidal graphite inclusions is more wear-resistant than it is with flake inclusions when the structure of the metallic base is the same. However, cast iron with fine spheroidal graphite inclusions, with a short distance between them, can have less wear resistance than graphite with larger inclusions of flake form. Thus we can conclude that an attempt must be made to obtain cast iron with troostite or troostite-sorbite structure and comparatively large graphite inclusions, which is difficult in practice.

The abrasive wear resistance of cast iron with spheroidal graphite [53] in many cases is higher than steel with high hardness.

Studies on the abrasive wear resistance of cast iron with spheroidal graphite and a different metallic base (tests on the Amsler machine with sliding friction and a lubricant containing abrasive) of a steel roller along a casing of the tested cast iron, indicated [84] that, under these conditions, the greatest wear was found in pearlitic cast iron and the least in ferrite-cementite. Tests on the abrasive wear resistance of cast iron with spheroidal graphite on a Kh4-B machine [85] indicated that cast iron with spheroidal graphite and a pearlitic structure has significant advantages over inoculated cast iron MSCh 32-52, gray cast iron SCh 21-40, and cast carbon steel 30L. High-strength cast iron with martensite structure had the highest wear resistance, while high-strength cast iron with pearlite structure had lower wear resistance. The more ferrite in the structure of cast iron with spheroidal graphite, the lower its wear resistance. If the wear resistance of steel 50 during abrasive wear is taken as unity, then the wear resistance of other materials will be: white cast iron – 1.71, high-strength cast iron with martensite structure – 1.63, high-strength cast iron with pearlite structure – 1.12, steel 30 – 0.96, SCh 21-40-0.95, and VCh 40-10-0.86.

The amount of abrasive wear in ferrite and pearlitic cast irons with spheroidal graphite after isothermal transformation of austenite at low temperatures (below 350°) changes similarly to the change in hardness and strength limit, while at higher temperatures the change is similar to the change in the amount of residual austenite [86].

The relative wear resistance of pearlitic cast iron with spheroidal graphite subjected to isothermal hardening according to the optimal mode (300°C — 1 h) is somewhat higher than the wear resistance of even white cast iron and cast iron hardened to martensite without tempering, as well as cast irons which are cast, normalized, and temper-hardened. It is assumed that the high abrasive-wear resistance of high-strength cast iron after isothermal hardening is connected not only with the amount of residual austenite. If the wear resistance were increased only because of the drop in residual austenite with the formation of martensite, then cast iron with a predominance of martensite in the structure before testing would not have high wear as compared with isothermally hardened cast iron, the moreso since the hardness of the first is 180-200 kgf/mm^2 higher than the hardness of cast iron after isothermal hardening.

In this work [86] it is indicated that in cast iron, with a certain mode of isothermal hardening, a structure is formed which is capable of being significantly deformed in microvolumes without rupture, with intense work hardening.

The work hardening in the process of deformation during abrasive wear counteracts the breaking off of particles and thereby protects the metal from rupture.

Phosphorus has no effect on the wear resistance of cast iron in a free abrasive [87], while it quite effectively increases the wear resistance during the sliding friction of metal along metal [4, 8-12].

The wear resistance of cast iron significantly increases when alloyed with manganese (below 1.5%) and chromium combined with nickel (1.5% chromium and 0.5% nickel).

The highest wear resistance in an earth mass is found in acicular troostite obtained by isothermal treatment. The smallest increase in wear resistance provides ferrite-carbide mixtures of granular structure, which are formed as a result of temper hardening.

Austenite of steel G13L has very low wear resistance in an earth mass. Austenite of nickel steel N25 is characterized by lower wear resistance than manganese steel, and in steel Kh18N9 austenite has a wear resistance equal to the wear resistance of cast steel G13L [87].

Plowshares are included among the parts which operate under conditions of abrasive wear. These parts, subject to considerable wear, are manufactured in large numbers. In this country the yearly consumption of plowshares is 12 million pieces, of cultivator teeth 8 million pieces [88].

Also quite high is the consumption of cutting parts and milling machines, various cultivators, hillers, teeth of beet-harvesting combines, teeth of potato diggers, and the working parts of other agricultural machines. As the working parts wear, the quality of soil processing drops significantly and operational expenditures increase.

Soils can be rated in the following order based on the degree of wear in working parts:

1) sand and gravel (maximum),
2) clay loam,
3) clay leached by chernozem,
4) medium loam alkaline forest soils,
5) light loamy podzols (minimum).

