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This pamphlet examines in detail the basic characteristics of stainless steels, which are being used to an increasing extent in the production of ships' propellers of the highest and the normal classes; presents comparative data relative to operational durability of stainless steel propellers and of those made of cast iron, carbon steel and colored metal alloys.

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STAINLESS STEEL SCREW PROPELLERS

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In the course of development of modern shipbuilding, requirements imposed on the material used in their propellers are constantly growing in severity. This is a result of the increase in power and number of revolutions of the engines, increase in cruising speeds and in the loads on the propellers, as well as from the effort to improve the efficiency and durability of the propellers. The growth of navigation in the Arctic and the Antarctic regions, where propellers operate at low temperatures and are subjected to impact and abrading loads also influences the growing severity of requirements.

As a result, there is a growing number of cases where the more common metallic materials used in propellers - carbon steels and special brasses - no longer meet the requirements of designers and operators. Carbon steel propellers have a very low resistance to corrosion and erosion. Their service life often amounts to only 1.5 - 2.5 years. Losses resulting from rapid corrosive and erosive destruction of carbon steel propellers amount to tens of millions of rubles per year.

Special brass due to its inadequate strength (σ_m = 20-25 kg/mm^2) is not suited for use in highly stressed propellers of modern vessels. Under certain operating conditions brass deteriorates rapidly due to de-zincing and corrosive disintegration. In a number of cases, propellers made of special brass have been destroyed due to their poor resistance to corrosive fatigue. The currently growing trend toward substitution of bronze-aluminum in place of special brasses in some cases also fails to satisfy fully the designers' requirements, due to limitation in the strength of bronze-aluminum castings (σ_m=22-30 kg/mm^2)

Consequently, prospective materials for fabrication of propellers of various classes and types are the stainless steels. Use of stainless steels with a low nickel content furnishes a manifold increase in service durability of propellers of the conventional class and saves large amounts of rare colored metals in the production of the highest type propellers.

Fabrication of highly stressed propellers of the highest class with the use of highly durable and high-strength dispersionally hardened stainless steels leads to an improvement in service characteristics (mechanical strength hydrodynamic properties, etc.) of propellers, due to a 1.5-2 fold increase in strength. In addition, stainless steels, compared to bronzes and brasses, have a much better resistance to destruction due to erosion and cavitation and a higher resistance against corrosive fatigue. Among the advantages of stainless steels should also be listed their high resistance to corrosional cracking in sea water and their specific gravity, lower than that of brasses.

The tonnage of stainless steel used in the fabrication of propellers is growing annually. A substantial number of stainless steel propellers have been put into service in ships and have demonstrated their durability under operating conditions.

Technology of fabrication of stainless steel propellers is being perfected. New casting methods are coming into use, bringing about an investment in quality of cast blade surfaces. New molding materials used reduce sand crust and obstructions in castings; allowances for machining are reduced through calculation (in design of casting appliances) of the casting deformations of the blades, etc. Introduction of such improvements permits even a greater increase in production of steel propellers through elimination to a large extent, of the difficulties associated with the technological properties of stainless steels (lower fluidity in casting and more difficult machining).

There is very little information in technical literature relative to properties of stainless steels used in propellers or the technology of their production. This hampers further penetration of this field by stainless steels. This article makes the first attempt to assemble and systematize the available information relative to this subject.

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CHAPTER I

STRUCTURAL STEELS, CAST IRONS, AND COLORED METAL ALLOYS USED IN THE FABRICATION OF SCREW PROPELLERS FOR SHIPS.

The use of various metallic materials in the fabrication of ships' propellers is basically governed by various standards and technical specifications, both in the USSR and abroad. The most complete classification of such materials appears in GOST 8054-59, compiled in the USSR.

In compliance with this standard, metallic propellers of all types of ships of the merchant marine are subdivided into two classes - the highest and the normal. Propellers of the highest class are distinguished by a cleaner surface, greater precision of dimensions, shape and weight and also by their greater resistance to corrosion and erosion.

GOST 8054-59 establishes the uses for the following metallic materials: for fabrication of propellers of the highest class:

1) mark LMtsG 55-3-1 brass per GOST 1019-47;
2) stainless steel - with no reference to brand (in accordance with technical specifications accompanying the order)[1].

Footnote 1: $\sigma_B \geq 60$ kg/mm^2; $\delta_5 \geq 15\%$; $\psi \geq 35\%$; $\alpha_k \geq 3$ kgM/cm^2.

For fabrication of propellers of the normal class:

1) stainless steel - with no reference to brand (in accordance with technical specifications accompanying the order)[1];
2) carbon steel marks 25L, 30L, and 35L in accordance with GOST 977-58 (Group II);
3) cast iron marks SCh 21-40, SCh 24-44, SCh 28-48, SCh 32-52 and SCh 35-56 according to GOST 1412-54;
4) high-strength cast iron VCh 40-10 according to GOST 7293-54.

In addition to the materials covered by GOST 8054-59, the following are used in the USSR in the fabrication of ships' propellers:

1) aluminum brass having high strength and durability, designation LAMtsG 67-5-2-2 (for small propellers of the highest class).
2) cast, forged and rolled steel of weldable type (for welded propellers of the normal class.

Abroad, screw propellers of the highest class are made chiefly of special brasses and aluminum bronzes. Special brasses are being increasingly displaced by aluminum bronzes because of greater strength, resistance to fatigue, resistance to corrosion and erosion, absence of tendency toward corrosive cracking and lower specific gravity of the latter.

Stainless steels are used only to a limited extent in the production of propellers of the highest class.

Abroad, propellers of the normal class are cast principally of carbon steels and cast irons; colored metal alloys based on copper (brasses and bronzes), stainless steels and structural steel alloys are used in some cases. The latter are used instead of carbon steels, chiefly for the sake of increasing the durability of propellers in the course of operation due to their higher mechanical strength and the resistance to erosive deterioration possessed by the structural steel alloys.

Basic data relating to the properties of materials used in the USSR and abroad in the production of propellers is furnished below.

Structural Carbon Steels.

In accordance with GOST 8054-59, carbon steel designations 25L, 30L and 35L (Group II) are used in the casting of propellers. Per GOST 977-58 the chemical composition of castings of the above steels must conform to the values listed in Table 1. Their mechanical properties, subsequent to heat treatment, must meet the requirements of Table 2.

