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NEW MATERIALS FOR SHIPBUILDING

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NEW MATERIALS FOR SHIPBUILDING

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This publication contains a partial translation of the Russian-language book Novyye Materialy dlya Sudostroyeniya (English version above), by Lev Yakovlevich Popilov, Leningrad, Sudostroyeniye Publishing House, 1966, pages 1-50.

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Only steels and (stainless steels) are covered in this report.
mechanical properties
etc

→ p'

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ANNOTATION

The book describes the principal properties of a large number of new and very new technical materials for domestic and foreign industry, including materials for shipbuilding, ship machinebuilding and instrument-making. P 15

An examination is made of relatively well-known shipbuilding materials (high-strength steel, heat-resistant alloys, alloy bronzes, precision alloys, solders, etc.), less well-known metalloceramics, cermets, carbon-graphites, special ceramics, antifriction materials, etc.), and also those materials that thus far have not been used, but that can find application in the very near future (micrometals, electroluminescent enamels, intermetallide alloys, etc.).

Data given in the book intended first of all to expand the technical outlook of shipbuilders can to some extent serve as a handbook, relieving the reader of the need to search himself for information in many scattered sources.

The book is designed for designers, technologists, and specialists in material and technical supply services in the shipbuilding industry, and also can be used by workers in related branches of industry and by students in the relevant VUZ [vyshyye uchebnyye zavedeniya; higher educational institutions].

SYMBOLS

σ_B = tensile strength, kg/mm^2, kg/cm^2
σ_{Γ} = tensile creep limit, kg/mm^2, kg/cm^2
σ_{bend} = bending strength, kg/mm^2, kg/cm^2
σ_{comp} = compression strength, kg/mm^2, kg/cm^2
σ_{-1} = fatigue limit in cyclic loading, kg/mm^2, kg/cm^2
δ = elongation, %
ψ = reduction in area, %
a_H = specific toughness (kgm/cm^2; kgcm/cm^2)
E = modulus of elasticity, kg/mm^2; kg/cm^2
HB = Brinell hardness number
γ = density, g/cm^3
α = coefficient of linear expansion, micrometers/°C
B_r = residual induction, gauss
ρ = specific electrical resistance, ohm·mm^2/meter
H_c = coercivity, oersteds
(BH) = magnetic energy, gauss·oersteds
f = coefficient of friction
λ = thermal conductivity, cal/cm·sec °C; kcal/m·hr °C
μ = magnetic permeability, gauss/oersted

FOREWORD

In the past decade the assortment of materials used in shipbuilding has been much expanded[1].

Wood and steel, in the past the main shipbuilding materials, have for quite some time now been supplemented with light aluminum-based alloys, shipconstruction concrete, and lately by a large group of nonmetallic materials based on synthetic resins, and some alloys of titanium.

Metallic alloys of desired properties (precision alloys) play a marked role in marine machinebuilding, including antifriction heat-resistant, corrosion-resistant, and special nonmetallic materials, of organic and inorganic origin.

Given the radical modernization of modern facilities of marine electrical equipment and communications, navigation (including radar), and also the sweeping automation of technological processes of ship construction and control operations, it is necessary to use many new electrotechnical, radiotechnical, and special materials.

The number of finishing, paint and varnish, heat insulating, sound insulating, protective (from biological growths and corrosion), and other materials has increased.

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[1] Here and below the term shipbuilding designates all areas of science and technology associated with the erection and operation of ships (ship hull-construction, machinebuilding, instrumentmaking, ship electrical equipment and communications, ship power engineering, etc.) approximately within the framework of the complex reflected in the branch scheme of the universal decimal classification (section in *Sudostroyeniye, vodnyy transport i smezhnyye voprosy nauki i tekhniki* [Shipbuilding, Water Transport, and Related Questions of Science and Technology], Sudostroyeniye Publishing House, Leningrad, 1964.

The changeover to use of atomic energy in marine power plants has made it vital to use a large number of new materials that are resistant to radiation, serving design, protective, technological, and other functions.

The substantial expansion of the selection of shipbuilding materials has been attended by an increase in the number of publications devoted to their properties and applications. In recent years, the Sudostroyeniye Publishing House alone has released several dozens of books and booklets devoted to materials (S. S. Kanfor, Korpusnaya stal' [Hull Steel], 1960; L. S. Moroz et al., Titan i yego splavy [Titanium and Its Alloys], vol. 1, 1960; K. Ya. Zhilinskiy and O. I. Raush, Spravochnik po sudovoy teploizolyutsii [Manual on Marine Heat Insulation], 1963; A. I. Pavlov and Ye. L. Poting, Primeneniye alyuminiyevykh splavov v sudostroyenii [Use of Aluminum Alloys in Shipbuilding], 1961; B. A. Arkhangel'skiy, Plasticheskiye massy [Plastics], 1962, etc.)

But the literature dealing with a more probing examination of the properties and applications of individual materials, as a rule, is intended for specialists working in fields associated with the use of these materials, predominantly for scientific workers, researchers in plant laboratories, etc.

This literature is a bit too specialized for wide circles of production technologists, designers, supervisory technical personnel, and economists, demands extra time for its selection and study, and in actual fact is rarely used by them. And popular booklets and textbooks on material science contain generally information only on materials already widely used and quite well-known, but they almost never examine new materials.

As a result, the situation has evolved in which designers and shipbuilder-technologists, well oriented in matters of properties and application of widely accepted "old" shipbuilding materials, have available to them very limited facts about the flood of new, recently applied, and specialized materials, though the significance of the new materials in modern technology is steadily mounting and familiarity with them is obligatory for any specialist.

A consequence of such a situation is the inadequately well-timed or limited incorporation of many new materials into shipbuilding, since facts about them percolate down to wide circles of specialists relatively slowly.

So, it appears worthwhile to produce a book that occupies an intermediate position between specialized scientific monographs devoted to individual kinds of materials (titanium, hull steel, construction plastics, etc.) and popular booklets or textbooks in which information is gathered without special detailing about the whole gamut of new materials of interest to the shipbuilder.

Such a book intended for persons not specializing in questions of material science, but in need of broadening their technical outlook must give an essential minimum of information in the most convenient form.

Moreover, in communicating to a wide circle of shipbuilders the initial information on the very rich plenitude of materials available to modern technology, the book will contain bibliographic references for a deeper study of individual areas.

An incidental task of the book is passing on to instructors in material science in shipbuilding educational establishments factual information supplementing the curriculum, since textbooks, due to the size of the program, cover only a most limited range of questions of today's material science.

We note that difficulties were met in deciding on arrangement of material in the book.

Two methods can be used in presenting such a variety of information: group different materials by their purposes (hull, machinebuilding, finishing, etc.) or merge them by composition and properties (metallic, nometallic, etc.).

The author preferred the second method, bypassing many repetitions and affording easier access to the needed material, the more so in that the field of application of a given material cannot be held as strictly permanent and the scope of articles manufacturable from this material is continually changing and widening.

A detailed bibliography affords speedier location of information on materials, as does also a detailed table of contents.

Due to the large volume of information presented, the book is divided into two parts. The present, first, part contains information on metallic and nonmetallic inorganic (mineral) materials.

The second part examines synthetic, organic, and specialized materials (natural and synthetic rubber, cements and sealing agents, plastics, radiation protection materials, optical materials, ship paints, inhibitors, surface-active compounds, ion-exchange resins, specialized electrotechnical materials, organic coolants, luminescing materials, etc.).

Since the book offered the reader is the first attempt to give information about new materials to a wide circle of shipbuilders, it naturally is not without shortcomings, and the publisher and authors will be extremely grateful if these are called to their attention.

INTRODUCTION

In surveying a century and a half of progress in hull-construction, starting with the construction of the first ship, the Vulcan (1819) in Great Britain, with a metal hull, and up to the launching of the atomic icebreaker Lenin in the USSR, we can be guided by observing several principal stages.

The beginning of the first stage can, approximately, be held to be the 1820's -- the birth of metallic shipbuilding. The main material for building of hulls during this period was puddled iron, a material of nonuniform composition and properties, the requirements for which had just begun to be specified at that time.

The second stage, starting in the 1860's, was the transition to the wide use of Bessemer sheet steel, and then -- open-hearth steel of higher quality.

The long period from the end of the last century to the 1940's, during which the main material in hull construction was open-hearth steel and in small amounts, for example in the Russian fleet, low-alloy, stronger steel, is the third stage in the development of metallic shipbuilding.

Practical use of light aluminum-magnesium alloys in shipbuilding got underway in the 1930's. Though attempts at using aluminum, and then its alloys, in shipbuilding were first made much earlier, their use began to be noticeable only after sufficiently strong, corrosion-resistant, and workable aluminum alloys were formulated.

Characteristic of the contemporary period, whose beginning can be set tentatively at the close of the 1950's, is the universal application of high quality carbon and low-alloy steels and the transition to new hull materials -- high-strength and special steels and alloys, nonmetallic construction materials, in particular, armored plastics, special concretes, etc.

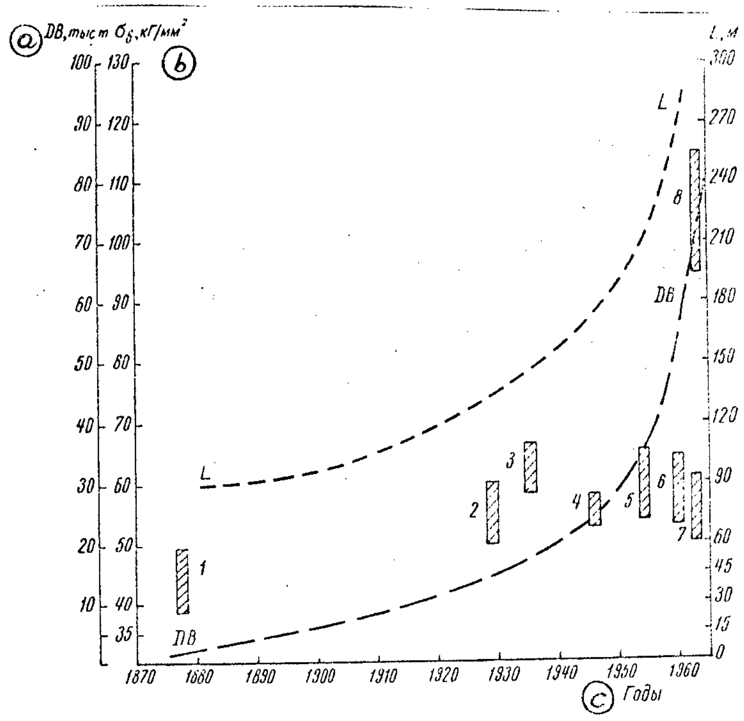


Figure 1. Variation of strength indices of construction steels and certain ship characteristics for 1920-1960.

-------- ship length, L, meters; — — —-- deadweight, tons; 1-8 σ_B values of hull steels during this period.

LEGEND: a) 1000's of tons; b) kg/mm^2; c) years.

Chronologically, each of the above-cited stages, characterized by qualitative changes in shipbuilding, coincideswith qualitative changes in metallurgy and the chemical industry producing the corresponding materials. The appearance of new materials opened up new potentialities for the designer, and the devising of new designs calls for improving the properties of materials or the formulating of new materials.

In noting the exceptional complexity of operating-technical characteristics of ships as functions of properties of materials used in construction, we point to the similarity of the nature of enhancing strength characteristics of steels and operating indices of ships. In Figure 1, illustrating this similarity, this is pointed out not only by the parallel course of curves different in character, but also by the abrupt jump in all indices in the relatively brief period of 1950-1960, reflecting key technical changes occurring during this period and closely associated with the use of new materials.

The complexity of change in indices compared in Figure 1 allows us to see how substantial is the improvement in properties of hull materials for technical progress in shipbuilding.

Similar functions, though much harder to display, can be established for materials of marine machinebuilding, marine electrotechnology and power engineering, and marine instrument-making.

Use of stronger or new shipbuilding materials, especially strongly developing in the past decade, reflects substantial technical and economic changes taking place in domestic and foreign shipbuilding: the transition from riveted ships to wholly welded ships, new forms of organization of shipbuilding production, and new technology affording, for example, working with materials of enhanced strength and greater thickness, increase in water displacement and operating speeds of series-produced ships, specialization of ships by types of cargoes, etc.