Plowshares are made from special steel, chilled cast iron, and recently from high-strength cast iron with spheroidal graphite.

A considerable number of studies [88-96] has been made on the wear resistance of cast iron plowshares.

In reference [89] it is noted that the plowshares having the best wear resistance also have a martensite structure. Tests on plowshares in chernozem did not show the same considerable wear as in sandy soil.

Plowshares and shares made from chilled cast iron can be successfully used when there are no impacts [90]. Soil tests on plowshares of high-strength cast iron with spheroidal graphite reveal their usefulness for the Ukrain, Siberia, the land along the Volga, and Belorussia [91]. The service life of plowshares from high-strength cast iron is less, by a factor of approximately 20, than that of plowshares made of cast iron with flake graphite and a chilled cutting edge [92].

Plowshares cast from high-strength cast iron with a thickened nose section can operate in sandy soils as long as they are not also rocky [93]. Cast iron plowshares cast from naturally alloyed Elizabethan or Khalilova cast irons and inoculated with calcium-silicon were recommended in reference [94]. In this same reference it is mentioned that even plowshares from ordinary cast iron can be used in pillage since they are not inferior in operation to steel. Tests have shown that cast iron plowshares are self-sharpening while in use.

Plowshares of high-strength cast iron cast in a metal dye are normalized. High-strength cast iron after such processing is not inferior to steel with respect to strength but is considerably inferior to it with respect to ductility. However, the ductility which can be achieved ensures the operation of plowshares without breakdown [95].

In annealed or normalized state, plowshares cannot have sufficiently high wear resistance to counteract the abrasive wear during friction against the soil. High wear resistance is achieved by hardening the plowshare at spots of highest wear. Local heat treatment is performed, along the cutting surface and the nose section. However, it is important, as indicated in this work, that those parts of the plowshare which are not subjected to hardening also have higher wear resistance. For this reason, the structure of the unhardened part (the back of the plowshare) must not contain a large amount of ferrite. Breakdowns and high wear from breaking off have occurred when the hardness of cast iron plowshares is high (HB--550-600 kg/mm^2).

The wear-resistance coefficient for plowshares from high-strength cast iron can be taken as 0.8 as compared with standard steel of the hardness HB-550-650 kgf/mm^2. High-strength cast iron with martensite structure is not inferior in wear resistance to hardened steel. However the service life of a plowshare is determined not only by the wear resistance but also by the strength and impact toughness; optimal strength and ductility cannot be achieved except to the detriment of wear resistance.

For this reason, cast iron plowshares have approximately 20% lower wear resistance than steel; however, nose section breakdown and cutting edge breakoffs are not observed.

Under the same scale of production, plowshares of high-strength cast iron cast in a metal dye are one-third cheaper than steel [96]. It is certainly of interest to study further the wear resistance of cast iron as a material for plowshares. Obviously, the studies must be directed toward finding wear-resistant cast iron for specific soil conditions.

Studies in industrial conditions have shown [97] that high-strength cast iron can be successfully used for parts of mining equipment.

Reference [98] describes in detail the production process, the mechanical properties, and the abrasive wear resistance of various hard cast irons. It is of considerable practical value to find materials and, specifically, cast irons which are resistant to cavitation damage.

A study on the resistance of cast irons to cavitation wear [99], using a magnetostrictive vibrator, has shown that pearlitic cast iron has very low resistance: weight losses were greater than steel 25 by a factor of 2-3. The resistance of inoculated cast iron (HB-190 kgf/mm^2) was higher: weight losses the same as steel 25. Cast iron with spheroidal graphite had comparatively high resistance; weight loss was 37% the weight loss of steel 25. The resistance of a number of low-alloyed cast irons was low.

Chromium-nickel cast iron and this same cast iron with 1% tungsten had the highest resistance. Cast irons with copper had lower cavitation resistance than gray pearlitic cast iron. Austenite resisted breaking better than the ferrite component of pearlitic cast irons [100].