Table I

Chemical composition of 25L, 30L and 35L steels

Steel Designat'n.	Chemical composition, %									
	C	Mn	Si	Ni	Cr	Cu	S		P	
							Basic Steel	Acid Steel	Basic Steel	Acid Steel
				not over						
25L	0.22-0.30	0.5-0.8	0.17-0.37	0.3	0.3	0.3	0.045	0.06	0.04	0.06
30L	0.27-0.35	0.5-0.8	0.17-0.37	0.3	0.3	0.3	0.045	0.06	0.04	0.06
35L	0.32-0.40	0.5-0.8	0.17-0.37	0.3	0.3	0.3	0.045	0.06	0.04	0.06

Table 2

Mechanical properties of 25L, 30L and 35L steels

Steel Designation	σ_m	σ_V	δ_5	ψ	a_k, kgM/cm^2	Brinel Hardness H_B
	kg/mm^2		%			
	Not less than					
25L	24	45	19	30	4.0	124 - 179
30L	26	48	17	30	3.5	-
35L	28	50	15	25	3.5	138 - 190

In some cases, principally on comparatively small and low-speed vessels, (certain types of tugs, self-propelled barges, etc.), welded propellers of normal class with stamped blades of rolled plate and rolled, forged, or cast hubs are being used. The following designations of weldable steels are employed:

1) for blades - rolled plate St. 3C; St. 4C. -
2) for hubs - rolled sections St. 3C; St. 4C; 10; 15; 20.
3) for forged hubs - St. 3; St. 4; 10; 15; 20; and other weldable steels;
4) for cast hubs - 20L.

The chemical composition and levels of mechanical properties of carbon steels used in casting propellers for vessels of the German merchant marine (taking into account the requirements of German Lloyd /16/, /38/, are listed in Table 3. Steel designation Stg 45.81 is specified for casting propellers for cargo carriers, tugs and passenger vessels of medium displacement. Stg 52.81 steel designation is specified for propellers of large vessels and icebreakers.

According to the rules of English Lloyd (1956) /39/ steels having $\sigma_V = 41 - 55$ kg/mm^2 and a relative elongation of not less than 20% must be used in steel castings of propellers and other shipbuilding components. The following relationship between the actual values of ultimate tensile stress and relative elongation must also be maintained: $\sigma_V + \delta \geq 57$.

Tension failure tests must be made on specimens having the following dimensions, mm:

Diameter d	Calculated length l
14	50
20	75
25	90

Table 3

Chemical composition and mechanical properties of carbon steels for cast propellers of the German merchant marine.

Steel Designation	Chemical composition, %					
	C	Mn	Si	P	S	S+P
			Not higher than			
Stg 45.81	0.25-0.30	0.5-0.7	0.35	0.05	0.05	0.09
Stg 52.81	0.28-0.32	0.8-1.0	0.35	0.05	0.05	0.09
Steel Designation	**Mechanical properties**					
	σ_V, kg/mm^2	σ_t, kg/mm^2	δ_s, %	Angle* of bend degr.	Brinel Hardness, H_B	
	not less than					
Stg 45.81	45	22	22	90	125	
Stg 52.81	52	25	19	90	145	

* Mandrel diameter in bending test is three times specimen thickness

Bending tests are made on rectangular specimens of 25 x 19 mm cross-section, with corners rounded off to 1.5 mm, and on circular section ones, with a d = 25 mm. These specimens must withstand 120° bends made over a pin having a diameter d = 50 mm.

According to "Rules for the Construction and Classification of Steel Ships" of Bureau Veritas (France) /37/, shipbuilding steel castings, including propellers, are tested in tension, cold bending, impact fall (sometimes replaced with impact blow tests) and hammer tapping.

Two types of tension specimens are used:
A (d = 13.8 mm; l = 100 mm) and B (d $\geq$ 15 mm; l = 15d).

Ultimate tensile strength must be within 40-55 kg/mm^2. Minimum values of relative elongation corresponding to the ultimate tensile stress are shown in Table 4.

Table 4.

Relations between standard elongations and ultimate tensile strength for cast steel for propellers according to Bureau Veritas.

Specimen	σ_V, kg/mm^2			
	40	45	50	55
	δ, %			
A	20	18	16	14
B	20	20	18	16

The cold bending test is made on rectangular specimens with 25 x 25 mm sections, length = 250 mm, over a pin having d - 50 mm. Minimum angles of bending of specimens without cracking, related to the magnitude of the ultimate tensile strength, are shown in Table 5.

Table 5.

Relation between standard angles of bend and the ultimate tensile strength of cast steel used in propellers according to Bureau Veritas.

σ_V kg/mm^2	40	45	50	55
Angle of bend, degr.	120	120	90	90

Impact test (in lieu of dropping the casting) is made on bars measuring 30 x 30 x 225 mm. The distance between supports is 160 mm; weight of drop hammer 18 kg; height of drop 2.75 M. The specimens must withstand 10 blows without fracture.

Alloyed Structural Steels.

Alloyed structural steels, having higher strength and ductility than carbon steels, are often used in casting propellers (complete and in parts) of the normal type. This leads to a certain reduction in weight of the propellers and reduces the thickness of the blades, it also increases their capacity to take impact loading under operating conditions. The chemical composition and mechanical properties of these steels are shown in Table 6.

Nickel steel with a 3% average nickel content was formerly used for cast propellers. This steel, along with an increase in strength, also possesses greater plasticity and resistance to impact at low temperatures. Because of these properties, this steel was used in casting propellers (chiefly with demountable blades) for icebreakers. Currently, steel with 3% Ni is not used in the USSR in the production of propellers of the normal type, since operational experience does not confirm any appreciable advantages resulting from its use.

Steel alloyed by small additions of copper and chrome is used in Holland in casting propellers. There are indications that such steel is much more corrosion and erosion resistant than carbon steel in sea water.

Chrome-nickel-molibdenum structural steel is used in Belgium for improved resistance to erosive damage to propeller.

Table 6

Chemical composition and mechanical properties of alloyed structural steels used in propellers.