We will enumerate the main directions in improving shipbuilding materials typical for all technical materials over the past few decades, namely:

1) Growing complexity and differentiation of demands on properties of materials.

2) Specialization of properties and increase in assortment of materials applicable in industry.

3) Growth in use of synthetic materials and reduction in the proportion of natural and artificial materials in general consumption.

4) Expansion of the range of industrially used materials and their incorporation of almost all known elements; also, the broader use of industrial wastes as technical materials.

5) The mounting influence of the nature of materials used on their technological processing and the technological compatibility of structures.

6) The steady development of new methods and means of striving to increase reliability and longevity, preservation, and economy in construction materials.

We will consider each direction briefly.

1) Technical demands placed on shipbuilding materials are growing steadily more complex.

Thus, for example, while at the close of the last century the requirements on quality of shipbuilding hull steel were limited only to setting the standards of the main chemical composition and also such indices of mechanical properties, as strength and relative elongation, at the present time requirements on hull steels are governing already a considerably greater number of property indices, for example: deformability, critical temperature of brittleness, appearance of fracture and extent of fibrousness, size sensitivity of toughness, temperature reserve of toughness, good weldability, explosion-resistance, resistance to notch corrosion, and many others.

Since the scale of shipbuilding production has risen, and its organization and technology have been improved, ever greater importance is marking such characteristics of materials, as stability and reproducibility of indices of properties, accessibility of material in large quantities, moderate cost, technological compatibility, etc.

2) Intimately related to the first direction, essentially mirroring its requirement, is the second main direction in improvement of shipbuilding materials -- specialization of properties and expansion of their assortment.

This direction to some extent characterizes the level of technical progress in the area of formulating new materials and improving the properties of already existing materials.

The effort to attain maximum correspondence between material properties and technological and operating requirements leads to the buildup of extensive "families" of materials, with a common foundation, but so specialized that essentially they can be viewed as new, independent materials.

A graphic illustration of this can be found in a widely used material -- glass. Whereas relatively recently only a few modifications of glass found extensive use (window, construction, optical, and ship), now the "family" of glass numbers more than 40 modifications, including those so differing in properties as foam glass, fiber glass, heat-resistant glass, electroconductive glass (heating), ultrastrong glass, radiation-protective glass, glass of variable transparency, etc.

Similar examples are not hard to bring up when referring also to other materials -- steel, rubber, concrete, ceramics, etc.

Specialization of materials is a progressive trend; it eases the choice of material that has optimal properties and that affords the building of the most rational structures.

3) As has already been stated above, a steady growth in applications of synthetic materials has been observed, together with a reduction in the proportion of natural and artificial materials in general consumption. As examples, we can cite the replacement of natural rubber, natural wool and silk with synthetic counterparts, edible oils -- with synthetic products in detergent compositions, etc.

Such a substitution, ensuring that materials are obtained with higher and more precisely controlled properties than in natural materials, at the same time provides substantial technical and economic benefits.

At present, in shipbuilding this trend is clearly in evidence, for example, in the transition from metallic hull-building based wholly on an artificial material -- steel, to plastic construction, based on the broadest use of synthetic resins, or in the replacement of plant cables, ropes, cotton fabric, cork, etc. with materials of synthetic fibers, foam-plastics, etc.

We recall that synthetic materials have the following advantages over natural and artificial materials: the possibility of their manufacture with precisely desired properties; diversity of valuable technical properties in the same representative (for example, in fluoroplastic), which affords their use where many natural materials are inapplicable; ease in fabrication (good workability); unrestricted reserves of raw material; low labor load in manufacturing, etc.

4) The number of industrially used materials is rising steadily.

The expansion of the range of industrially used materials is following several routes. One is the industrial application of such materials that until quite recently found no practical use. The most graphic example can be cited in the use of titanium and its alloys as a high-quality construction material. Titanium, still wholly unknown as a construction material until fairly recently, right now enjoys wide application. In the US industrial production of titanium began only in 1948. By 1957 its output has climbed to 15,600 tons a year, and by 1980, based on preliminary figures, its production must surpass 200,000 tons.

Wide use has lately been found for many rare and widely scattered elements. Among these, for example, are gallium, obtained as one of the byproducts in pouring of aluminum (each 50,000 kg of ore contains 1 kg of gallium); germanium, the production of which for a concentration in the ore of 0.001-0.002% is already industrially profitable; lanthanum (average content in the earth's crust 0.00035%); cerium (0.0015%); rhenium, serving as an additive in heat-resistant alloys; niobium -- an additive to steel; lithium, used in lubricants; beryllium -- the base of heat-resistant alloys of high elasticity; tantalum -- a metal of high chemical stability, etc. The output of niobium in the US in 1958 was 30 tons, but from recently published data its production in the very near future is projected to rise to 10,000 tons a year.

Increasing the number of industrially used materials is afforded also by the comprehensive utilization of raw material and waste -- typical for today's conditions.

Thus, for example, aluminum, until recently the main product obtained from nephelin ores, is now simultaneously added to alumina, soda, potash, Portland cement, gallium, etc. Thallium and tellurium, selenium and goal, arsenic, copper, and other elements, obtained from the waste of sulfuric acid production, are a thousand times more expensive than the main product -- sulfuric acid. Ethylene, contained in effluent gases, is the main raw material for obtaining synthetic resins and plastics -- polyethylene, fluoroplastics, and other products. Germanium is extracted from the ash of anthracite coal; metallic slags serve as the starting raw material for production of mineral wool, square beams [bruschatki], cast articles, cement, fertilizers, etc.

5) The nature of materials used influences technological processes involved in their manufacture and the technological compatibility of structures.

In marine machinebuilding wide use is made of metalloceramic hard alloys for manufacturing cutting instruments, presses, press molds, and other articles. The difficulty in processing these materials by ordinary methods has served as one of the causes underlying founding of several new divisions of technology -- electrophysical, electrochemical, and ultrasonic methods of processing, in whose use the hardness of material being worked on already no longer influences the processing rate, as, for example, hardness does in mechanical cutting.

Use of hard-to-work and titanium alloys entailed development and introduction of such new technological methods as chemical milling, explosive stamping, electromagnetic form-making, cutting in inert gas atmosphere, etc.

Use of infusible materials has led to industrial mastery of methods of electron-beam piercing, fusing and welding; plasma cutting, welding, and application of coatings; quantum-optical processing, etc.

In their turn, all these new processes, completely altering customary ideas of technologists about the relationship between strength of the instrument and the articles being worked on, about the effect of hardness on workability, etc., following their mastery afford the development and application of new, still stronger and harder materials, thus promoting the devising of new, improved structures.

6) Development of new methods and means of increasing reliability, longevity, and economy of construction materials is a continual process in shipbuilding -- from the first days of its inception.

We note that in addition to design and technological procedures of ensuring reliability, longevity, and safety of ships, these qualities can be attained also by the proper selection and employment of materials, particularly new materials, without any particular deterioration in economic indices. For example, use of clad steel (stainless + carbon) instead of simple carbon steel for manufacturing hulls of ships considerably adds to their longevity, reducing corrosion damage; replacement of the cork used as heat insulating material with nonflammable synthetic foam- and poroplastics increases the safety of ship operation and prolongs the service life of the insulating structures; replacement of metallic screw propellers with plastic counterparts increases their erosion resistance and leads to sizable economies in nonferrous metals; use of corrosion inhibitors often affords a way out of using less effective and more costly protective coatings.

Use of these potentialities in the simultaneous use of design and technological ways of increasing ship reliability and longevity makes it possible to attain also a marked economic benefit, which is vital in the present situation due to the steady growth in the capacities of the shipbuilding industry and the struggle to improve economic indices in all levels of the national economy.

As an example we can cite the use of the easily weldable steels of grades 08GDNL (SL-30) and 08GDNFL (SL-2), etc., for manufacturing welded hull structures (stems, stern-posts, and foundation frames) instead of cast articles made from steels of limited weldability. New steels, not requiring heat treatment either prior to welding, or after, afford a reduction in weight of structure, retaining desired strength, and reducing the labor involved in its fabrication.

A similar example can be found in the replacement of stainless steel with bilayer carbon, modified cast iron or with light alloys.

For the sake of greater objectivity, we note that in many cases the transition to use of new materials, unquestionably technically progressive, is accompanied by temporary or local deterioration of economic or technological indices. Thus, new materials, especially at the outset of their mastery, cost somewhat more than widely used standard materials that have been mastered by industry, and of which there is no shortage.

Use of new materials is often severely complicated owing to the greater difficulty of their workability, need to use special measures to shield them against oxidation, development of special technological processes (thermal, chemical, and electrical processing) and increase in the number of conversions in the operations involved.

Appropriately, the changeover to use of new materials requires in many cases modernization or replacement of the main technological equipment by more powerful units (for example, presses, cutters, and bending machine tools), or by special (vacuum furnaces, electrophysical machine tools, "clean" shops and chambers, etc.) units.

Changes in technological processes, especially under conditions of individual and small-size series production, such as shipbuilding is, add to the labor load and cost of working on parts and articles and also require use of workers of higher qualifications and a substantial rise in the proportion of labor of engineering-technical personnel in construction of the ship. But, in spite of all these difficulties and costs associated with use of new materials, their use ultimately gives sizable technical advantages and as a whole is extremely effective.

Use of new materials in shipbuilding makes it possible to improve tactical and technical characteristics of ships, increase their reliability and longevity, maneuverability, increase the ship's speed, cut down on operating costs, and reduce weight. All this opens up possibilities for building new more improved and more complex structures.

CHAPTER ONE

STEEL AND NICKEL- AND COPPER-BASED ALLOYS

Steel still remains the most widely used material in shipbuilding. Thus, based on literature data the consumption of metals in US shipbuilding in 1960 was as follows.

	Consumption in percentages of total use of metals
Steel:	
carbon	66
alloy	25
Copper and its alloys	5
Other metals and alloys	4

Carbon and low-alloy steels are the main material for manufacture of hulls of metallic ships, marine mechanical equipment, anchor, mooring, and other marine assemblies, fittings, technological rigging of shipbuilding enterprises, etc. Alloy steels are being more widely used in manufacture of marine reinforcement, screw propellers, submerged vanes of high speed ships, in marine turbine- and engine-building, for parts of navigation devices and equipment, parts of marine mechanisms, etc.

To ensure reliability and longevity of hulls of modern ships, especially large ships, it is necessary to use steel exhibiting increased toughness and strength, the capacity to withstand spread of cracks and to some extent prevent their inception. These steels are characterized by high toughness and low critical temperature of brittleness; they must be welded satisfactorily, must not cause additional technological and design difficulties in ship construction, and must ensure the necessary fatigue strength of the hull.

Improving properties and compositions of shipbuilding steels is one of the conditions for developing metallic shipbuilding; the pace of this improvement has risen sharply in the past few decades.

In modern shipbuilding, a trend has arisen in which application is made of steels exhibiting improved mechanical properties, good technological compatibility, adequate corrosion resistance, and which are relatively inexpensive.

Approaches toward bettering strength characteristics differ, but under today's conditions the following have found the widest acceptance:

1) alloying of steel with small amounts of elements promoting pulverization of grain and formation of structures of increased strength (bainite, martensite);

2) incorporation in steel of various additives (modifiers) bringing about changes in structure, in particular, promoting formation of finely dispersed solid phases, acting as a strengthing matrix;

3) increasing purity of steel -- removal from it of physical and chemical impurities and contaminations, including solute gases;

4) special technology affording attainment of beneficial structural changes, for example, thermomechanical or thermomechanomagnetic treatment.

These are the main methods of strengthening, and they can be used both individually, as well as in various combinations.

Below are listed the grades of steels developed in the USSR and abroad in the past 10-15 years and now finding industrial application. Where possible, in each case the most typical examples will be cited.

For sake of convenience of the survey, we group all steels in several groups based on their common features:

1) steels of general use, widely employed for diversified purposes and constituting the most massive product of metallurgy;

2) special steels, in which given physical or chemical properties predominate (for example, heat resistance, nonmagneticity, and wear resistance) and which are intended for special operating conditions;

3) steels treated under a special technology that affords improvement of their quality or lends them special properties.

Steels from the following countries are described and compared: USSR, USA, Japan, England, Norway, Italy, and Germany. Examples of U.S. Steels listed are: 15 - HY-80, T-1, HST-100, 4340, STRUX, (300M), (98BV40 mod), Stainless steels (17-4PH, AM 350, etc.) end

Since a special technology can be used both in treating general-use steels, as well as special steels, this group is presented independently.