Reference [101] describes cavitation damage in cast iron containing 3.5% carbon, 2.3% silicon, and approximately 10.0% manganese with a structure of austenite, carbides, and graphite. Damage occurred along the graphite inclusions and on the boundary between the carbides and the austenite. The large surface and the branching of the carbide component intensifies damage. The homogenization of the alloy by multiple heat treatment, which causes some dissolution of carbides in the austenite, increases the cavitation resistance (Table 1). Cavitation damage in austenite occurs along the grain boundaries (just as in ferrite) and is gradually propagated to the grain itself. If there are twins on the austenite grains, the damage occurs along their boundaries.

Table 1. Comparative resistance of cast iron [101].

State of cast iron	Weight loss in mg after each hour of testing						
	1	2	3	4	5	6	7
Cast	337.0	486.4	654.0	935.8	1098.0	1326.0	1402.4
After multiple heating to 1100°C	28.6	50.1	110.0	190.5	240.0	300.0	401.7

Cavitation resistance in austenite steels is determined by the carbon content, the degree of alloying, and the nature of the alloying elements (Table 2).

Table 2. Resistance of austenitic steels [101].

Steel	Hardness, HB kg/mm²	Weight loss in mg after 6 hours of testing
80G14..............................	200	36.4
70N25..............................	141	90.0
40G118Kh4..........................	162	152.0
40G8Kh11N8.........................	190	377.0

As is seen from the data presented, the resistance of austenite can be quite different even when the hardness is almost the same but the alloying is different. Steel 80G14, with manganese austenite, has the highest resistance.

The authors of this work note that when the decomposition of austenite occurs with the formation of martensite, the resistance to cavitation damage increases. It is also noted that heat treatment has an effect on cavitation damage, in addition to the resistance composition of steels, which leads either to the formation of homogeneous structure or the evolution of excess phases, or to a change in the grain size and boundary (Table 3).

Table 3. The effect of heat treatment on cavitation resistance in austenitic steels [101].

Steel	Type of heat treatment	Hardness, HB kgf/mm²	Weight loss in mg every two hours of testing		
			2	4	6
80G14....	Hardening	170	4	22	40
	Aging at 700°C, 70 hours	223	30	155	400
G13......	Hardening	200	3	12	22
	Aging at 700°C, 70 hours	290	20	250	590

Hardening creates a homogeneous structure and thus increases the resistance to cavitation damage as compared with cast steel.

After aging, excess phase is distinguished, hardness increases, and cavitation resistance of steel drops sharply. However, the decomposition of austenite with the formation of martensite structure leads to a sharp increase in the resistance of austenitic steels.

Martensite is of the greatest interest with respect to the resistance to cavitation damage from austenite decomposition products. Because of its homogeneity and considerable hardness, martensite has the highest resistance to cavitation damage.

The smaller the grain size, the less the cavitation resistance of homogeneous solid solutions. Damage begins from the grain boundaries anddepends upon their extent; the latter is greater the smaller the grain. Thus, maximum resistance to cavitation damage occurs with maximum grain size.

During cavitation damage, variations in the fine structure can occur, which are detected under x-ray analysis.

As a result of the cavitation effect, the width of the alpha-phase line [220] of austenitic steel increases, which varies in the initial period quite severely and then stabilizes. After a period of stabilization microfractures appear in the surface and variation in line width cannot be detected. The character of variation in alpha-phase line width [220], as a result of the cavitation effect on chromium-nickel and chromium-manganese steel, is identical.

There are, however, certain differences in the behavior of these steels.

With the same duration of tests, the alpha-phase line for chromium-nickel steel is somewhat wider than it is for chromium-manganese steel. Line width varies as a result of increase in stresses of the second type and the crushing of blocks in the structural mosaic. Disorientation of the mosaic blocks in austenite of various compositions occurs with various intensities. Phase transformations can also occur, as a result of which new phases of a different nature are formed. It is noted that considerable hardening is possible in austenitic steels since it is brought about by both plastic flow and phase transformations.

Austenitic steels fall into two different groups [101]: those which are work-hardened easily and those which are work-hardened with difficulty. Manganese austenite is the easest to harden and nickel austenite the most difficult.

The tendency of austenitic steel toward work hardening also determines its high resistance to cavitation damage. The resistance of manganese austenite is considerably higher than nickel. The cavitation effect increases the hardness; manganese austenite is considerably harder than nickel. The hardening of austenite during plastic flow due to displacement hardening is considerably less severe than that due to austenite decomposition and the formation of new phases.