Steel	Country	Chemical composition, %									Mechanical properties					
		C	Si	Mn	Ni	Cr	Cu	Mo	S	P	σ_y, kg/mm²	σ_b, kg/mm²	δ%	a_k [illegible]	[illegible]	[illegible] HB
Nickel	USSR	0.2-0.3	0.2-0.4	0.5-0.8	2.7-3.2	—	—	—	≤[illegible]	≤[illegible]	>55	—	>20 (?4-5)	—	—	—
Chrome-Cuprous	Holland	0.2-0.4	0.2-0.75	0.5-1.0	—	1.0	2.0	—	≤0.05	≤[illegible]	50-55	25-29	18	4	16	[illegible]
Chrome-nickel-molibdenum	Belgium	—	—	—	3.5	1.25	—	0.25	—	—	[illegible]	75-80	10-12	6	—	[illegible]
Nickel-Vanadium	USA	0.18	—	—	1.5	—	—	[illegible]	—	—	56.2	42.1	30	[illegible] 31	[illegible] 55	—
Nickel	USA	0.13	—	—	2.5	—	—	0.25	—	—	57.5	39.4	30	—	[illegible]	—

CAST IRONS

Cast iron propellers of the normal class, conforming to GOST 8054-59, are cast of gray cast iron (including a modified one) with graphitic laminations (designations SCh 21-40; SCh 24-44; SCh 28-48; SCh 32-52 and SCh 35-56). Table 7 shows the levels of mechanical properties of the above cast irons per GOST 1412-54. Designations SCh 28-48, SCh 32-52 and SCh 35-56 are produced by the modification method.

Table 7.

Mechanical properties of cast irons, according to GOST 1412 - 54

Cast iron Designation	Mechanical properties, not less than				
	Temporary tensile strength kg/mm²	Temporary flexural strength kg/mm²	Deflection reading (mm) for support spacing, mm: 600	300	Brinell Hardness H_B
C Ch21-40	21	40	9	3	170 - 241
C Ch24-44	24	44	9	3	170 - 241
C Ch28-48	28	48	9	3	170 - 241
C Ch32-52	32	52	9	3	187 - 255
C Ch35-56	35	56	9	3	197 - 269

Table 8.

Prescribed mechanical properties of cast iron for use in ships' propellers according to Bureau Veritas.

Cast iron Designation	Shear test	Bending test	Brinell Hardness
	σ_y, kg/mm²	load at failure kg.	H_B
High strength	23	500	160 - 200
Strong	18	400	140 - 200

For casting of more highly-stressed propellers GOST 8054-59 specifies the use of high-strength cast iron, designation VCh 40-10, GOST 7293-54. VCh 40-10 cast iron (containing globular graphite), on specimens cut from trefoil-shaped stock, must have the following minimum values of mechanical properties: σ_v = 40 kg/mm^2; σ_t = 30 kg/mm^2; δ = 10%; σ_k (on specimens 10 x 10 x 55, without notching) = 3 kgM/cm^2; H_B = 156— 197.

Regulations of the Bureau Veritas require the metal from castings of gray cast iron propellers to be tested in shear, bending and for hardness. The shear test is made on cylinders of 25 mm cross-section. Bending test is made on rectangular specimens 8 x 10 x 40 mm, with a 30 mm spacing of supports. Table 8 lists the requirements for cast iron for propellers and other components, according to Bureau Veritas regulations.

Table 9 gives the standards of chemical composition and mechanical properties of gray cast iron for casting propellers of the normal class for merchant vessels, effective in Germany.

Table 9.

Chemical composition and mechanical properties of cast iron for use in propellers, according to German specifications.

Cast iron designat'n	Chemical composition, %					σ_B, kg/mm^2
	C	Si	Mn	P		
Ge 22.91	2.6-3.0	1.0-1.2	0.8-1.0	⩽0.35	⩽0.08	⩾22
Ge 26.91	2.8-3.2	1.0-1.5	1.0-1.2	⩽0.35	⩽0.08	⩾26

Non-ferrous Alloys.

Currently an overwhelming majority of the highest class propellers in the USSR are cast of LMtsZh 55-3-1 ferro-manganous brass. The chemical composition and mechanical properties of this brass are shown in Table 10.

Chemical Composition and Mechanical Properties of LMtsZh 55-3-1

Type of copper	Chemical Composition, %					Mechanical properties, not less		
	Cu	Mu	FE	Zn	Total admixtures	σ_B kg/mm^2	δ, %	angle of bending
LMtsZh 55-3-1	53-58	3-4	0.5-1.5	Ost.	≤ 2.0	48	20	30

Under modern methods of designing propellers for strength one of the basic quality indicators of a material is its elastic limit. The LMtsZh 55-3-1 brass has a (approximate) $\sigma_t \geqslant 20$ kg/mm^2 (on specimens cast integral with the blades). Structure of LMtsZh 55-3-1 consists of $\alpha + \beta$ - phases.

In order to increase the strength of a propeller, its efficiency and resistance to corrosive cracking, and to reduce its weight, aluminum-mangano-ferrous brass, designation LAMtsZh 67-5-2-2, is used for casting small propellers. A refined consistency of a similar type of brass used in casting medium and large propellers is designated LAMtsZh 68-5.5-2-2.

Standards of chemical composition and mechanical properties of these two brass designations are shown in Table 11. The LAMtsZh 68-5.5-2-2 brass has a $\sigma_t \geqslant 25$ kg/mm^2 (on specimens cast integral with the blades). Brass LAMtsZh 67-5-2-2 has a structure consisting of $\alpha + \beta$ - phases.

Table 11.

Chemical composition and mechanical properties of brass designations LAMtsZh 67-5-2-2 and LAMtsZh 68-5.5-2-2.

Brass designation and type of propeller.	Chemical composition, %						Mechanical properties		
	Cu	Mn	Fe	Al	Zn	Total ~~addits.~~ impurities	σ_t kg/mm^2	δ %	[illegible]
AMtsZh 67-5-2-2 (Small propellers)	67-70	2 -3	2- 3	5 -6	Balance ~~Excess~~	1.0	62	12	25
AMtsZh 68-5.5-2-2 (Large and medium propellers)	66-70	2 -3	2- 3	5.4 - 5.8	20.5- 22.0	1.0	55	16	-

Prior to World War II all the principal foreign firms in casting propellers of the highest class used $\alpha + \beta$ brasses containing from 33 to 42% Zn and alloyed with various additives. Table 12 gives the data relative to the chemical composition and mechanical properties of these brasses /16/, /33/.

Continuing increase in the speed of vessels and in the power of prime movers demands the imposition of greater proportional loadings on their propellers. This calls for the use of stronger alloys, however, an increase in the strength of special brasses (in the manufacturing specifications for propellers) can only actually be achieved by increasing the proportion of alloying components. This in most cases leads to an increase in the amount of the β-phase in the structure of the alloy and, in consequence, increases the tendency of brasses toward corrosive checking.

Table 12.