GENERAL-PURPOSE STEELS

The group of general-purpose steels includes construction steels of various designations, including hull and cast. Therefore, it takes in carbon, low- and moderate-alloy steels of ordinary, increased, and high strength, which represent the main construction metal in fabrication of ship structures, mechanisms, and equipment.

Construction Steels of Increased and High Strength

Since the purpose and applicability of construction steels are mainly determined by their mechanical strength, we can provisionally isolate all construction steels used in shipbuilding and ship machinebuilding into the following categories (Table 1).

TABLE 1

Classification of Construction Steels by Strength

ⓐ Категория стали	ⓑ Предел прочности $\sigma_в$, $кГ/мм^2$	ⓒ Удлинение δ, %
ⓓ Обычной прочности	ⓗ До 50	ⓙ Выше 25
ⓔ Повышенной прочности	50—100	25—20
ⓕ Высокопрочная	100—300	20—8
ⓖ Сверхпрочная	ⓘ Выше 300	8—5

LEGEND: a) category of steel;
b) strength, σ_B, kg/mm^2;
c) elongation;
d) ordinary strength;
e) increased strength;
f) high-strength;
g) ultrahigh-strength;
h) up to 50;
i) higher than 300;
j) higher than 25.

Noteworthy is the fact that the terms strong steel, steel of increased strength, high-strength steel, etc. are provisional, since at different stages of development in metallurgy and in different fields of metal use, absolute values of strength indices corresponding to these terms differ.

The breakdown given in Table 1 is the most representative at the present time.

Steels of increased strength, including hull steels, used in modern shipbuilding, exhibit indices of the second category according to Table 1 (steels of increased strength) and only to some extent the first category (ordinary strength). The main characteristics of these steels are given in Tables 2-3. A detailed description of their properties and characteristics is the subject of extensive literature and of relevant GOST [USSR State Standards] and will not be given here.

Use of steels of increased strength (one of the conditions of technical progress in shipbuilding) affords some reduction in hull weight and improvement of many technical-operating characteristics of ships.

This question has been comprehensively examined in several works, including the study (2.9), from which we have borrowed Table 4 given below as an example, illustrating the effectiveness of use of steels of increased strength in shipbuilding.

Another example can be found in the rejection in Japanese shipbuilding of the use of ordinary hull steel in hull structures and the transition to using steel of increased strength of the T-1 type, which yields the following economies (1.1): 57% in weight of metal; 46% in outlays for welding; 100% in costs for heat treatment and stress removal; and 29% in overall cost of construction.

We can cite similar data in considering the shipbuilding of a number of countries.

The universal transition to welded shipbuilding has compelled a degree of restriction of the use of simple carbon steels in domestic shipbuilding (2.8).

By 1950 use of rimmed steel of grade St.16 and St.26 had been discontinued; the limiting content of carbon in steel of grades St.4S, St.4L, and St.4F has been reduced to 0.25%; use of steel of grades St.5 and St.5S in welded structure has been prohibited.

By 1958-1959, based on the experience of use of welded ships in shipbuilding, requirements for carbon hull steels have been additionally corrected and the composition of recommended steel grades has been somewhat modified: low-alloy steels of grades M18S and 09G2 have been introduced (Table 3) with increased manganese (09G2) and copper (M and M18S) content.

Compared with other modern hull steels, the steel 09G2 is relatively inexpensive and exhibits satisfactory weldability and reduced proneness to brittle failures.

TABLE 2

Chemical Composition of Certain Carbon and Low-alloy Steels of Increased Strength

ⓐ Марка стали	ⓑ Страна	ⓒ Содержание элементов, % (предельное)					
		C	Si	Mn	Cr	Ni	ⓓ прочие элементы
09G2	ⓔ СССР	0,12	0,20—0,40	1,45—1,70	0,3	<0,3	Cu 0,3
10KhSND(SKhL-4)		0,12	0,80—1,10	0,50—0,80	0,60—0,90	0,5—0,8	Cu 0,4—0,65
10KhGSND(MS-1)		0,12	0,7—1,10	0,8—1,20	0,30—0,60	1,0—1,30	Cu 0,30—0,50
10GSND(MK)		0,12	0,6—1,10	1,30—1,65	0,30	0,30	Cu 0,15—0,30
10KhSN2D(SKhL-45)		0,12	0,7—1,0	0,5—0,9	0,4—0,7	1,3—1,6	Cu 0,3—0,6
KS		0,12	0,5—0,8	0,9—1,2	0,3	1,4—1,7	Cu 0,3
M18S		0,14—0,22	0,12—0,35	0,4—0,8	0,3	0,3	Cu 0,4
M(09G2T)		0,12	0,5—0,8	1,3—1,7	0,3	0,3	Cu 0,3; Ti 0,01—0,03
18G2S		0,14—0,23	0,60—0,90	1,20—1,60	0,3	0,3	Cu 0,3
14G2		0,12—0,18	0,20—0,40	1,20—1,60	0,3	0,3	Cu 0,3
35GS		0,30—0,37	0,60—0,90	0,8—1,2	0,3	0,3	Cu 0,3
15KhGN		0,12—0,18	0,20—0,40	0,90—1,30	0,2—0,6	0,8—1,3	Cu 0,3
16GT(3N)		0,14—0,18	0,4—0,7	0,9—1,2	0,3	0,3	Cu 0,3; Ti 0,01—0,03
19G		0,16—0,22	0,20—0,40	0,70—1,0	0,3	0,3	Cu 0,3
14KhGS		0,11—0,17	0,40—0,70	0,90—1,30	0,50—0,80	0,3	Cu 0,3
15G2S		0,12—0,18	0,70—1,0	0,90—1,30	0,30	0,30	Cu 0,3
12KhG(BNL2)		0,14	0,25—0,50	0,40—0,80	0,40—0,70	0,30	Cu 0,3

TABLE 2 [concluded]

ⓐ Марка стали	ⓑ Страна	ⓒ Содержание элементов, % (предельное)					
		C	Si	Mn	Cr	Ni	ⓓ прочие элементы
15GYuT	ⓔ СССР	0,11—0,13	0,2—0,25	1,3—1,4	—	—	Ti 0,07; Cu 0,18—0,20; Al 0,03
15GDYuT		0,11—0,13	0,28—0,33	1,3—1,4	—	—	Ti 0,10; Cu 0,28—0,30; Al 0,05
HY-80 T-1	ⓕ США	0,18—0,22	0,12—0,35	0,1—0,4	0,85—1,9	2,0—3,2	Cu 0,24; Mo 0,15—0,65; V 0,02; Ti 0,01
Wel—TeN-80	ⓖ Япония	0,18	0,15—0,35	0,6—1,2	0,4—0,8	1,5	Cu 0,15—0,50; Mo 0,6; V 0,10; B 0,006
FTW		0,18	0,55	1,50	—	—	
SM50		0,18	0,55	1,50	—	—	
Ko		0,10—0,20	0,15—0,35	0,60—1,0	0,4—0,8	0,7—1,0	Cu 0,15—0,50; Mo 0,40—0,60; V 0,03—1,1; B 0,002—0,006
QT60A		0,12	0,15—0,35	0,6—1,0	0,4—0,7	0,4—0,7	Cu 0,40; Mo 0,2; V 0,03—0,6
NVF NVG; NVH	ⓗ Норвегия	0,20 0,18	0,55 0,15—0,55	1,4 1,4	0,2 0,2	0,2 0,2	Cu 04 Cu 04
ERSL	ⓘ Италия	0,20	0,35	1,5	—	—	

LEGEND: a) steel grade;
b) country;
c) content of elements, % (limiting);
d) other elements;
e) USSR;
f) US;
g) Japan;
h) Norway;
i) Italy.

TABLE 3

Main Mechanical Properties of Several Carbon and Low-alloy Steels of Increased Strength

ⓐ Марка стали	ⓑ Страна	ⓒ Механические свойства (не ниже)				ⓕ Примечание
		ⓓ σ_T, $кГ/мм^2$	ⓓ σ_B, $кГ/мм^2$	δ, %	ⓔ a_H, $кГм/см^2$	
09G2	ⓖ СССР	30	45	18	3—5	ⓗ $a_н$ при —40° С; 3 — для листов 4—20 *мм*; 5 — для листов 21—30 *мм*
10KhSND(SKhL-4)		40	54—75	16	4—5	ⓘ $a_н$ при —40° С; 4 — для листов 10—15 *мм*; 5 — для листов 16—32 *мм*
10KhGSND(MS-1)		40	54—75	16	4—5	ⓙ $a_н$ при —40° С; 4 — для листов 10—15 *мм*; 5 — для листов 16—32 *мм*
10GSND(MK)		38	50—70	18	4—5	ⓚ $a_н$ при —40° С; 4 — для листов 10—15 *мм*; 5 — для листов 16—32 *мм*
10KhSN2D(SKhL-45)		45	56—68	16	3—5	ⓛ $a_н$ при —40° С; лист 4—15 *мм*
KS, M18S		24	41—50	20	6	ⓜ $a_н$ при +20° С
M(09G2T)		35—27	50—44	18	6—3,5	ⓝ Первое значение $a_н$ при 20° С; второе — при —40° С; лист 4—160 *мм*
MK-40		40	54—66	16	5	ⓞ $a_н$ при —40° С; лист 16—32 *мм*
18G2S		30	50	14	—	ⓟ Листы 40—90 *мм*
14G2		30—34	44—48	18	—	ⓠ Первое значение для листов 25—30 *мм*; второе — для листов 4—10 *мм*
35GS		33—40	47—60	18—14	—	ⓡ Первое — для листов 11—20 *мм*; второе — для листов 6—40 *мм*
15KhGN		36—35	52—49	18	—	ⓢ Первое значение — для листов 4—10 *мм*, второе — для листов 11—20 *мм*

TABLE 3 [concluded]

ⓐ Марка стали	ⓑ Страна	ⓒ ⓓ $\sigma_т$, кГ/мм²	ⓓ [illegible]	[illegible]	ⓔ [illegible]	ⓕ [illegible]
16GT(3N)	ⓖ СССР	33—28	50—46	18	6	ⓧ Листы 4—160 мм при 20° С
19G		30	47	18	—	ⓨ Листы 4—20 мм
14KhGS		35	50	18	—	ⓨ Листы 4—20 мм
15G2S		35—35	48—50	18	—	ⓨ Листы 4—20 мм
12KhG(BNL-2)		33	46	15	—	ⓩ Листы 8—20 мм
HY-80	ⓣ США	58—62	72—75	21—24		
Wel—TeN-80	ⓤ Япония	70	80—95	18—20	6	(a') Листы 6—50 мм
FTW		35—46	52—68	20—16	6—8	(b') Первое значение — для горячекатаной стали; второе — для термически обработанной
SM50	ⓤ Япония	32	50—60	22	3,5—6	(c') Первое значение — для термообработанной стали; второе — для нормализованной
KO		70	80—95	18	6	(d') Термообработанная сталь
QT60A		48	60	16	8	(d') Термообработанная сталь
NVF	ⓥ Норвегия	33	50—60	20	—	
NVG		33	50—60	22	>2,8	(e') $a_н$ при —10° С
NVH		33	50—60	23	>2,8	(f') $a_н$ при —40° С
ERSL	ⓦ Италия	34	52—60	22	7	(g') Итальянский регистр

[LEGEND on following page]

[LEGEND to Table 3 on preceding two pages]

a) steel grade;
b) country;
c) mechanical properties (not less than);
d) kg/mm^2;
e) kgm/cm^2;
f) remark;
g) USSR;
h) a_H at -40° C; 3 -- for 4-20 mm sheets; 5 -- for 21-30 mm sheets;
i) a_H at -40° C; 4 -- for 10-15 mm sheets; 5 -- for 16-32 mm sheets;
j) a_H at -40° C; 4 -- for 10-15 mm sheets; 5 -- for 16-32 mm sheets;
k) a_H at -40° C; 4 -- for 1015 10-15 mm sheets; 5 -- for 16-32 mm sheets;
l) a_H at -40° C; 4-15 mm sheets;
m) a_H at +20° C;
n) first value of a_H at 20° C; second value at -40° C; 4-160 mm sheets;
o) a_H at -40° C; 16-32 mm sheets;
p) 40-90 mm sheets;
q) first value for 25-30 mm sheets; second -- for 4-10 mm sheets;
r) first value for 11-20 mm sheets; second -- for 6-40 mm sheets;
s) first value -- for 4-10 mm sheets; second -- for 11-20 mm sheets;
t) US;
u) Japan;
v) Norway;
w) Italy;
x) 4-160 mm at 20° C;
y) 4-20 mm sheets;
z) 8-20 mm sheets;
a') 6-50 mm sheets;
b') first value -- for hot-rolled steel; second -- for heat treated steel;
c') first value -- for heat-treated steel; second -- for normalized steel;
d') heat-treated steel;
e') a_H at -10° C;
f') a_H at -40° C;
g') Italian register.