A study of the magnetic susceptibility of manganese and nickel austenite, depending upon the time of the cavitation effect, shows that, as a result of this effect, a considerable variation in magnetic susceptibility occurs in manganese austenite, caused by the formation of ferromagnetic phases and the change in fine structure. Magnetic susceptibility of nickel austenite is virtually constant depending upon the time period of the test, which indicates an absence of ferromagnetic phases in this austenite as a result of plastic flow.

It is affirmed [101] that displacement hardening plays the chief role in the resistance of nickel austenite to cavitation damage.

As a result of the tests made, it is concluded that the selection of cavitation-resistant alloys should be oriented toward austenitic steels of unstable character and, particularly, to chromium-manganese and chromium-nickel steels. The resistance of chromium-manganese steels is considerably higher than chromium-nickel and nickel-manganese. Chromium-nickel austenite ruptures very intensely and nonuniformly, while chromium-manganese austenite ruptures uniformly over its entire surface.

Other things being equal, the depth of the work hardening in chromium-manganese austenite is considerably greater than it is in chromium-nickel and nickel-manganese.

The authors recommend that the selection of the brand of steel be based on the same assumptions as the selection of cast iron, taking as one of the most important conditions, the selection of the proper structure to ensure the maximum resistance of the steel. This should be based on the following two basic principles:

1) the steel must have a homogeneous structure of a homogeneous solid solution — austenite or martensite;

2) when operating under the effect of plastic flow, the steel must be work-hardened, with a considerable reserve of elasticity.

Although martensite can be work-hardened for the cavitation effect, considerably higher resistance can be achieved for steel if martensite is formed in the process of self-deformation as a result of hydraulic shock.

Medium-carbon, chromium-manganese steels with unstable structure which are work-hardened are best.

Under the joint action of sand and water austenite steels with unstable structure also have an advantage over other types of steels, and for these operating conditions chromium-manganese steels are recommended.

A study of this interesting work reveals the paths to follow in seeking cast irons which are resistant to cavitation damage under the joint action of water and sand. Such cast irons can be manganese alloys with an unsuitable austenite structure, which tends toward displacement and phase hardening, and spheroidal graphite. Thanks to the homogenizing effect, hardening of these alloys should improve their resistance to cavitation damage.

References [101, 102] indicate that the chromium-manganese alloy 30Kh10G10, whose austenite during cavitation decomposes generally with the formation of martensite (E-phase can occur partially), possesses high cavitation resistance.

Chromium-manganese alloys [103] have higher cavitation resistance than nickel-manganese alloys. In chromium-manganese alloys the structure ($\gamma + \varepsilon$), obtained during heat treatment, provides significantly less wear resistance than the single-phase structure of austenite which can undergo phase transformations.

When alloying an alloy of iron and 20% manganese with nickel, the reverse relationship was observed: two-phased alloys appeared more stable than single-phased alloys with a structure of unstable austenite. Thus, cavitation resistance depends not only upon the initial structure of the alloy and the phase transformations which occur during strain, but also, chiefly, on the character of the solid solution alloying which determines its resistance to microshocks. Chromium-manganese austenite, in this respect, considerably surpasses nickel-manganese. It is noted that in the first, rupture proceeds more uniformly than in the second. The formation of ε-phase and its reverse transition into austenite during cavitation contributes to stress relaxation, which increases the resistance of alloys. This explains [103] the slower damage of unstable austenite as compared with stable.

Reference [104] indicates that the manganese austenitic alloy G38 with various types of damage is more intensely work-hardened than the nickel alloy N36. The alloy G38 surpasses the resistance of the alloy N36 not only in water but also in liquid lead [105].

The high anti-corrosion properties of metal cannot serve as a criterion either for the cavitation effect in water or in melt. Cavitation-erosion damage in cast irons was studied in reference [106]. It was found that cast iron with spheroidal graphite has considerably more cavitation-erosion resistance than a cast iron with flake graphite.

Unlike cast iron with spheroidal graphite in which damage has a local character, in cast iron with flake graphite cavitation-erosion damage occurs throughout. This explains the low cavitation-erosion resistance of cast iron with flake graphite [106, 107]. The metallic base of cast iron must have a certain combination of hardness and ductility.

A pearlite, bainite, and sorbite (tempering) metallic base ensures the highest resistance to cavitation-erosion damage for cast iron with flake graphite. For cast iron with spheroidal graphite the highest resistance to this type of damage is obtained with a bainite, martensite, and sorbite (tempering) metallic base.