Chemical composition and mechanical properties of foreign special brasses used for the casting of propellers

Company	Country	Chemical composition, %							Mechanical Properties	
		Cu	Zn	Mn	Ni	Al	Fe	Sn	V, kg/mm	%
Ansaldo .	Italy	54.0	40.6	1.8	1.8	0.4	1.2	0.2	48.0	20.0
Navy Yard*	USA	56-62	Res.	1.5	-	1.5	2.0	1.5	42.2-54.8	[illegible]5-30
Coppers ..	"	58.0	39.0	1.0	-	1.0	1.0	-	49.0	35.0
Stone ..	England	56.8	40.5	0.19	Trcs	0.22	1.01	1.11	52.5	26.0
Theo.Zeiss	FRG	58.0	38.0	1.0	-	1.0	1.0	1.0	50.0	25.0
Atlass Wke.	"	54.0	40.6	1.8	1.8	0.4	1.2	0.2	50.0	20.0
Loeps . . .	Holland.	56-59	Res.	2.0-5.0	-	1.0	1.0	-	45-50	20.0
Loeps (Spec. bronze).	"	55-60	"	0.5-2.5	-	0.5-2.0	0.5-2.0	-	50-55	22.0
Mitzubishi	Japan	Res.	33.0-36.0	2.5-3.5	-	1.5-2.5	0.2	-	-	-
"	"	"	38.0-41.0	≤0.5	7.0-9.0	0.5	2.0-3.0	-	-	-

* Lead 0.5 - 1.5 %; total additives ≤0.25 %; t 17.6 - 28.1 kg/mm².

Continuing increase in the speed of vessels and of the power of prime movers creates the need to impose greater proportional loadings on their propellers. This requires the use of stronger alloys, however, an increase in strength of special brasses (in the production specifications for propellers) can be only practically achieved through the increase of in the proportion of alloying components. This in most cases leads to an increase in the amount of the β phase in the structure of the alloy and, as a consequence, increases the tendency of these brasses to be subject to corrosive checking.

As a result of research to find new alloys for casting propellers with higher mechanical properties and a smaller tendency toward corrosive cracking and de-zincing, the use of aluminum brass containing approximately 20% Zn and 6% Al was proposed in the USA, even prior to the war.

For example, the following composition of aluminum brass was published in their literature /16/: 5% Al; 3% Fe; 4% Mn; 18% Zn; Cu - remainder. This brass had a σ_V = 58 - 65 kg/mm^2; σ_t - 31 kg/mm^2 and δ = 18 - 25%, and was used for casting propellers for high-speed launches.

To obtain still higher resistance to corrosion and erosion, corrosive fatigue and corrosive cracking, and to ensure higher strength, aluminum bronzes wholly devoid of zinc began to be used abroad even before the war. These studies have been especially intensified recently. A number of prominent companies, especially in England, Holland, and the USA /31/, /32/, /33/, have undertaken the production of large propellers (weighing up to 30.5 T and with diameters up to 6 M) using alloyed aluminum bronzes known as "Nialite," "Nickalium," "Kunial," "Novostone", and others. *Table 13 presents the data relating to the chemical composition and the mechanical properties of these bronzes of which the strongest is the English "Novostone."

According to the regulations of the British Lloyd (1956) ultimate tensile strength of bronze used in propellers and their blades must not be less than 44 kg/mm^2. Actual values of ultimate tensile strength and of relative elongation, obtained by testing, must satisfy the relation $0.635\,\sigma_V + \delta \geqq 48$. However, the absolute magnitude of elongation must at the same time be not less than 15%. Tests for elongation are made on specimens with a d = 14 or 20 mm and an l = 50 mm.

According to the regulations of the French Bureau Veritas, (1951), bronze used in propellers and in their blades must have $\sigma_V \geqq 43$ kg/mm^2. The minimum relative elongation of the alloy used in propellers must satisfy the equation $\sigma_V + 2\delta \geqq 83$, depending upon the magnitude of the ultimate tensile stress. Elongation tests are made on specimens with a d = 18.8 mm and l = 100 mm.

As said before, the structural carbon steels, cast irons, and brasses designated LMtsZh 55-3-1, currently used in the production of propellers, possess certain serious deficiencies which shorten the useful life of propellers and which in many cases fail to provide assurance that the required structural quality is being obtained.

Among these shortcomings are the following:

1) Low mechanical strength (yield point) of carbon steel, cast iron and LMtsZh 55-3-1 brass.

2) insufficient plasticity and ductility of cast iron, as well as the high critical temperature of transition of carbon steel and cast iron into the brittle state.

* See page 16 for Table 13.

3) low resistance to corrosion and erosion in sea water of carbon steel and cast iron.

4) inadequate resistance of carbon steel, cast iron and brass to destructive action of cavitation and to the mechanical wear caused by operation in water containing sand in suspension.

5) carbon steel's, cast iron's and brasses' low resistance to fatigue when imersed in sea water.

6) tendency toward corrosional checking and dezincing possessed by the LMtsZh 55-3-1 brass.

7) high specific gravity of LMtsZh 55-3-1 brass.

Data relative to operational durability of propellers made of various materials is presented below.

Carbon Steel Propellers of the Normal Class. On the basis of operating experience at sea, extending over many years, it has been established that propellers of the normal class made of carbon steel show a very low resistance toward corrosion and erosion. As a result of corrosive and erosive deterioration of steel propellers during theinitial stages of their service, the roughness of their surfaces increases.

Table 14

Average roughness of normal class, carbon steel propellers' blade surfaces.

Initial	After 1 year	After 2 years	After 2.5 Years
mk			
500	1500	2500	3250

In Table 14 (Engr. F.M. Katzman's data) there is a list of comparative values of average roughnesses of propeller blade surfaces, made of carbon steel, related to their length-in-service. It should be noted that these figures apply to blade surfaces and do not represent the deterioration at their edges, where the metal usually turns into a "sponge" after 1.5-2.5 years of service, is riddled by transverse cavities and has often broken off due to loss of strength.

Due to such rapid increase in roughness, there is a substantial drop in the propeller's efficiency, decrease in the vessel's speed and capabilities and an increase in fuel consumption. The ships must be dry docked for overhaul and replacement of propellers, leading to substantial expanse and loss of productive time.

Table 13.