Economic Benefit From Use of Various Grades of Steel

TABLE 4

ⓐ Показатели	ⓑ Сухогрузное судно с корпусом из стали марок				ⓓ Танкер с корпусом из стали марок			
	Ст. 3С и Ст. 4С ⓒ	09G2	MK-35	SKhL-4	Ст. 3С и Ст. 4С ⓒ	09G2	MK-35	SKhL-4
ⓔ Объем применения стали повышенной прочности, %	—	55,7	54,6	54,4	—	70	68,1	66,1
ⓕ Выигрыш в весе металлического корпуса, %	—	9	11	11,8	—	12	17	22
ⓖ Вес корпуса, *т*	3843	3500	3424	3393	13 000	11 450	10 810	10 160
ⓗ Стоимость 1 *т* стали в составе корпуса, руб.	87,6	98,7	101	132	84.5	94,5	99,5	127,5
%	100	112,68	115,3	150,6	100	111,86	117,74	150,9
ⓘ Стоимость 1 *т* корпуса, руб.	299	321	326	342	254	277,5	289	317
%	100	107,36	109,02	114,38	100	109,25	117,71	124,8
ⓙ Стоимость корпуса, тыс. руб.	1149,1	1121,9	1113,9	1166,4	3300	3181	3129	3223
%	100	97,6	96,9	101,5	100	96,3	94,8	97,7
ⓚ Строительная стоимость судна, тыс. руб.	4105,5	4021,4	4001,4	4049,4	7912	7628,5	7549	7621,3
%	100	97,9	97,4	98,6	100	96,4	95,4	96,3
ⓛ Себестоимость перевозок, *руб/т*	10.62	10,51	10,48	10,49	6,914	6,814	6,774	6,759
%	100	99	98,7	98,8	100	98,5	98	97,8
ⓜ Удельные капитальные вложения, *руб/т*	47.19	46,22	45.99	46,55	20,733	19,989	19,782	19,971
%	100	97,9	97,4	98,6	100	96,4	95,4	96,3
ⓝ Удельные приведенные затраты, *руб/т*	17,7	17,44	17,38	17,47	10,023	9,812	9,741	9,755
%	100	98,5	98,7	98,7	100	97,9	97,2	97,3
ⓞ Экономический эффект, тыс. руб./год	—	22,6	27,9	20	—	80,5	108,4	102,1

LEGEND:
a) indices;
b) dry-cargo ship with hull made of steel grade listed;
c) St. 3S and St. 4S;
d) tanker with hull made of steel grade listed;
e) volume of use of steel of increased strength;
f) gain in weight of metallic hull;
g) weight of hull, tons;
h) cost of 1 ton of steel in hull composition, rubles;
i) cost of 1 ton of hull, rubles; j) cost of hull, 1000's of rubles;
k) construction cost of ship, 1000's of rubles;
l) cost of trips, rubles/ton; m) specific capital investments, rubles/ton;
n) specific prorated costs, rubles/ton;
o) economic benefit, 1000's of rubles/year.

We must regard as the strongest of shipbuilding low-alloy weldable steels SKhL-45 and KS, used in maritime shipbuilding as sheets and various shaped members.

Several grades of low-alloy steels, in particular, silicomanganese, given the appropriate heat treatment (thermohardening), can acquire still greater strength, retaining good weldability, which opens up the prospect of replacing expensive steels widely used at present (for example, SKhL-4 containing nickel) with more inexpensive.

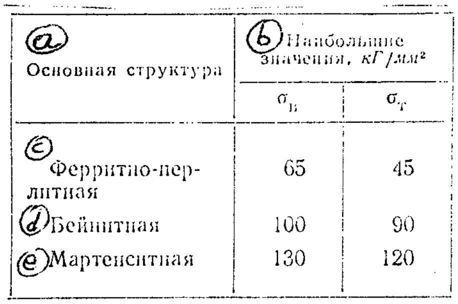
The transition from carbon to low-alloy, stronger steels occurring in the last decade is also due to the fact that for weldable hull steels obtained on the basis of carbon and manganese, the strength values cannot exceed 50-60 kg/mm^2 without deterioration of weldability.

Low-alloy steels developed especially for welded structures acquire, following heat treatment, a martensitic or bainitic structure, which gives the steels heightened strength (Table 5), and also the essential toughness at low temperatures.

Alloying elements in such steels can be vanadium, molybdenum, copper, nickel, and niobium. We must regard niobium as particularly promising, since even a small amount of it improves weldability of steel and reduces its proneness to hardening.

TABLE 5

Strength Characteristics of Steel



ⓐ Основная структура	ⓑ Наибольшие значения, кГ/мм²	
	$\sigma_в$	$\sigma_т$
ⓒ Ферритно-перлитная	65	45
ⓓ Бейнитная	100	90
ⓔ Мартенситная	130	120

LEGEND: a) principal structure;
b) highest values, kg/mm^2;
c) ferritic-perlitic;
d) bainitic;
e) martensitic.

A large part of the steels examined here are thermostrengthened, acquiring increased strength as a result of the appropriate heat treatment. Heat treatment usually consists of hardening and tempering, the optimal temperatures for which, for various steels, differ (for example, for 09G2 -- tempering 550-600° C; for 14G2, 19G, and 14KhGS -- 600-680° C, etc.).

The economic benefit from introduction of these steels is significant, in particular, owing to the fact that with thermostrengthened rolling steel can bypass separate heating, but be subjected to hardening directly upon exiting from the rolling mill.

With such treatment, a 1.5-2 times increase in strength can be attained, which affords sizable reductions in outlays for rolling (up to 40%).

The creep limit of thermostrengthened steels is as high as 70-80 kg/mm^2.

Predominantly, killed and semikilled steels are recommended for thermostrengthening.

Thermostrengthening reduces the cold brittleness of steel.

We must view as some disadvantage in thermostrengthened steels the fact that when they are welded a reversible process is possible in the weld zone -- thermosoftening, the extent of which depends on the chemical makeup of the welded steel, structure, running power in welding, and the rate of cooling following welding.

In recent years, low-alloy and moderate-alloy steels of increased strength have enjoyed wide acceptance in several foreign countries. Figure 2 shows the growth in Japanese output of construction steel of increased strength, including sheet steel, which is mainly used in shipbuilding. In this country, industrial production of several grades of carbon steel of increased strength exhibiting good weldability and intended for shipbuilding was begun in 1956 (Table 2).

Thus, for example, the steel FTW ($\sigma_B = 52\text{-}62\ kg/mm^2$, and $\sigma_T = 35\ kg/mm^2$) is used in building large-tonnage ships (ore-carriers, 65,000 tons).

In the same country, since 1961 industrial production of low-alloy steel of increased strength has been underway -- Wel-TeN80, similar in composition and properties to the American steel of increased strength T-1. Characteristics of these steels are also given in Tables 2 and 3.

We can regard as typical of modern American low-alloy steels of increased strength the steel HY-80, widely used in submarine-building in the US (1.2). This steel in sheet and plate form from 10 to 76 mm thick is used in manufacturing welded strong hulls of atomic submarines. In the hardened and tempered state the steel HY-80 exhibits high indices of strength, plasticity, and toughness with good technological compatibility and explosion-resistance. The characteristics of this steel are shown in Table 2.

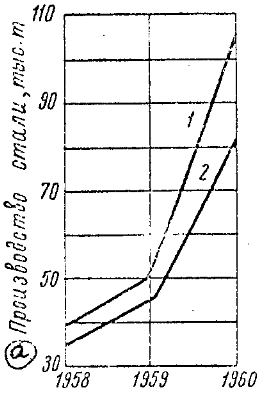


Figure 2. Growth in production of steel of increased strength in Japan. LEGEND: a) steel output, 1000's of tons.
1 -- general amount; 2 -- sheet steel.

Since steels of increased strength have found wide acceptance in shipbuilding, in several countries their application for hulls of ocean-going vessels has begun to be standardized by shipbuilding classifying societies. Thus, the Norwegian Veritas provides for use of three classes of steels of increased strength NVF, NVG, and NVH with different indices of toughness (Table 3). Steel of the NVF class must be killed or semi-killed, of the NVG class -- wholly deoxidized with silicon, of the NVH class -- must still exhibit, in addition to characteristics of the NVG class, fine-grain structure. Normalization is obligatory for steels of all three classes.

The Italian register stipulates in the appropriate regulations the use of steel with high creep limit ERSL (Table 2). This steel must be wholly killed and fine-grain. Sheets must be subjected to normalization.

British Lloyds in 1964 introduced in suitable regulation form the instructions about use of steels of increased strength (classes AH, DH, and EH) for hulls of tankers and ships carrying bulk cargoes.

The American Bureau of Shipping provides in new regulations the use of steel of increased strength in areas of stress concentration on ships.

In addition to new grades of construction sheet steel of increased strength, used chiefly in construction of hull structures, in recent years in the USSR and abroad grades of steel have been developed that are suitable for manufacturing forgings and especially welded forged parts. In manufacturing welded parts, use can be made, as we know, of only satisfactorily welded steels, resistant to brittle failure and crack formation, and exhibiting good plasticity.

Typical representatives of construction low-alloy steel of increased strength, replacing less technological compatible steel 30T can be found in the steels 15GYuT and 15GDYuT (1.6).

The mechanical properties of these steels are given in Table 6.

New dispersion-strengthened weldable alloy steels 08GDNF and 08GDN are also of interest as promising materials for manufacturing forgings and welded-forged structures.

Almost all steels previously used in shipbuilding forgings required preliminary heating up prior to welding, and after welding -- heat treatment (normalization, annealing, tempering). The steels 08GDN and 08GDNF, developed in recent years, do not require heating up prior to welding and heat treatment after welding and are suitable for manufacture of key welded forged parts, the walls of which are up to 200 mm thick.

The main characteristics of these steels are given in Table 7.

Low- and moderate-alloy steels of increased strength. In recent years, new steels of high strength (σ_T higher than 100 kg/mm^2) have begun to enjoy ever-wider use both in the USSR and abroad.

Generally, these are low- and moderate-alloy steels, not corrosion resistant, acquiring high strength via the appropriate heat treatment, sufficiently plastic and tough in the original condition for manufacture of parts by methods of hot pressure working or mechanical cutting. The maximum attainable values of σ_B for these steels are governed by the carbon content.

Development and output of such steels is caused by the demand for materials that in addition to high indices of static strength and good weldability also have a large plasticity reserve and high resistance to inception and spread of brittle failure.

To some extent, these requirements can be satisfied by using complex alloying (up to five-six alloying elements) and heat treatment of various kinds (usual or isothermal hardening with tempering).

TABLE 6

Mechanical Properties of Steels

ⓐ Марка стали	ⓑ Состояние	ⓒ Показатели					
		НВ	$\sigma_В$, кГ/мм² ⓓ	$\sigma_Т$, кГ/мм² ⓓ	δ, %	ⓔ $a_н$, кГ/см²	
						ⓕ до старения	ⓖ после старения
30T	ⓗ Горячекатаное ⓘ После низкотемпературного отжига	214 154	74,3 53,0	60,0 35,0	14,7 23,3	7—11	6—8
15GYuT	ⓙ Низкотемпературный отжиг	156 143—170	53,3 48—57	40,9 36—43	21,5 20—23	—	—
15GDYuT	ⓗ Горячекатаное ⓙ Низкотемпературный отжиг	276 174	80,2 57	50,0 43	16,2 20,6	— 10—19	— 17—17

LEGEND: a) grade of steel;
b) state;
c) indices;
d) kg/mm^2;
e) kg/cm^2;
f) prior to aging;
g) prior to aging;
h) hot-rolled;
i) after low-temperature annealing;
j) low-temperature annealing.