Cast iron alloyed with 1% nickel and 0.28% molybdenum possesses significantly higher cavitation-erosion resistance than unalloyed cast iron.

The hardness of alloyed and unalloyed cast iron with the appropriate heat treatment is identical. However, cast iron alloyed with 1% nickel and 0.28% molybdenum has a higher cavitation-erosion resistance than unalloyed cast iron. Cast irons with austenitic structure and graphite of flake and spheroidal form are of great interest as material for parts operating under wear.

Data are available concerning the high wear resistance of austenitic cast irons containing chromium, nickel, copper [108-111].

An austenite sleeve for an internal combustion engine, cast from cast iron containing nickel, chromium, and copper, had a decisive effect on the service life of the engine. Not only was the wear of the case itself reduced but also the wear of other parts such as, for example, piston rings and connecting rod pins [112].

According to other data, austenitic cast iron containing the same alloying elements has shown a wear resistance five times higher than unalloyed cast irons [19, 113].

Reference [114] concerns the wear resistance of cast irons (gray inoculated with ferrosilicon, low-alloyed and austenitic, containing nickel, chromium, and copper) studied under laboratory conditions and operating conditions. Laboratory tests were made on a sliding friction machine with reciprocal motion, which produced damage of the metallic surfaces by seizing. Test conditions were as follows: specific pressure – 70.0 kgf/cm^2, speed – 0.33 m/s, lubricant – kerosene (3-5 drops per minute), duration of test – 3 hours.

The wear resistance of the friction pair gray cast iron and steel is less by a factor of 1.8 than for the same combination with inoculated cast iron, is less by a factor of 2.43 than this combination with low-alloyed cast iron, and is less by 4.35 than with austenitic cast iron.

Thus austenitic cast iron had the best wear resistance. In addition to laboratory studies, tests were made under operating conditions on GAZ-MM motors installed in passenger cars – taxies which have undergone major repairs. All test motors had standard piston rings of gray pearlitic cast iron. Wear in sleeves of austenitic cast iron was less by a factor of 1.8 than in sleeves of gray cast iron and by a factor of 1.1 than in sleeves of medium-alloyed cast iron. Wear of piston rings in sleeves of low-alloyed cast iron was less by a factor of 2.3, and with sleeves of austenitic cast iron by a factor of 3.9, than with sleeves of gray cast iron. Pistons with sleeves of austenitic cast iron wore 1.9 times less than with sleeves of low-alloyed cast iron. These data proved conclusively the advantages of austenitic cast iron. There is also information of interest on the use of forgings of austenitic manganese cast iron for making links for the caterpillars of tanks [111]. A melt of these cast irons was made in a cupola with ferromanganese, melted separately, added into the ladle, in an electric furnace, by the duplex method. Molding and lining of parts was accomplished as with pearlitic malleable cast iron. Then decarburizing annealing was performed in a gaseous medium at a temperature of 1050-1075°C for 40 hours with subsequent hardening directly from the furnace or after repeated heating. The mechanical properties of an unalloyed brand after annealing are as follows: strength limit 35-42 kgf/mm^2 with an elongation of 15-20% (sample diameter 50 mm). Surface hardness after annealing is 250-300 units and after work hardening is 600-650 units, using the Vickers scale. The wear resistance of such cast iron was not inferior to the wear resistance of austenitic manganese steel.

The long process required to obtain this cast iron, in spite of the high quality and high resistance, naturally limits its use.

In addition to data on the high wear resistance of austenitic cast irons with flake graphite, there is some information on austenitic cast irons with spheroidal graphite containing nickel and chromium [115-117], as well as nickel, chromium, and copper [118].

The possibility is discussed of introducing into production jet engines of austenitic cast iron, Ni-resist, with spheroidal graphite which is characterized, in the cast state, by the following values: $\sigma_B = 39.0 + 44.0$ kgf/mm^2; $\sigma_y = 20.0 + 27.0$ kgf/mm^2; $\delta = 10 + 20\%$; HB = 120 + 170 kgf/cm^2. High corrosion resistance and high-temperature strength are characteristic of this cast iron [115]. Reference [116] describes austenitic cast iron with spheroidal graphite, 18.0-22.0% nickel and 2.0-2.5% chromium. Another work [117] discusses the use of this same cast iron for making parts for chemical equipment of paper-making machines, bearing journals for jet engines, and other parts which operate at high temperatures. Reference [118] is a study of 7 specimens of austenitic cast iron with spheroidal graphite.