Chemical composition and mechanical properties of foreign special aluminum bronzes used for the casting of propellers

Alloy	Country	Chemical composition, %							Physical properties			
		Cu	Al	Ni	Fe	Mn	Zn	Total Addts.	σv, kg/mm²	σt kg/mm²	δ, %	[illegible] HB
Nealite ..	USA	≥78	9.0-11.5	3.0-5.5	3.0-5.[illegible]	≤3.5	—	≤0.5	≥56.2	—	≥15	[illegible]
Nickelium	"	—	—	—	—	—	—	—	≥65	≥26.4	≥18	[illegible]
BS1400-AB2-C	England	Rmdr.	9.5	4.5	4.0	1.5	—	—	—	22.5	—	160
Langley-Ellois	"	Rmdr.	10.0	5.0	5.0	1.0	—	—	≥[illegible]	—	≥15.0	—
Kunial	Holland	Rmdr	8.5-10.5	3.0-5.5	3.0-5.5	≤3.0	≤0.5	—	60-65	26.0	[illegible]	170
Novostone	England	7[illegible]-76	6.5-9.4	1.5-6.0	2-4	10-15	—	—	62	30	22.0	—
Osterman Companies	FRG	80.0	10.0	5.0	Rmdr	—	—	—	7[illegible]	—	12	—
Nibral	USA	Rmdr	9.25	5.0	4.0	1.5	—	—	≥56.2	≥2[illegible]	≥[illegible]5	[illegible]
Cunickel	"	"	9.5	5.0	4.3	0.75	—	—	≥56.2	≥26.7	≥[illegible]5	—
Nickelium III	"	"	9.0	1.5	7.0	7.0	—	—	69.0	[illegible]6.7	25	1[illegible]

Substantial corrosive and erosive damage to carbon steel propeller blades occurs as early as 6 months after their installation. After 1.5-2.5 years of operation, such propellers are usually completely worn out, as confirmed by the following examples:

1) A carbon steel propeller installed in 1945 on the S.S. Captain Gastello became useless in 1946. In 1947 this propeller was replaced by a new one, also cast of carbon steel; the new propeller soon also became useless and had to be replaced in 1949. The loss in the vessel's speed over a period of one year, due to deterioration of the propeller, amounted to 0.5 knots.

2) On T.S. Alexander Matrosov, during four years of service (1945-49) two steel screws were replaced. Loss of speed of this vessel after two years of service amounted to 1.5 knots.

3) On T.S. Dimitriy Donskoy, a carbon steel propeller installed in 1950 already had to be replaced in 1951, due to heavy corrosive-erosive deterioration. The ship sailed on a Leningrad-Tsingtao-Stettin cruise and on the return trip its speed had decreased by 1.2 knots. While traversing the Red Sea, one of the propeller blades was lost, due to heavy corrosive deterioration.

4) Steel propellers were installed on the S.S. Outess on 20 April 1952. An inspection made on 25 September 1952 revealed transverse corrosive-erosive cavities and pitting of the edges of the blades. These propellers were condemned.

5). On T.S. Akhmolinsk new carbon steel propellers were installed in November 1955 and were found to be completely deteriorated after a period of 21 months.

6) Normal-class propellers of carbon steel were installed in the whaling ships of the "Slava" flotilla and during the course of each cruise, (approximately 30,000 miles) nearly 30% of the blade surfaces have been destroyed through the action of corrosion and erosion. Edges of the blades assume the appearance of "sponges". The corrosion and erosion damaged areas are repaired each year by welding. Damage to the propeller blades in some cases has lowered the speed of the ships by 17-20%. Average service life of normal class carbon steel propellers under operating conditions encountered by the whaling ships of the "Slava" flotilla (including annual repairs) amounts to 2-3 years.

Fig. 1, a and b, shows the steel propeller of a fishing trawler which has been operating in the Barents Sea over a period of two years. The blades of this propeller in the area of the leading edge and at the tips are completely destroyed by corrosion and erosion. The surfaces of the remaining parts of the blades, adjacent to the destroyed edges, are covered by corrosional pits up to 10 mm deep.

Domestic information relative to corrosive-erosive destruction of normal-class steel propellers agrees with similar foreign experience. For instance, blades of propellers made in Belgium of type 25L (0.29% C) carbon steel, in one year of operation showed considerable deterioration, both on the compressive and the suction surfaces of the blades. Through cavities penetrated the edges of the blades.

Apart from being put out of commission rapidly due to corrosive-erosive damage, a great number of carbon steel propellers, especially those operating in icy waters, have to be discarded prematurely owing to mechanical damage to the blades from impact of ice, rocks, submerged timber and similar objects. Such injuries are aggravated due to the low mechanical strength of carbon steel and by its comparatively low resistance to brittle failure (especially at low temperatures).

Cast Iron Propellers of the Normal Class. Durability of normal class propellers made of cast iron is considered (in the absence of mechanical failures in the course of exploitation) to be somewhat higher than that of carbon steel ones. If the maximum service life of blade surfaces before their normal wear out averages 2.5 years of carbon steel, for cast iron propellers it extends to 5 years.

However, other data fails to confirm this. For instance, Professor I.N. Voskresenskiy /6/ states that a trawler's cast-iron propeller (2.9-3.0 m diameter; engine power approximately 600 h.p.) may be destroyed by corosion and erosion within 15 to 24 months. Corrosive-erosive deterioration of the blades of a cast iron propeller can be already observed after six months of service and repairs become necessary after 12 months. The most severe corrosive-erosive damage is usually found at the tips of the propellers and along their leading edges.

Fig. 1. Corrosive-erosive deterioration of a carbon steel propeller after 2 years of service in the Barens Sea: a - overall view of the propeller; b - damage to the blade.

M. Spitkovskiy and A. Verlhoshapov /18/ describe the corrosive-erosive damage to a four-blade cast iron propeller 2650 mm in diameter installed on a tanker. After two years of service the tips of the blades were found to be pitted over a distance of 400-500 mm; while the tips of three of the blades were almost entirely destroyed, the fourth one still retained the damaged spongy part.

Figure 2 shows an overall view of a cast iron propeller the blades of which have undergone corrosive-erosive destruction.