In the USSR several grades of high-strength low-alloy steels (Tables 8 and 9), improved by heat treatment, have been developed in recent years.

In particular, of them notice must be taken of air hardened steels VL-1 and VL-1D (30Kh2GSNVM), exhibiting good weldability both in automatic and in manual argon-arc welding. Hardening in air ensures minimum deformation of parts and almost wholly does away with the need for trimming. The steels 30KhGSNA and 30KhGSNMA are used in manufacture of large-size forgings, and the steel EI643 for manufacturing forgings and hot-rolled tubing.

Several new grades of low-alloy steels of high strength have been developed in the US and the United Kingdom in recent years.

The most typical of them are presented in Tables 8 and 9.

Of interest is the group of three steels of the HST type. The first of these -- HST-100 has σ_B within the limits of 157 to 221 kg/mm^2

TABLE 7

Mechanical Properties of Forgings Made of Dispersion-Strengthened Welding Steel

ⓐ Марка стали	ⓑ Механические свойства					ⓗ Твердость, НВ	ⓘ Рекомендуемый режим термообработки
	ⓒ предел текучести, кГ/$мм^2$	ⓓ временное сопротивление разрыву, кГ/$мм^2$	ⓔ относительное удлинение, %	ⓕ относительное сужение, %	ⓖ ударная вязкость при температуре —40°, кГ м/$см^2$		
	ⓙ не менее						
O8GDNF	45	55	20	45	4	159—208	ⓚ Закалка 900—940°, вода; отпуск при 590—630°, воздух
O8GDNF	40	50	20	45	4	159—192	ⓛ Нормализация 900—940°, воздух; отпуск при 590—630°, воздух
O8GDN	30	40	20	45	4	120—167	ⓛ Нормализация 900—940°, воздух; отпуск при 590—630°, воздух

LEGEND:
a) grade of steel;
b) mechanical properties;
c) creep limit, kg/mm^2;
d) critical point of rupture, kg/mm^2;
e) relative elongation;
f) relative area reduction;
g) toughness at temperature of -40° C, kgm/cm^2;
h) Brinell hardness number;
i) recommended heat treatment conditions;
j) not less than values listed;
k) hardening 900-940°, water; tempering at 590-630°, air;
l) normalization 900-940°, air; tempering at 590-630°, air.

after hardening in air and tempering (1.7).

Two other steels differ little in carbon content from the steel HST-100, but they acquire high hardness during the hardening period and at the same tempering temperature retain high strength. These steels have been assigned the grades HST-120 and HST-140; they have respective breaking points of 189 and 220.5 kg/mm^2 at room temperature. Both steels can be hardened in air and in oil depending on the cross-sectional size.

The silicon content in steels of all three grades is less than 0.4%.

These steels following tempering at 600° C have breaking points, respectively, of 154.3, 165.4, and 215.8 kg/mm^2 and exhibit good plasticity. For instance, the steel HST-140 exhibits the following qualities: 13% elongation and 41% area reduction with a breaking point of 214.5 kg/mm^2. From the HST steels there can be produced sheet billets, blooms, slabs, and ingots. Ingots are delivered annealed, and also following hardening with tempering.

The ranks of new steels of high strength include the steel USS-Strux. This steel can be subjected to forging and mechanical working. After heat treatment, its breaking point is 197-211 kg/mm^2.

To get a breaking point not lower than 197 kg/mm^2, it is recommended to use heat treatment with the following set of conditions: normalization from 871-899° C, hardening in oil at temperature [not specified]. In the US (1.8), a high-strength steel has been developed containing 0.5% carbon, 2% tungsten, 1% molybdenum, 0.5% vanadium, and 0.1% niobium. The new steel retains high strength after tempering at temperatures of 538-704° C. The tensile strength in the tempered state is, at room temperature, 197-211 kg/mm^2, at 427° C -- 164 kg/mm^2, and at 538° C -- 112 kg/mm^2. At 538° C the specific strength of steel after 1000 hours is higher than for titanium alloys, though resistance to oxidation is worse. A creep limit of the steel at 538° C has also been noted as being higher than for titanium. The new steel exhibits the capacity for strengthening when tempered after hardening in air until bainite is obtained. Tempering at temperatures of 566 and 677° considerably increase notch strength.

The content of alloying elements in high-strength steels can vary within relatively wide limits. As an example, we can cite the study (1.11) made in selecting a method for welding sheet steel.

Research was conducted on low-alloy sheet steel of various chemical compositions: 15 grades of steel with 0.37-0.48% carbon, 0.30-0.82% manganese, 0.19-1.90% silicon, 0-5.16% chromium, 0.065-1.94% nickel, 0.24-1.34% molybdenum, and 0.04-0.50% vanadium. In addition to the elements cited, in one of the studies of steels cobalt was present (1.1%), in another -- copper (0.86%).

Tensile tests were made of specimens with notch and without notch made of welded unions of sheet steels. And, in testing the test vessels were subjected to hydrostatic pressure to failure. The test vessels were made of 1-3 mm thick sheets and welded longitudinally by electron beam and the arc method in inert gas atmosphere using tungsten electrodes.

TABLE 8

Chemical Composition of Certain Low- and Moderate-Alloy High-Strength Steels

ⓐ Марка стали	ⓑ Страна	ⓒ Содержание элементов, % (предельное)					ⓓ Прочие (основа Fe)
		C	Si	Mn	Cr	Ni	
30KhGSNA		0,27—0,34	0,9—1,2	1,0—1,3	0,9—1,2	1,4—1,8	
VL-1		0,24—0,31	0,9—1,2	1,0—1,3	1,5—2,0	2,0—2,5	W 0,9—1,3; Mo 0,4—0,5
VL-1D(30Kh2GSNVM)		0,26—0,33	0,9—1,2	1,0—1,3	1,5—2,0	1,0—1,3	W 0,3—1,3; Mo 0,4—0,5
30KhGSNMA		0,27—0,34	0,9—1,2	1,0—1,3	0,9—1,2	1,4—1,8	Mo 0,4—0,5
EI643	ⓔ СССР	0,36—0,43	0,7—1,0	0,5—0,8	0,8—1,1	2,5—3,0	W 0,8—1,2
30KhGSA		0,28—0,35	0,9—1,2	0,8—1,1	0,8—1,1	0,4	—
37KhGNV2T		0,37	0,20	1,30	1,50		W 1,8; Ti 0,15
43KhN2V3		0,43	0,20	0,40	1,50		W 2,90
45KhN2SV2		0,45	1,05	0,40	1,30		W 2,00

TABLE 8 [concluded]

ⓐ Марка стали	ⓑ Страна	ⓒ Содержание элементов, % (предельное)					ⓓ Прочие (основа Fe)
		C	Si	Mn	Cr	Ni	
Strux	ⓕ США	0,40—0,47	0,5—0,8	0,75—1,0	0,8—1,05	0,6—0,9	Mo 0,45—0,60; V 0,01; B 0,0005
AISI4330		0,26—0,34	0,35—0,60	0,6—0,9	0,8—1,0	1,65—2,0	Mo 0,35—0,45
4330M		0,3—0,35	1,4—1,7	0,75—1,0	0,8—1,0	1,5—2,0	Mo 0,4—0,6; V 0,08—0,12
300M; Tricent		0,43	1,60	0,80	0,80	1,80	Mo 0,40
4340; AMS6415		0,40	0,30	0,70	0,80	1,85	Mo 0,25; 0,07 V
Hi—TuF; AMS6418		0,25	1,50	1,30	0,30	1,80	Mo 0,40
Thermold I		0,50	1,0	0,40	5,0	1,50	Mo 1,75; V 1,0
WA245	ⓖ ФРГ	0,45	1,0	0,30	1,0	—	V 0,20; W 2,0
MOG510		0,40	1,0		5,0	—	Mo 1,5; V 0,6
En26	ⓗ Англия	0,40	0,20	0,60	0,65	2,50	Mo 0,55
Rex539		0,35	1,55	1,57	0,11	1,80	V 0,21; Mo 0,34
RS140; Fox769; HST-100		0,40	0,20—0,30	0,65	3,0	0,25	Mo 1,0; V 0,20
HST-140		0,40	0,20	0,60	5,0	—	Mo 2,0; V 0,45
H50		0,40	0,60	0,65	5,0	—	Mo 1,3; V 0,8

LEGEND: a) grade of steel; f) US;
b) country; g) FRG;
c) content of elements, % (limiting); h) Great Britain.
d) others (Fe base);
e) USSR;

Main Mechanical Properties of Certain Low- and Moderate-Alloy High-Strength Steels TABLE 9

ⓐ Марка стали	ⓑ Страна	ⓒ Механические свойства (не ниже)				ⓕ Температура отпуска, °C
		ⓓ $\sigma_т$, кГ/мм²	ⓓ $\sigma_в$, кГ/мм²	δ, %	ⓔ $a_н$, кГм/см²	
30KhGSNA	ⓖ СССР	135	175	10	6—7	250
VL-1		135	175	10	6—7	250
VL-1D(30Kh2GSNVM)			80—160 *	16—7	1,8—6,0	
30KhGSNMA		120—125	150—165	11—13	7—8	
EI643		140—150 **	190—200	11—10	6—5,5	
30KhGSNA		135	175	9	5—6	220
37KhGNV2T		167	201	9	6	200
43KhN2V3		175	223	7	4	200
45KhN2SV2		183	231	8	4	200
Strux	ⓗ США	150	197—211	6		370
AISI4330		112—122	126—157	5—8		
4330M		147	179	10		245
300M; Tricent		170	200—210	8—9		260
4340; AMS6415		164	198	10		230
Hi-TuF		135	165	14		290
AMS6418		132	160	13		340
Thermold I		170	209	9		320
WA245	ⓘ ФРГ	—	189	—		370
MOG510		192				540
En26	ⓙ Англия	160	186	13		250
Rex539		151	181	10		350
RS140; Fox769; HST-100		135—140	165—175	15		450
HST-140		160	214	13		600
H50		140	198	10		560

ⓚ * Первые значения — отожженное состояние; вторые — закалка при 930° C на воздухе; отпуск при 250° C.
ⓛ ** Первое значение — изотермическая закалка; второе — закалка с отпуском при 220° C.

LEGEND:
- a) grade of steel;
- b) country;
- c) mechanical properties (not lower than listed);
- d) kg/mm^2;
- e) kgm/cm^2;
- f) annealing temperature
- g) USSR;
- h) US;
- i) FRG;
- j) Great Britain;
- k) * first values -- annealed state; second -- hardening at 930° C in air; tempering at 250° C;
- l) ** first value -- isothermal hardening; second -- hardening with tempering at 220° C.

In testing metal of weld seams made with an electron beam and using a tungsten electrode in argon atmosphere, after heat treatment (austenization, hardening, and tempering) a breaking point of 176-200 kg/mm^2 was obtained; the relative elongation was 4-8%; the creep limit was 99-161 kg/mm^2.

When testing with hydrostatic pressure, failure occurred at a stress which was somewhat lower than the breaking point value.

Tables 8 and 9 present information on several modern low-alloy foreign steels of increased and high strength.

Low- and moderate-alloy steels of high strength are used in manufacturing various mechanically worked and welded parts, in whose performance there can be no abrupt stress concentrations. These steels can be welded with each other, and also with low-carbon nonalloy and alloy steel. They are best used in manufacturing members of structures operating under compression and exhibiting increased rigidity.

Cast Steels

In spite of the progressiveness of using welding in manufacturing complexly shaped parts of ship hull and ship articles, in several cases it proves economically worthwhile and more technological to manufacture parts by the casting method.

Castings are used in making stems, stern-posts, brackets and hubs of screw propeller shafts, deadwood tubing, anchor defiles [klyuzy], screw propellers, bedplates, rudder sectors, anchor, anchor chains, mooring cleats, control and measuring instruments, reinforcement, parts of pipelines, bedplates of searchlights, bolt bars, pilot wheel stands, guardrail brackets, etc.

Use of new technological processes of casting (precision casting with meltable models, casting in permanent molds, special kinds of casting) afford production of articles whose dimensions are close to the desired ones, which means a sizable economic gain, especially when casting parts from hard-to-work alloys.