These cast irons had the following contents (in %): C – 2.6 + + 2.8; Si – 1.72 + 4.25; Mn – 0.95 + 1.92%; P – 0.03–0.05; Ni – 15.90 + 32.62; Cr – below 1.18; Cu – below 3.90; Mg – 0.07 + 0.134.

The indices of mechanical properties in austenitic cast irons with spheroidal graphite are considerably higher than those cast irons with flake graphite. These indices are even better after normalization. Especially good indices are found for cast irons containing (in %): Cr – 1.1; Cu – 3.9; Ni – 17.26 ($\sigma_B = 55.0$ kgf/mm^2) $\sigma_y = 30.0$ kgf/δ – 25%; bending deflection = 3.6 + 3.8 mm and Mesnager Ak = 2.17 kgf m/cm^2 before normalizing and 2.88 kgf m/cm^2 after normalizing.

The corrosion resistance of austenitic cast irons with spheroidal graphite is the same as the resistance of cast irons of the same composition but with flake graphite, while the high-temperature strength of austenitic cast iron with spheroidal graphite is considerably higher.

It has been mentioned [12] that austenitic cast iron has heat resistance up to 600°C, good friction resistance with respect to EYalT steel and other steels, and a high coefficient of linear expansion (near that of EYalT steel). For this reason, austenitic cast iron (alloyed with chromium, nickel, and copper), in spite of its high cost, is used for making sleeves for internal combustion engines in automobiles and also parts which operate at low temperatures in refrigerators since it is not a cold-short metal. Austenitic cast iron resists well the action of sulfuric and hydrochloric acids [112, 119]. It has low magnetic permeability, as well as high specific electrical resistance, is nonmagnetic, and is used in electrical machine building for making various parts. In its magnetic properties, austenitic cast iron is scarcely inferior to such nonmagnetic metals and alloys as copper, aluminum, and brass, and significantly exceeds them in electrical resistance [118]. Thus, as is seen from the examined references, austenitic cast irons containing nickel, chromium, and copper possess a group of properties which make this material extremely valuable in the manufacture of various machine parts.

However, the high cost of these cast irons limits their use to a considerable extent. For this reason, nickel is partially or completely replaced by the cheaper manganese and copper.

A partial replacement of nickel with manganese has been proposed in reference [120]. The castings had a martensite structure. Austenitic structure was obtained by heating the castings to 950-1000°C and hardening them in water.

The complete replacement of nickel with manganese, copper, and aluminum has been proposed by a number of authors [121-127]. These cast irons, as nonmagnetic material, have found application in electrical machine building.

Based on studies of austenitic manganese cast irons under laboratory conditions, we have found that they are more wear resistant than many other types of cast irons during friction without lubrication [128].

A comparison of the wear resistance of austenitic manganese cast iron and austenitic cast iron with chromium, nickel, and copper has shown that the wear resistance of the former is higher [125].

Data from experience in plants indicate that the replacement of ordinary pearlitic cast irons with austenitic manganese cast iron increases the service life of parts (small conical pinions, wheels of pouring conveyers in foundries, etc.) by a factor of 2-3 [128, 129].

The authors of these works have studied austenitic manganese cast irons with additions of copper and aluminum and flake graphite in cast state.

It is of interest to study the wear resistance of austenitic manganese cast iron with flake and spheroidal graphite in various conditions of wear (sliding friction without lubrication, with lubricant, with lubricant and abrasive, with abrasive friction, etc.).

In references [130, 131] we have shown the high wear resistance of austenitic manganese cast irons during sliding friction on a MI machine with a roller of hardened steel along a race of the tested material without lubricant at various specific pressures.

Austenitic manganese cast iron with spheroidal graphite has, under these conditons, especially high wear resistance.

Austenitic manganese cast iron has considerably higher wear resistance than ordinary high-strength and gray cast irons. A substantial difference was found between austenitic cast irons with spheroidal graphite and austenitic cast irons with flake graphite as well as between high-strength and gray cast irons.

It has been said that the process of wear in austenitic cast irons, due to the compact crystal lattice of austenite, its great ductility and the wear products forming, its corrosion resistance and tendency toward work hardening connected with the transformation of austenite into martensite, occurs differently than it does in gray cast irons which do not possess the above properties and are more brittle.