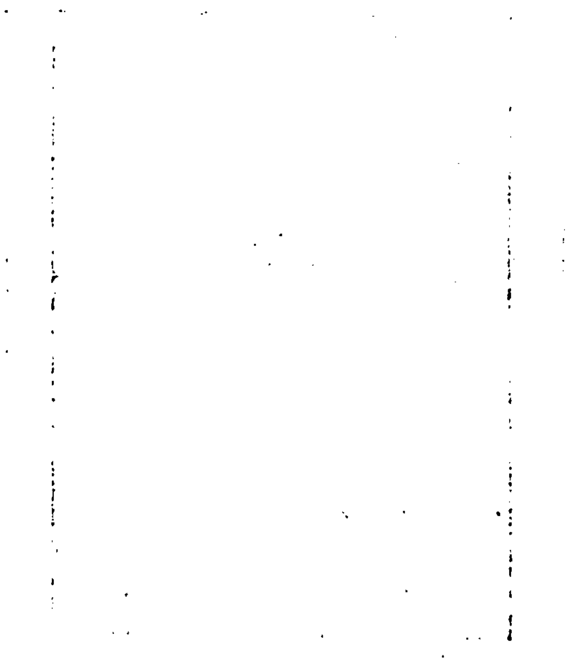

Fig. 2. Corrosive-erosive destruction of the blades of a cast iron propeller screw.

This evidence testifies to the fact that durability of cast iron propellers under sea-going conditions does not differ materially from that of carbon steel ones.

Contradictory information relative to the comparative durability of steel and cast iron propellers evidently results from failure to account accurately for some features of exploitation of certain cast iron propellers. The later are usually employed on vessels cruising on lakes and rivers and also in regions of the sea situated near the mouths of large rivers, that is, in locations presenting less severe conditions. Evidently this is exactly the reason why certain people engaged in this type of research have formed the conclusion as to superiority of cast iron propellers.

Table 15 presents the results of corrosion tests of cast iron and carbon steel made in sea water, carried out by Y.E. Zobachev /12/. This data demonstrates that cast iron propellers should present no advantages in the matter of corrosion resistance as compared with carbon steel ones, for operation in sea water. Corrosion resistance of cast iron propellers is also very low. Resistance of gray cast iron propellers to erosion also does not differ materially from that of carbon steel ones.

A serious disadvantage of gray cast iron propellers is their low strength and brittleness, both substantially below those of cast steel propellers.

These shortcomings of cast iron propellers can be somewhat diminished by casting them of high-strength cast iron with spheroidal graphite, however, this material has not yet attained the wide use which it merits.

Table 15.

Results of tests of corrosive resistance of cast iron and carbon steel in sea water immersion

Material	Rate of corrosion, mm / year	
	Alternating immersion apparatus	Pivoting apparatus (jet corrosion)
Gray cast iron	0.382	0.240
Modified cast iron	0.375	0.319
High-strength cast iron	0.333	0.195
Carbon steel (0.12 % C)	0.295	0.165
do (0.31 % C)	0.258	0.145

Means of increasing corrosion resistance of structural steel and of cast iron propellers. Substitution of low-alloy structural steel for carbon steel and cast iron results in improved mechanical properties of normal class propellers, slightly improves their resistance to erosion, but virtually no improvement in corrosion resistance.

L. A. Glickman and Y. E. Zobachev /12/ have done some important research to investigate the possibilities of improving corrosion resistance of steel propellers by means of enameling, electroplating with zinc, brass and stainless steel; thermal diffusional chroming and zincing; mechanical strengthening by shot blasting; electro-spark hardening with sormite, ferrochrome and the T30K4 hard alloy; electrolythic chrome and zinc plating; application of non-metallic coatings (polyisobutilene, bitumen and polyten). However, according to the authors' report, none of these protective treatments gave any positive results.

Vulcanization of the blade surfaces and of the hub with a coating of rubber is sometimes used abroad to increase the durability of steel propellers, but this method has not attained widespread popularity, probably due to the difficulty of accomplishment and inadequate resistance of the rubber coating to the various mechanical agents encountered in service (impact of rocks, submerged timber; abrasive action of steel cables which get wound around the propeller, etc.).

Favorable results are obtained through the use of the method of protecting steel propellers from corrosion described by L.A. Glickman, Y.E. Zobatchev, G.I. Mart'yanov, N.N. Plishkin and N. Katzman /3/. This method consists of facing the surfaces of a cast propeller of carbon steel with a thin

(2 mm) sheet of rolled stainless steel, designation 1Kh18N9T, fastened with electrically driven rivets and manual electrowelding. It is however obvious that such a method cannot be used for protecting propeller blades having small thickness and sharp edges, fabricated under rigorous limitations as to the accuracy of dimensions and shape. Besides, it is probable that this method would not prove to be economically feasible for line production of propellers, due to high labor costs.

Propellers of the Highest class, Made of Brass and Bronze. As mentioned before, the great majority of propellers of the higher class are in the USSR are made of LMtsZh 55-3-1 brass having the following basic faults.

1. Insufficient strength: the guaranteed magnitude $\sigma_t \approx 20$ kg/mm^2. In the design of propellers for modern vessels there is often a possibility of reducing the blade thickness through the use of a stronger material ($\sigma_t \approx$ 25-35 kg/mm^2), but due to the lack of such a material it becomes necessary to employ propellers of greater thickness and weight. Thickening of the blades has an adverse effect on the hydrodynamic properties of the propellers leading to a decrease in efficiency, to a non-productive increase in the power of prime movers, drop in speed, increase in fuel consumption and intensification of corrosive-erosive deterioration.

According to the data furnished by F. Hudson /31/ the use of special brass with $\sigma_t \approx 17$ kg/mm^2 leads to the thickening of propeller blades amounting to approximately 8% and to a reduction in its efficiency of approximately 1.5%, as compared with a propeller made of special aluminum bronze with $\sigma_t \approx 25$ kg/mm^2.

An increase in the weight of a propeller resulting from the use of a lower-strength material also gives rise to the necessity of increasing the engine power and accentuates the rate of wear of the propeller shaft bearings.

2. The trend toward intensive corrosional deterioration as a result of dezincing, occurring chiefly with the use of brass propellers in wooden-hulled vessels.

According to available data, the dezincing process of LMtsZh 55-3-1 brass of some wooden-hulled vessel's propellers during 1-1.5 years of service produces complete destruction of the blades' edges. The radical drop in strength of the blade material caused by dezincing frequently leads to their complete break-down.

3. The likelyhood of corrosive checking due to the effects of sea water (or even of industrial air polution), and tensile stresses caused by the application of external loads and the effect of secondary stresses (for instance, stresses produced by the welding of defects). The trend toward corrosive checking of LMtsZh 55-3-1 brass grows with the amount of β-phase in its structure.