Researchers are trying to formulate casting steels exhibiting good flowability, moderate shrinkage, and that lend themselves well to working by cutting in the cast or annealed state, are not prone to crack formation, and acquiring increased or high strength after heat treatment or aging, readily weldable, not containing a large amount of alloying elements, plastic and tough, with stable properties in different cross-sectional zones.

To a substantial extent these requirements can be met by complex alloying of low- and moderate-carbon steels with several elements in different amounts.

In complex alloying with several elements simultaneously, the advantages given steels by each element are combined, and good casting properties of casting are thereby obtained, but in castings steel acquires fine-grain structure, good rolling capacity, resistance to tempering, high strength, plasticity, and toughness.

Only castings of ordinary purposes, whose dimensions are determined not by calculation, and also casting intended for operating under pressures up to 10 kg/cm^2 and moderate temperatures are made from ordinary cast carbon steels 15L, 25L, 35L, and 55L (GOST 977-58), and similar steels.

Castings of key purposes, of increased strength, operating under heating up to 400-500°, exhibiting increased resistance to corrosion in seawater, shaped castings with abrupt changes in cross-section, etc. are made from alloy steels of various degrees of alloying (Tables 10 and 11).

Complex alloying with silicon, manganese, chromium, nickel, etc. affords an increase in σ_B of steel to 150-170 kg/mm^2 with retention of satisfactory plasticity.

Steels alloyed with silicon and manganese are used for casting parts with increased σ_B and σ_T and wear resistance, manganese steels containing nickel, silicon, and tungsten -- for parts that must exhibit hardness, strength, and high toughness.

Of new casting steels, which are used in shipbuilding in manufacturing cast-welded and combined (cast-forged, cast-sheetwelded) structures, we must note the dispersion-strengthened easily weldable steels 08GDNL and 08GDNFL. Since in these steels the carbon content is low, no splitting of the basis metal in the zone of thermal influence takes place, and correspondingly there is no need of heat treatment of steels after welding by all the ordinary methods, which affords manufacture from these steels of large-size structures (stern-posts, stems, brackets of screw propeller shafts) comprised of any number of parts.

In addition to casting steels of mass use listed in Tables 10 and 11, in recent years in the USSR and abroad several grades of stainless, heat-resistant, acid-resistant, and other steels with good casting properties and adequate strength have been formulated. They include new strong and corrosion-resistant austenitic-ferritic stainless steel of the grade 0Kh17N3G4D2T and the steel 1Kh14NDL of the martensitic-ferritic class, the chemical composition and properties of which are also given in Tables 10 and 11.

TABLE 10

Chemical Composition of Certain Cast Alloy Steels

ⓐ Марка стали	ⓑ Страна	ⓒ Содержание элементов, %					
		C	Si	Mn	Cr	Ni	ⓓ прочие
30GSL	ⓔ СССР	0,25—0,35	0,60—0,80	1,10—1,40	0,30	0,40	Cu 0,3
08GDNFL		0,10	0,15—0,40	0,6—1,0	0,30	1,15—1,55	Cu 0,8—1,2; V 0,1
08GDNL		0,10	0,15—0,4	0,8—1,2	0,30	0,35—0,65	Cu 0,8—1,2
20KhML		0,15—0,25	0,17—0,37	0,5—0,8	0,4—0,7	0,30	Mo 0,4—0,6
Kh18N9TL		0,14	1,0	1,0—2,0	17—20	8—11	ⓕ Ti до 0,8
Kh18N12M3TL		0,12	1,0	1,0—2,0	16—19	11—13	ⓖ Окалиностойкая Mo 3—4; Ti 0,3—0,6
1Kh14NDL		0,10	0,40	0,3—0,6	13,5—15	1,2—1,6	ⓖ Окалиностойкая Cu 1,2—1,6
0Kh17N3G4D2TL		0,10	0,7—1,6	3,2—4,2	16,5—18,5	2,0—3,2	Cu 2,0—2,6; Ti 0,10—0,25
Kh13N3VFL		0,09—0,15	0,2—0,8	0,2—0,8	11,5—13,5	2,3—3	W 1,6—2,2; V 0,18—0,28
Kh17N3SL		0,05—0,12	0,8—1,5	0,3—0,8	15—16	2,8—3,8	
30KhNVL		0,28—0,35	0,17—0,37	0,5—0,8	1,3—1,6	1,3—1,6	Cu 0,3; W 0,5—0,8
Kh17M2TL		0,08—0,1	0,8—1,5	0,4—0,9	15,5—17,5		Mo 2—2,8; Ti 0,3—1,0
Kh25M2T		0,10	—	—	24—26		Mo 2,0; Ti 1—1,5
Kh11LA		0,12—0,19	0,5	0,5—1,0	10—11,5	0,6—1,0	Mo 0,6—0,8; V 0,25—0,30; Nb 0,15—0,25
Kh11V2NMF-L(TsZh-5)		0,10—0,15	0,17—0,40	0,6—0,8	10,5—12,5	0,8—1,1	Mo 0,6—0,8; V 0,20—0,35; W 1,7—2,2
25-20L		0,18	0,8—2,0	0,7—1,5	22—26	17—21	
LA1		0,16	0,55	0,7	14—16	14—16	Mo 1,8—2,2; Co 2,8—3,2;

TABLE 10 [concluded]

ⓐ Марка стали	ⓑ Страна	ⓒ Содержание элементов, %					
		C	Si	Mn	Cr	Ni	ⓓ прочие
LA1		0,16	0,55	0,7	14—16	14—16	W 0,8—1,2; Ti 0,15—0,35
LA5		0,12—0,20	0,55	0,4—0,7	14—16	15—17	Mo 1,8—2,2; Co 2,8—3,2; W 0,8—1,2; Ti 0,15—0,35; ⓙ Nb до 1,2
LA6		0,11—0,15	0,55	0,5—1,0	13—15	13—15	Mo 1,7—2,1; W 1,25—1,65; ⓙ Nb до 1,2
LA3		0,12—0,18	0,55	1,0	13—15	13—15	Mo 1,8—2,2; W 1,3—1,8; V 0,4—0,6; Nb 0,3—0,5; Ti 0,1—0,3
CA-15	ⓗ США	0,15	1,50	1,0	11—14	1	Mo 0,5
CC-50		0,50	1,0	1,0	26—30	4	
CF-3M		0,03	1,50	1,50	17—21	9—13	Mo 2—3
HA		0,20	1,0	0,35—0,65	8—10	—	Mo 0,9—1,2
HI		0,2—0,5	2,0	2,0	26—30	14—18	Mo 0,5
4330AISI		0,26—0,34	0,35—0,60	0,60—0,90	0,8—1,0	1,65—2,0	Mo 0,35—0,45
8740		0,37—0,44	0,35—0,60	0,75—1,0	0,8—1,0	0,40—0,70	Mo 0,35—0,45
CK-20		0,2	2,0	2,0	26	21	
HH		0,35	2,0	2,0	24	12	Mo 0,5; N_2 0,2
GS22CrMo5 4	ФРГ ⓘ	0,18—0,25	0,30—0,50	0,5—0,8	0,8—1,1		Mo 0,4—0,5
GS20MoV8 4		0,16—0,23	0,3—0,5	0,5—0,8	0,3		Mo 0,8—0,9; V 0,35—0,45
GX22CrMoV12—1		0,20—0,26	0,2—0,4	0,5—0,7	11,3—12,2	0,7—1,0	Mo 1—1,2; V 0,25—0,35

LEGEND: a) grade of steel;
b) country;
c) content of elements;
d) others;
e) USSR;
f) Ti up to 0.8;
g) scale-resistant;
h) US;
i) FRG;
j) Nb up to 1.2.

TABLE 11

Main Mechanical Properties of Certain Cast Alloy Steels

ⓐ Марка стали	ⓑ Страна	ⓒ Механические свойства (не ниже)					ⓕ Примечание
		ⓓ $\sigma_т$, $кГ/мм^2$	ⓓ $\sigma_в$, $кГ/мм^2$	δ, %	ⓔ $a_н$, $кГм/см^2$	ⓓ НВ, $кГ/мм^2$	
30GSL	ⓖ СССР	35	60	14	3,0	187—241	
08GDNFL		38	48	20	3,0	159—192	ⓗ При —40° С
08GDNL		30	40	20	3,0	120—167	» —10° С
20KhML		25	45	18	3,0	135—180	
Kh18N9TL		20	45	25	10,0	129—183	
Kh18N12M3TL		22	50	30	10,0	129—183	
1Kh14NDL		50	62	15	3,0	197—241	ⓘ При 0° С
0Kh17N3G4D2TL		30	70	15	6,0	183—223	
Kh13N3VFL		75—100	90—120	9—7	2—1,5		ⓙ Закалка при 1050° С; первое значение — отпуск при 680—720° С, второе — отпуск при 540—620° С
Kh17N3SL		65—75	85—95	6—8	10—2,5		ⓚ Закалка при 1050° С; первое значение — отпуск при 670—690° С; второе — отпуск при 540—560° С
30KhNVL		55	70	12	3,0		ⓛ Нормализация при 850—870° С; отпуск — при 600—650° С
Kh17M2TL		40	45			177—197	ⓜ Отжиг при 760° С
1Kh18N4G4L		25	45	25		170—200	

TABLE 11 [concluded]

ⓐ Марка стали	ⓑ Страна	ⓒ Механические свойства (не ниже) ⓓ σ_T, кГ/мм²	ⓓ σ_B, кГ/мм²	δ, %	ⓔ a_H, кГм/см²	ⓓ НВ кГ/мм²	ⓕ Примечание
Kh11LA	ⓖ СССР	50—57	60—71	15—17	5—9		ⓟ Отжиг + нормализация + + отпуск 700° С
Kh11V2NMF-L(TsZh-5)		61—70	77—86	10—16	2—6	229	ⓠ Гомогенизация + нормализация + отпуск при 730° С
25-20L		30—35	50—55	17—10	10—2,5	175—205	ⓡ Первое значение — литой; второе — состаренный
LA1		20—27	40—53	21—51	4—14		ⓢ После старения
LA3		25—29	45—58	20—32	7—13		» »
LA6		22—24	34—47	22—30	5—8		» »
4330AISI	ⓝ США	112	126	8			ⓣ В литом состоянии
		122	158	5			ⓤ Закалка + отпуск при 480° С
8740		147	183	3			ⓥ Закалка + отпуск при 204° С
GS22CrMo5—4	ⓞ ФРГ	30	53—70	20	4		
GS20MoV8—4		40	60—80	15	4		

LEGEND:
a) grade of steel;
b) country;
c) mechanical properties (not lower than listed);
d) kg/mm^2;
e) kgm/cm^2;
f) remark;
g) USSR;
h) at -40° C;
i) at 0° C;
j) hardening at 1050° C; first value -- annealing at 680-720° C, second -- annealing at 540-620° C;
k) hardening at 1050° C; first value -- annealing at 670-690° C; second -- annealing at 540-560° C;
l) normalization at 850-870° C; annealing -- at 600-650° C;
m) annealing at 760° C; [LEGEND continued on following page]

[LEGEND to Table 11, concluded]
n) US;
o) FRG;
p) annealing + normalization + tempering at 700° C;
q) homogenization + normalization + tempering at 730° C;
r) first value -- cast; second -- aged;
s) after aging;
t) in cast state;
u) hardening + tempering at 480° C;
v) hardening + tempering at 204° C.

These steels are used for manufacturing screw propellers, rudders, underwater vanes, brackets, onboard reinforcement, and other ship parts, replacing copper alloys and stainless austenitic steel 1Kh18N9T containing a considerably greater amount of nickel which is in short supply.

The casting steel of the following composition has been proposed (1.34) for casting thin-wall parts of engines, valve units, and rotor wheels at low-temperature operating conditions: $C \leq 0.10\%$; $Si \leq 0.7\%$; Mn 0.7%; Cr 20-22%; Ni 7-9%; Mo 2-3%; Cu 1-1.5%; P 0.25-0.30%, exhibiting high flowability and high strength ($\sigma_B = 70$ kg/mm^2; $\sigma_T = 55$ kg/mm^2; $\delta = 20\%$, and $a_H = 6$ kgm/cm^2).

In the FRG, a new steel has been developed that differs in its high strength properties, affording manufacture of any casting obtained from low-alloy steels and exhibiting good weldability.