In addition, there must be a substantial difference in the breaking-off process of metal particles during friction and wear in cast irons with spheroidal and flake graphite.

It is natural that particles break off more easily with flake graphite than with spheroidal graphite.

Analyzing the above reference data and also the results of our studies, we can reach a conclusion concerning the high wear resistance of austenitic manganese cast irons with flake and spheroidal graphite. However, many questions remain unanswered; there are no fundamental studies of this valuable material.

Depending upon the wear conditions, it is possible to create, with various structures, austenitic manganese cast irons which would have good antifriction properties and wear resistance.

With sliding friction the desirable structure of cast iron is a structure with a small amount of carbide and a considerable carbon content in the form of graphite in an austenitic metallic base.

With abrasive wear, obviously, a wear-resistant structure would be austenitic cast iron with a large amount of carbide and spheroidal graphite in an austenitic state. Cast iron with an unstable austenitic structure containing magnesium and cerium would have high resistance to cavitation and erosion-cavitation damage.

Subsequent thorough studies of austenitic manganese cast iron under various conditions make it possible to determine the area of its efficient use in industry.

Analysis of the properties of cast irons used in making parts which operate under wear leads to the following conclusions.

1. Antifriction cast irons, in spite of the fact that they are relatively inexpensive, have found comparatively little application since they have low wear resistance compared with other materials.

2. Antifriction cast irons include the pearlitic cast irons: gray, inoculated, high-strength with spheroidal graphite, and wrought iron (unalloyed and alloyed). It is recommended that these cast irons have a considerable amount of graphite.

3. Pearlite is the base of almost all antifriction cast irons. Ferrite has the lowest wear resistance. Cementite makes cast iron brittle and causes considerable wear of the coupled part (shaft). The phosphide eutectic in cast iron plays a double role: when there is a substantial deposit of it in the metallic base, it reduces wear (having high characteristic resistance to wear); when it breaks off and crumbles, it is an abrasive and considerably increases wear.

4. The graphite in cast iron has a very significant effect on its strength, antifriction properties, and wear resistance; on the one hand, it contributes to the breaking up of metal particles during wear and, on the other hand, it is a lubricant which counteracts wear and contributes to the adsorption of the liquid lubricant on the working surfaces.

5. Alloying cast irons with a small amount of chromium, nickel, titanium, copper, molybdenum, manganese, and other elements does not significantly improve antifriction properties and wear resistance. Some improvement in properties is achieved by alloying cast irons with sulfur and antimony.

6. High-strength cast iron with spheroidal graphite has been found to have good antifriction properties and high wear resistance as compared with other types of cast irons.

The wear resistance of high-strength cast iron with spheroidal graphite is often higher than that of tempered steel. The wear resistance of this cast iron can be further improved with heat treatment.

7. In order to work under conditions of abrasive wear, hard white cast irons are used, alloyed with boron, titanium, nickel, molybdenum, manganese, chromium, and tellurium.

8. With cavitation wear pearlitic cast iron has very low wear resistance. High-strength cast iron with spheroidal graphite has comparatively high wear resistance with this type of wear. Having the highest wear resistance under these conditions is a homogeneous structure of unstable austenite, which undergoes transformation into martensite under strain. Manganese austenite, alloyed with chromium, is the most wear-resistant.

9. Under the joint effect of sand and water austenitic alloys with unstable structure also have the advantage over alloys of other types. For these conditions, chromium-manganese steels are recommended.

10. It can be assumed that cast irons which are resistant to cavitation wear, as well as to the effect of sand and water, must be alloyed with manganese, have a structure of unstable austenite, and tend toward displacement and phase hardening.

11. Austenitic cast irons alloyed with nickel, chromium, and copper have high wear resistance; however, they are expensive and, for this reason, their use is limited. Austenitic manganese cast irons are considerably cheaper than austenitic cast irons alloyed with nickel, chromium, and copper and, in many cases, more wear-resistant.

The study of wear resistance in manganese cast irons under various types of wear has considerable theoretical and practical value.

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13. ABSTRACT

The use of antifriction and wear resistant cast irons in machine construction is reviewed. Influence of graphites and alloying elements on their properties is discussed. Of major theoretical and practical value is the wear resistance study of Mn-contg. cast irons ( ) [AT0021862]

14. KEY WORDS	LINK A		LINK B		LINK C	
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Cast Iron						
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