Foreign experience with the use of higher class propellers made of special brasses, installed in high-speed vessels, has disclosed another important shortcoming of non-ferrous alloys of this type, their inadequate resistance toward corrosive fatigue. According to F. Hudson /31/, aboard torpedo boats of the Royal Navy during World War II, there were frequently cases of destruction of special brass propellers due to their low resistance to corrosive fatigue. Growing fatigue cracks in the basal cross-sections of the blades often caused their complete break-off.

Brass designation LAMtsZh 67-5-2-2 (LAMtsZh 68-5.5-2-2) used in the USSR for the fabrication of the higher class propellers has a number of advantages over LMtsZh 55-3-1 brass: higher strength (σ_t = 25 kg/mm^2), higher corrosive resistance in turbulent sea water, a lower tendency toward dezincing and corrosive checking. Nevertheless, the strength of this brass is still insufficient to meet all of the requirements arising in the course of designing modern propellers. Besides, the presence of 20% Zn in the composition of the brass creates a certain tendency toward dezincing and corrosive checking.

Special aluminum bronzes (see Table 13), used for casting propellers abroad, do not have many of the major defects of the special brasses. With the use of the aluminum bronzes of this type, there is an increase in corrosion-eposion resistance of propellers, a virtual elimination of the tendency toward selective corrosion (dezincing) and corrosive checking, a greater resistance to corrosive fatigue, of 10-15%,lower weight of the propellers (due to lower specific gravities of aluminum bronzes and smaller blade thicknesses due to the greater strength of the material). Nevertheless, according to available information, strength of available aluminum bronzes is also limited and is inadequate for most installations. The elastic limit of such bronzes, in the face of the required level of plasticity currently does not exceed 30 kg/mm^2.

Thus, it is possible to conclude that the improvement in durability of mormal class propellers with the use of non-ferrous alloys in place of steel and cast iron (bronzes, brasses) cannot be recommended in view of the need to achieve all possible savings in the use of copper and the inadequate mechanical strength of non-ferrous alloys.

Plastics (nylon, plastic-glass fiber, etc.) have come into use in the last few years in the fabrication of propellers of 1.5 - 2.5 m diameter.

The low specific gravity of plastics, their high elasticity and durability in sea water and the possibility of fabricating propeller stocks by pressing (virtually without any subsequent machinging) offer attractive prospects for the use of these materials in the fabrication of a great variety of propellers. However, adoption of fabrication of plastic propellers and their testing under service conditions (especially of the larger types of propellers used on high-speed vessels) will undoubtedly require a certain amount of time.

The problem of fundamental improvement in quality of material used in normal and highest class propellers can be rationally solved in many instances through the use of stainless steels.

CHAPTER II

STAINLESS STEELS USED IN THE FABRICATION OF PROPELLERS IN FOREIGN COUNTRIES.

There is a scarcity of published material relating to composition and properties of stainless steels used in casting propellers abroad, however, existing information permits the establishment of the following fundamental rules which serve to guide the foreign companies using stainless steel for such purposes.

1. As compared to carbon structural steel, the use of stainless steel in the fabrication of the normal class propellers provides a substantial increase in corrosion and erosion resistance and in many cases, in the mechanical strength and resistance to impact. In casting propellers of this classification, chromous martensite or martenisic-ferritic stainless steels (of the 1 Kh 13 and 2 Kh 13 types) are commonly used, sometimes alloyed with small amounts of nickel (approximately 1% Ni).

2. The use of stainless steels in the fabrication of the highest class propellers in lieu of copper-base non-ferrous alloys (special brasses and bronzes) results in a saving in scarce colored metals, provides greater mechanical strength and resistance to corrosion fatigue, greater resistance to corrosive cracking, as well as better resistance to corrosional deterioration and to that caused by the abrasive action of water containing sand in suspension.

Austenitic and austeno-ferritic types of stainless steels are most often used for the fabrication of propellers of the highest class. There are some cases of employment of less durable martensitic and martensito-ferritic stainless steels attributable to the following considerations:

a) scarcity of certain alloying additives, primarily that of nickel.

b) insufficient strength of austenitic and austeno-ferritic stainless steels (their σ_t is inadequate to insure the reliability of certain types of highly stressed propellers);

c) relative newness and low availability of highly durable, high-strength dispersionally hardened stainless steels.

Available data relating to propellers of the normal and the highest classes made abroad of stainless steel is presented below.

Stainless Steels Used in the Fabrication of Normal Class Ships' Propellers.

1. Published /35/ data on the use of stainless steel propellers in whaling ships. Such operations are often carried out in regions abounding in floating ice. Under such operating conditions, propeller blades subjected to low temperatures are also abraded by floating ice and suffer impact. The use of stainless steel has resulted in a substantial increase in the propeller durability of these vessels. The steel used contains 12-14% Cr and has a σ_V = 65 - 70 kg/mm^2. Impact strength of the steel per Izode is 15 - 20 foot-pounds; δ = 25%. The steel is subjected to a cold bending test. The indicated set of characteristics makes stainless steel particularly suitable for propellers of ships cruising in the Arctic.

2. A stainless steel propeller fabricated abroad is installed in one of the whalers of the "Slava" flotilla. The chemical composition of this steel is as follows: 0.15% C; 0.52% Mn; 0.47% Si; 13.0% Cr; 0.95% Ni; 0.015% S; 0.02% P. The whaling ship equipped with this propeller has cruised in the Antarctic for a period of 8 years, covering over 200,000 miles. The stainless steel propeller has shown no evidence of deterioration.

3. Stainless steel with the following chemical composition is being used in Belgium for the fabrication of propellers: 0.1% C; 12-14% Cr; 1.0% Ni. This steel has a σ_V = 50 - 65 kg/mm^2; σ_t = 30 - 40 kg/mm^2; a_k - 6 kgM/cm^2; H_B = 150 - 200.

4. Ships built in Holland have stainless steel propellers with the following composition: 0.08% C; 0.40% Si; 13.2% Cr; 0.1% Ni; and 0.30% Mo. The mechanical properties of this steel determined from specimens taken from the propeller's blades: σ_V - 46.9 kg/mm^2; σ_t - 34.3 kg/mm^2; δ = 5%; a_k = 1.0 - 1.2 kgM/cm^2. Judging from the structure and the mechanical properties, this propeller has not been subjected to heat treatment.

5. On ships built in the GDR, stainless steel propellers are installed, having the following properties: ~ 0.1% C; 0.3-0.5% Si; 0.3-0.5% Mn; 13.5-15% Cr; 0.8-1.2% Ni; 0.1-0.2% V. The following mechanical properties are guaranteed: $\sigma_t \geq$ 38 kg/mm2; $\sigma_V \geq$ 75 kg/mm2; $\delta_5 \geq$ 15%; H_B = 180 - 240; impact resistance unspecified. The propellers are delivered without being heat treated, probably to preclude deformation of blades which occurs in the process of heat treatment.