The composition of the steel is as follows (%): 0.03 C; 0.1 Si; 0.1 Mn; 0.01 P; 0.01 S; 16.0-17.5 Ni; 9.5-11.0 Co; 4.4-4.8 Mo; 0.15-0.45 Ti; 0.05-0.15 Al; 0.003 B; 0.02 Zr; 0.05 Ca, and the rest -- Fe, with B, Zr, and Ca are additives.

Heat treatment of the steel consists of homogenization for four hours at 1205° C, subsequent cooling in air and aging for three hours at 480° C.

The mechanical properties of the steel are as follows: $\sigma_T = 160$-173 kg/mm^2, $\sigma_B = 170$-183 kg/mm^2, a_H according to Sharpy values 1.6-2.6 km/cm^2, relative elongation δ 5-11% and ψ 11-34%.

Steel castings made of the new steel correspond in their strength qualities to the earlier developed 8% nickel steels in rolled or forged state. Good weldability of the steel affords its use in any kinds of welding.

For comparison, Tables 10 and 11 present the compositions and properties of several present-day casting steels of different classes produced in the US. As these data show, based on physicochemical and technological properties alloy construction casting steels differ little from deformable construction steels of similar compositions. Plasticity and toughness in cast steels along the grain are somewhat lower, but counter to the grain -- higher than in deformable steel.

STEELS OF SPECIAL USES

Steels of special uses are assigned physical or chemical properties essential for the conditions of their performance. We can mention the following from steels of this kind that are of interest in shipbuilding:

construction stainless;
corrosion resistant;
nonmagnetic;
tool;
wear-resistant;
heat-resistant;
cryogenic.

High-strength Stainless Steels of Construction Use

Though when modern high-strength steels are formulated, as a rule, there is an effort to attain desired mechanical properties with low content of alloying additives, using external and internal mechanisms of strengthening, still sometimes steels of high alloying content have to be used.

This is necessary in those cases when, in addition to high strength properties, the material is required to have increased resistance to the action of chemically aggressive media, abrupt fluctuations in temperature, dynamic cyclic loading, etc.

Stainless steels[2] can be regarded as typical representatives of this group of relatively new steels that differ in high resistance to atmospheric and marine corrosion, resistance to the action of many aggressive agents and intercrystalline corrosion, and exhibit high strength and technological properties. Stainless steels each year are finding ever-greater use in shipbuilding; they are going into manufacture of

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[2] The term stainless usually denotes steel that well withstands atmospheric corrosion in contrast to acid-resistant steel, and that is resistant also to acids and various aggressive agents.

parts of ship mechanisms, ship installations, reinforcement, hull structures, screw propellers, underwater vanes of high speed ships, etc.

Also known are very many grades of stainless steels, and their number is steadily rising in accord with specialization of requirements on these materials and continual improvement of their properties. Many grades of stainless steels have been introduced in the appropriate GOST (5632-61 and others) and are described in detail in the literature (1.24, 1.27).

The composition of all modern stainless steels include a significant amount of chromium ($\geqslant$ 12-13%), causing formation of a strong oxide film on the steel surface, shielding the steel against failure (passivating surface).

The role of the other alloying elements in these steels amounts to ensuring austenitic structure (Ni, Mn) and strengthening via dispersion hardening (Al, Cu, B).

Stainless steels can in approximate terms be grouped in relation to their predominant structure in the following classes:

martensitic-ferritic (semiferritic) steels (MF, PF);
martensitic steels (M);
ferritic steels (F);
austenitic-martensitic steels (transitional class) (AM);
austenitic-ferritic (AF);
austenitic steels (A).

In some cases, some stainless steels of the same composition can have different predominant structure depending on the conditions of manufacturing and treatment, and appropriately enough are placed in different classes. In most cases, the class of steel determined by structure is retained through different treatment conditions.

An example of new stainless steels of the martensitic class can be cited in the steel VNS6 listed in Tables 12 and 13.

The same class takes in the stainless dispersion-hardened steel (1.28) of the following composition.

C	Si	Mn	Ni	Cr	Cu	Ti
0.08	0.7	1.0	4.0-5.5	14-15	1.75-2.5	0.6

Following heat treatment (hardening at 950°, air, aging at 350-450° for one hour), this steel exhibits the following strength.

σ_B, kg/mm^2	σ_T, kg/mm^2	δ , %	ψ , %
132	120	6.2	5.3

New semiferritic stainless steels include a steel easily worked on by cutting, proposed (1.29) for manufacture of parts of ship reinforcement. The composition (%) of this steel is as follows:

C	Si	Mn	Cr	Mo	S	Ni
0.12-0.18	0.3-0.5	0.5-0.8	16.0-17.5	0.2-0.4	0.2-0.3	Up to 0.6

and its mechanical properties are as follow:

$$\sigma_B = 50 \text{ kg/mm}^2; \ \sigma_T = 35 \text{ kg/mm}^2; \ \delta = 16\%; \ \psi = 35\%;$$

$$a_H = 4 \text{ kgm/cm}^2, \text{ Brinell hardness number} = 140\text{-}240.$$

Steel is semiferritic in the predominance of ferrite.

This same class of steels includes the new stainless steel 1Kh14ND of the semiferritic (martensitic-ferritic) class, shown in Tables 12 and 13.

A representative of new austenitic-ferritic steels is the stainless steel OKh17N3G4D2T presented above in Table 10, which is used in shipbuilding both in the cast state, and also after heat treatment; this steel consists of austenite (55-70%) and ferrite (45-30%). In the cast state of steels, accumulation of carbides is observed along grain boundaries.

New steels of the austentic-ferritic class includes the stainless steels EP26 and VNS4 (Table 12). Complexly-alloyed chrome-nickel-molybdenum-copper steel with titanium VNS4 (Kh20N6MD2T) exhibits high corrosion resistance, is not prone to intercrystalline corrosion, and is deformed in the cold and hot states. For softening, the steel undergoes hardening, and for strengthening -- tempering aging.

TABLE 12

Chemical Composition of High-Strength Stainless Steels

ⓐ Марка	ⓑ Страна	ⓒ Содержание элементов (предельно), %					
		C	Si	Mn	Cr	Ni	ⓓ прочие
1Kh18NA5(EP26)	ⓔ СССР	0,1	0,8	4—6	17—20	1,5—2,5	N_2 0,15—0,25
2Kh13N4G9(EP100) 2Kh17N2		0,15—0,30 0,22—0,28	0,80 0,80	8—10 0,8	10—12 16—18	3,7—4,7 1,5—2,5	
OKh15N9Yu(EI904, SM2)		0,05—0,09	0,7	0,7	14—16	7—9,4	Al 0,7—1,3
Kh17N5M3(EI925, SN3)		0,06—0,10	0,7—0,4	0,6—0,7	16—17,5	4,5—5,5	Mo 3—3,5
Kh15N7YuM2(SN4)		0,05—0,10	0,7	0,7	14,2—15,8	7—8,5	Mo 1,6—2,4; Al 1,2—1,8
OKh17N7Yu(EI973)		0,09	0,8	0,8	16—17,5	7,0—8,0	Al 0,50—0,90
EP310(VNS5)		0,10—0,16	0,7	1,0	14—16	4—5	Mo 2,2—2,9; N_2 0,05—0,1
EP288(SN2A)		0,05—0,09	0,7	1,0	15—17,5	5—8	—
VNS2		0,08	0,7	1,0	14—15,5	4,5—5,5	Cu 1,75—2,25
VNS4		0,10	0,7	1,0	19,5—21,5	5,0—7,5	Cu 1,8—2,5; Ti 0,65
VNS6		0,23—0,28	0,6	0,6	11,5—13,0	1,5—2,0	W 1,5—2,0; Mo 1,6—2,0; V 0,2—0,3

TABLE 12
[concluded]

ⓐ Марка	ⓑ Страна	ⓒ Содержание элементов (предельно), %					
		C	Si	Mn	Cr	Ni	ⓓ прочие
1Kh14ND	ⓔ СССР	0,10	0,4	0,3—0,6	13—15	1,2—1,6	Cu 1,2—1,6
Kh13N20TYu		0,07—0,14	1,2—1,6	0,4—0,8	12—15	18—21	Ti 1,7—2,0; Al 2,4—2,8
23Kh13NVMFA(EP65)		0,20—0,28	0,6	0,6	12—13,5	2—2,6	V 0,4—0,7; W 1,6—2,2; Mo 0,45—0,65
17-7PH	ⓕ США	0,09	1,0	1,0	16—18	6,5—7,8	Al 0,75—1,5
PH15-7M0		0,1	1,0	1,0	14—16	6,5—7,8	Mo 2—3; Al 0,75—1,5
AM-350		0,12	0,5	0,9	16—17	4—5	Mo 2,5—3,2; 0,1 N
AM-355		0,15	0,5	0,95	15—16	4—5	Mo 2,5—3,2; 0,1 N
AM-357		0,24	0,5	0,75	14	4	Mo 2,75; 0,13 N
17-14PH		0,12	—	—	16	14,0	Mo 2,5; Cu 3,0; Ti 0,25
17-4PH		0,07	1,0	1,0	15,5—17,5	3—5	Cu 3—4; (Nb+Ta) 0,25—0,45
FV520		0,07		1,0	16	6	Mo 1,5; Cu 1,5; Ti 0,3 Nb 0,35

LEGEND: a) grade;
b) country;
c) content of elements (limiting);
d) others;
e) USSR;
f) US.

TABLE 13

Main Mechanical Properties of Certain High-Strength Stainless Steels

ⓐ Марка	ⓑ Страна	ⓒ Механические свойства					ⓓ Примечание
		ⓔ σ_T, кГ/мм²	ⓔ σ_B, кГ/мм²	δ, %	ⓕ a_H, кГм/см²	ⓖ класс	
1Kh18NA5(EP26)	ⓗ СССР		75—113	36—54			
2Kh13N4G9(EI100)		25	65	35		AM *	
2Kh17N2		110	150	4		AM	
0Kh15N9Yu(EI904)		90	120			AM	
Kh17N5M3(EI925,SN3)		85	120			AM	
Kh15N7YuM2(SNCh)						AM	
0Kh17N7Yu(EI973)		80—105 52—70	92—106	10—23 >12	 >5	AM	
EP310 (VNS5) EP288 (SN2A)	ⓗ СССР	90—105 85	120—145 110—120	10—16 10—16	 12	AM AM	ⓘ Термообработка по оптимальному режиму
Kh15N5D2T (VNS2)	ⓗ СССР	80—130	90—140	9—4	5	AM	ⓙ Первые значения — при закалке на воздухе; вторые — при нагартовке и старении
Kh120N6MD2T(VNS4)	ⓗ СССР	60—100	80—130	2—15	6		ⓚ Первые значения — при термической обработке; вторые — при нагартовке и старении

TABLE 13 [concluded]

ⓐ Марка	ⓑ Страна	ⓒ Механические свойства					ⓓ Примечание
		ⓔ $\sigma_т$, $кГ/мм^2$	ⓔ $\sigma_в$, $кГ/мм^2$	δ, %	ⓕ $a_н$, $кГм/см^2$	ⓖ класс	
VNS6(EP311)	ⓗ СССР	95—107	115—140	6—13	4,5	М	
1Kh14ND	СССР ⓗ	50	62	15	3	МФ (ПФ)	ⓜ Для фасонных отливок и винтов неледового плавания
		45	60	15	6		ⓝ Для винтов ледового плавания
Kh13N20TYu	СССР ⓗ		95—105	30		А	
23Kh13NVMFA(EP65)	СССР ⓗ	110	155	10	4		ⓞ Нормализация — при 1050° С; закалка при 1050—1070° С; отпуск при 300—350° С
17-7PH PH15-7MO AM-350 AM-355 AM-357	ⓛ США	129—182 140—157 126 128—196 212	140—185 147—168 147 154—203 218	2—9 6—7 15 2—20 4		АМ АМ АМ АМ АМ	

ⓟ * АМ — аустенитно-мартенситный; А — аустенитный; М — мартенситный; МФ — мартенситно-ферритный; ПФ — полуферритный.

LEGEND: a) grade; b) country; c) mechanical properties; d) remark; e) kg/mm^2; f) kgm/cm^2; g) class; h) USSR; i) heat treatment under optimal conditions; j) first values -- for hardening in air; second values -- cold hardening and aging; k) first values -- for heat treatment; second -- for cold hardening and aging; l) US; m) for shaped forgings and propellers of non-ice navigation; n) for ice-navigation; propellers; o) normalization -- at 1050° C; hardening, 1050-1070° C; tempering, 300-350° C; p) * AM -- austenitic-martensitic; A -- austenitic; M -- martensitic; MФ -- martensitic-ferritic; ПФ -- semiferritic.

Of the new stainless steels we must also note steels of the austenitic class, strengthened by aging. These steels were formulated on the basis of earlier known chrome-nickel and chrome-manganese alloys. Under the action of various additives, these alloys acquire the capacity to be dispersion strengthened owing to the segregation of disperse carbide and intermetallic compounds.

Standard austenitic stainless steels do not always measure up to the requirements placed on strength properties, since the creep limit of these steels usually does not exceed 22 kg/mm^2 (at room temperature). The strength of austenitic stainless steels can be increased by subjecting them to cold deformation, but in so doing the plasticity of the metal is severely worsened, as a result of which the necessary mechanical properties of the steel during its operation at elevated temperatures cannot be ensured.

Considerably increasing the strength properties of these steels is afforded by alloying with elements that promote dispersion hardening, also ensuring good technological qualities.

Studies show that strengthening a solid solution of austenitic stainless steels does not afford a substantial increase in strength properties at room temperature; this strengthening more sizably improves mechanical properties at high temperatures (1.30).

The most effective method of increasing strength properties of these steels must be regarded as dispersion hardening. In dispersion hardening associated with carbides, the extent of strengthening depends on the overall content C + N + P. In those cases when the content of these elements in the total approaches 0.4-0.5%, a breaking point of about 96-110 kg/mm^2 can be ensured.

If the total of these elements contains more than 0.5%, the process of dispersion hardening is accompanied by a reduction in plastic properties. Combination of mechanical properties proves optimal when the breaking point is about 96 kg/mm^2.

The high mechanical properties of austenitic steels are ensured in those cases when intermetallides participate in the process of dispersion hardening.

Such steels include austenitic steels alloyed with Ni-Al, Ni-Ti, and Ni-Al-Ti.

In this case, dispersion hardening occurs at 750-800° C and ensures good mechanical properties at elevated temperatures. An example of such a steel can be cited in the steel containing 25% nickel, 15% chromium, 1% aluminum, and 2.5% titanium [sic], characterized by a combination of plastic and strength properties, for which its breaking point attains a value of 110 kg/mm^2.

Many steels of this type have been formulated in recent years in foreign countries; the characteristics of these steels are given in Table Tables 12 and 13.

The newest and most promising steels in shipbuilding must take in high-strength stainless steels of the transitional, austenitic-martensitic class, the main feature of which is the possibility of widely varying the mechanical properties via heat treatment and cold plastic deformation.

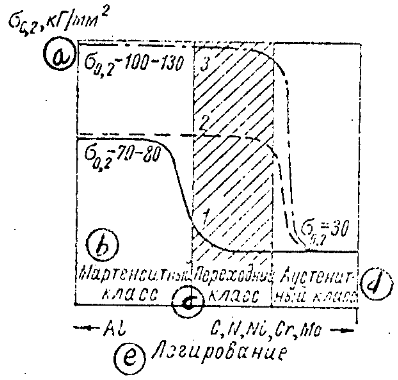

Figure 3. Variation in creep limit of aging low-carbon stainless steels in relation to alloying. 1 -- hardening; 2 -- hardening and cold working; 3 -- hardening, cold working, and aging. LEGEND: a) kg/mm^2; b) martensitic class; c) transitional class; d) austenitic class; e) alloying.

These steels can be brought into a "mild" state, in which their structure will consist of austenite, or into a strengthened state -- then their structure will consist of martensite.

The position of these steels in the system of steels of austenitic and martensitic classes is shown schematically in Figure 3 (1.32).

The beginning of the martensitic transformation in these steels occurs at a temperature close to room temperature.

In cold working austenite is transformed into martensite; subsequent tempering - aging leads to dispersion hardening of the α-phase.

This treatment makes it possible to attain high mechanical properties of the steels (1.33).

If we increase the extent of alloying of martensitic steels with elements that reduce the temperature of the martensitic transformation, their transition to the austenitic class takes place. This change in structure leads to a substantial decrease in the strength and creep limit. Steels of the transitional class exhibit specific features.

After steel is hardened in water or in air, austenitic structure generally predominates, therefore steel has a low hardness value and low creep limit with high plasticity and toughness.

Steels of the transitional class in contrast to austenitic have a high strength value, which is accounted for by the transformation of austenite into martensite with plastic deformation during the period of specimen testing. By the onset of failure of specimen, in the metal is formed a sizable amount of martensite and, hence, its properties determine the strength value.

When steel is cold-worked, intensive martensitic transformation takes place, which leads to an increase in strength and especially of the creep limit of steel. However, a sizable amount of austenite remaining in steel even after cold-working makes it possible to produce a favorable combination of high strength and toughness.

In cold plastic deformation (rolling, drawing, stamping, etc.), there also is a martensitic transformation in steel. The intensity of the martensitic transformation depends on the deformation temperature. With a small deformation temperature rise (above the point M_{α}), the martensite transformation is halted.

When steels are heated up to 650-850°, there is an impoverishment of the austenite in carbon and in carbide-forming alloying elements, which raises the martensite point. Therefore, with subsequent cooling to room temperature, the martensite transformation takes place. At 650-850° the carbides are segregated chiefly along the grain boundaries, which can produce brittleness of the steel following martensitic transformation and aging. In specimens containing domains of delta-ferrite, the carbides are segregated mainly along the boundaries of such domains with austenite, which to a large extent reduces the segregation of carbides along grain boundaries between austenite grains and, hence, reduces the brittleness of steel.

Aging steels of the transitional austenitic-martensitic class are additionally strengthened at 400-600°. In aging, martensite and the delta-ferrite domains are strengthened; austenite is not. Therefore, aging of steels of the transitional class is carried out only following heat treatment producing martensitic transformation, or after cold plastic deformation.

Alloying elements reducing the martensitic point (C, N, Ni, Cr, Mo, and Mn) promote the transition of steel from the martensitic class to the austenitic.

If in the steels of the transitional class the content of carbon and other alloying elements reducing the martensitic point is increased, the intensity of strengthening following cold working and heating at 750° is reduced. Simultaneously, the strength is reduced and the plasticity of the hardened steel is increased.

Increasing the amount of aluminum, promoting a rise in the martensitic point, brings the steel structure close to the martensitic (Figure 4). Also, introduction of aluminum speeds up the aging process.

With a specific content of alloying elements, steel can contain delta-ferrite. In the presence of delta-ferrite, the field of steels of the transitional class as to content of alloying elements is substantially narrowed.

If the hardening temperature is changed, as a result of dissolution and segregation of carbides and the corresponding changes in the chemical composition of the austenite, the martensitic point can be sharply shifted.

Steels containing titanium, with a substantial rise in hardening temperature (up to 1050° C), producing dissolution of carbides containing titanium, can pass from the martensitic class to the transitional.

Cold plastic deformation of steels of the transitional class produces intensive strengthening (Figure 5). And the creep limit will rise more abruptly than the strength value.

Cold working, just as cold hardening, is one of the main methods of strengthening steels of the transitional class. The intensity of the martensitic transformation depends chiefly on to what extent the steel approximates in composition the martensitic or the austenitic classes, and on the completeness of dissolution of the carbides determining the alloying capacity of the austenite.

A typical steel of the transitional (AM) class with improved properties is the new dispersion-hardening stainless steel 0Kh17N7Yu, used for winged installations of ocean-going vessels (Tables 12 and 13). In the cast state, after forging, and also after hardening in air from 1050-1070° C, it consists of austenite and ferrite. After twofold intermediate treatment and tempering, the structure of the steel is sorbite, somewhat oriented along the martensite, austenite, and a certain amount of residual austenite and ferrite. A similar steel has been developed in the US; it contains 0.02-0.05% C; 13.5-15.59% Cr; 7.5-9.5% Ni; 2.0-3.0% Mo; 0.75-1.5% Al; up to 1% Si and 1% Mn. It differs from stainless steels of earlier produced grades in the combination of high toughness and strength, stability of properties under conditions of prolonged performance at elevated temperatures, resistance to corrosion under stress, and good weldability (1.31).

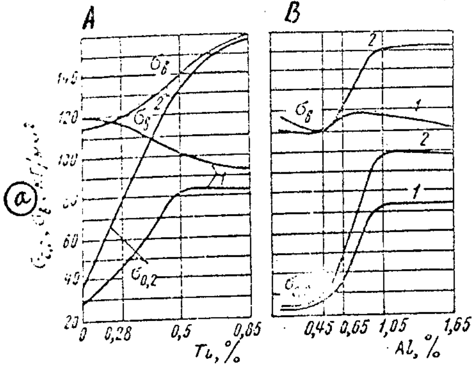

Figure 4. Mechanical properties of steel as a function of content of titanium and aluminum (%): A -- 0.05 C; 0.30 Si; 0.70 Mn; 16.0 Cr; 6.8 Ni; B -- 0.06 C; 0.25 Si; 0.82 Mn; 16.1 Cr; 6.6 Ni.
1 -- hardening from 1050° C;
2 -- hardening from 1050° C;
3 -- aging at 500° C for one hour.
LEGEND: a) kg/mm^2.

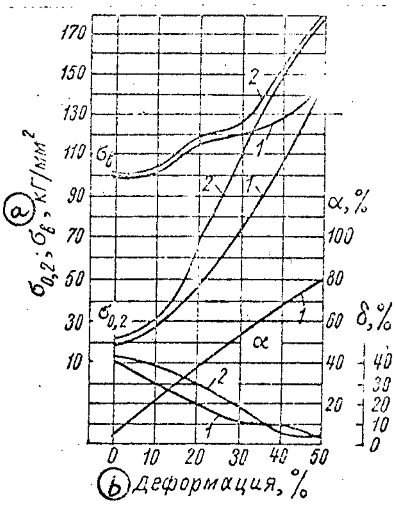

Figure 5. Effect of plastic deformation in rolling on the amount of martensite and mechanical properties of the steel SN2.
1 -- after deformation; 2 -- after aging at 480° C for 1 hour.
LEGEND: a) kg/mm^2; b) deformation.

To produce the highest mechanical properties, steel is treated under the following set of conditions: hardening from 930° C in air, subsequent cooling down to -80° C (not later than one hour after hardening), and maintenance at this temperature for eight hours, aging at 510° C for one hour. After this treatment, the steel acquires a structure that is 80% martensite (remainder -- austenite and delta-ferrite) and exhibits the following properties: $\sigma_B = 165$ kg/mm^2, $\sigma_T = 150$ kg/mm^2, $\delta = 5\%$, and HRC = 49.

Following normalization (temperature 980-1010° C), $\sigma_B = 88$ kg/mm^2, $\sigma_T = 39$ kg/mm^2, and $\delta = 25\%$.

Prolonged exposure at a temperature of 340° C (about 1000 hours) has no effect on mechanical properties. Steel is not sensitive to notches, and this sensitivity is not increased as a result of prolonged exposure under load at elevated temperatures.

Resistance to corrosion under stress in a sea atmosphere is fairly high, and specimens preliminarily exposed for 1000 hours at 340° C did not fail under a load of 0.5 σ_T for ten months, but under a load of 0.8 σ_T they failed in 84-86 days.

In the normalized state (structure -- 90% austenite) steel welds satisfactorily; rods of the same composition are used as additive material. After heat treatment following the optimal set of conditions, the strength of the weld seam at temperatures from -80 to 340° C is 90-100% of the strength of the basis metal.

Stainless high-strength steels exhibit high strength and resistance to oxidation in a gaseous medium at temperatures up to 600° C, satisfactory corrosion resistance in a humid atmosphere and in freshwater, if the surface of the steel has a cleanness $\nabla 7$ and higher.

These steels also go into the manufacture of welded and nonwelded parts performing for long periods of time under atmospheric conditions and in an environment of combustion products at temperatures up to 300° C and for short periods -- up to 800° C.

Tables 12 and 13, in addition to data on domestic stainless construction steels of the most widely used grades, for sake of comparison compositions and properties of several steels of the transitional austenitic-martensitic class (AM) produced in the USSR and abroad are given.

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- END -