Stainless Steels Used in the Fabrication of Propellers of the Highest Class.

1. Propellers of the highest class of the passenger ship "Europa" /16/ were case in austenitic stainless steel V2AE. Their diameter was 4450 mm; rough weight 15 T. Their composition: 0.1% C; 17.8% Cr; 8.5% Ni; 0.025% P; 0.02% S. In addition, small amounts of Titanium and Tantalum were introduced to reduce the grain size and eliminate the tendency toward intercrystalline corrosion. To reduce the deformation of the blades these propellers were not heat treated in the course of fabrication.

The stainless steel employed had the following mechanical properties: σ_t = 18-24 kg/mm^2; σ_V = 57-61 kg/mm^2; δ = 20-28%; H_B = 155-190.

Stainless steel was used in the "Europa's" propellers in order to increase their resistance to cavitational damage.

2. In the fabrication of highest class propellers for installation on special ships in the FRG, according to Lloyd's data /16/, they use austenito-ferritic steel with the following chemical composition: 0.1-0.15% C; 1.5-2.0 Si; 0.5-1.0% Mn; 5.5-7.0% Ni; 21.5-23.0% Cr.

3. In France, as early as 1932 /36/, they developed and used in place of bronze for highest class propellers, a stainless austenito-ferritic steel with the following chemical composition: 0.06% C; 0.6% Si; 0.5% Mn; 20% Cr; 8.0% Ni; 2.5% Mo; 1.5% Cu. Heat treatment of this steel consisted of austenization at 1150^o and stabilization at 900^o with a 6-hour exposure.

4. In Belgium stainless austenitic steel, designation 18/8, with the following composition is used for the production of the highest class propellers: 0.1% C; 18.0% Cr; 8.0% Ni.

The mechanical properties of this steel, according to the manufacturer's data: σ_V= 50-60 kg/mm^2; σ_t = 25-35 kg/mm^2; δ = 15-20%; a_k = 15-20 kgM/cm^2.

5. A four-blade stainless steel propeller was installed in the SS Matsesta, built in Germany in 1925, (diameter of this propeller 3.6M, weight 3.5 T). This propeller has been in service in the "Matsesta" for 35 years and has never been overhauled. Its surface is smooth and bright, showing no traces of corrosional or erosional pitting.

A chemical analysis and hardness test of the steel from the SS Matsesta propeller furnished the following data: 0.19% C; 1.5% Mn; 21.5% Cr; 10.0% Ni; 0.02% P; 0.015% S; Brinnel hardness H_B = 242.

6. Table 16 shows the results of chemical analyses of a highest class stainless steel propeller (diameter 3300 mm; weight 6019 kg), fabricated by one of the German firms. Examination of this data shows that the propeller was cast of stainless steel alloyed with 23-24% Cr and 6% Ni. Small additions of Titanium and Vanadium were made evidently to refine the basic granular structure.

Table 16

Chemical composition of a stainless steel propeller of

a 3.3 M diameter.

Analysis No.	Chemical composition, %									
	C	Si	Mn.	Cr	Ni	Ti	Cu	V	P	S
1	0.15	1.57	0.84	23.53	5.90	0.03	0.040	0.12	0.003	0.015
2	0.16	1.65	0.95	23.55	6.45	0.05	0.086	0.31	0.005	0.010

Mechanical properties of this stainless steel, obtained from specimens cut from the blades of the propeller, are shown in Table 17. The low plasticity and toughness levels of this steel are attributable to the fact that the propeller was fabricated without resorting to heat treatment. The steel's structure consisted of austenitic polyhedrons, with oblong grains of alloyed ferrite located along their circumference. Large accumulations of carbide could be observed along the edges of the ferritic granules. Table 18 presents the mechanical properties of this propeller's stainless steel subsequent to a variety of thermal treatments. From this data it is apparent that the highest values of strength, plasticity and malleability were obtained upon its austenization at 1150° without subsequent annealing. The microstructure of the steel following its austenization at 1150° consisted solely of austenite and ferrite.

Table 17.

Mechanical properties of stainless steel obtained on specimens cut from a 3.3 M - diameter propeller

(for all specimens $\psi = 0\%$)

Specimen No.	Location at which specimen was taken	D of tens. specimen mm	kg/mm^2	kg/mm^2	δ, %	a_k, kgM/cm^2
1	Edge of blade	6	39.0	59.0	10.0	1.4
2	Same location	6	40.0	61.0	11.0	1.4
3	350 mm from edge of blade; surface layer.	10	46.0	59.5	10.0	1.1
4	Same location					

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The propellers' fairing and its cover plates were made of 2 Kh 13 steel with a small addition of nickel; the fairing plug - of type 2 Kh 13 steel; the hub ring - of type 1 Kh 18 N 9 T steel and the ring pin of 3 Kh 13 steel.

7. Chrome stainless steel, martensite class, designation StgCr14KM was used for casting propellers of the highest class for the German Navy during the war, it had the following chemical composition: 0.2% C; 13.0% Cr; 0.7% Mn; 0.35%Si; 0.04% P; 0.03% S (S + P ... 0.07%).

After heat treatment, StgCr14KM steel had the following mechanical properties: $_v$ 65 kg/mm^2; $_t$ 40 kg/mm^2; δ (with 1/d = 5) ≥ 12%; a_k (Menage) ≥ 3 kgm/cm^2; angle of bend (over a pin with d = 3a) 180°; H_B = 190 - 240.

8. J. R. Getz and B. Refnes /28/ tell of the widespread use on Norwegian coastal vessels of adjustable pitch propellers made of martensite class stainless steel, with 13% Cr. The use of chrome stainless steel was evidently brought about by the need for high strengths, not obtainable with the use of austenitic and austeno-ferritic steels which do provide a higher resistance to corrosion.

9. Carter Z. Henry /27/ tells of research carried out at New Orleans (USA) related to the use of the highest class propellers made of austenitic stainless steel on tugboats cruising on inland waterways. In this case, stainless steel propellers were used in lieu of non-ferrous alloy ones in order to obtain higher resistance to abrasive action of water containing sand in suspension (shallow water cruising), and also to reduce the number of break-downs caused by impact of various debris floating in such waters. In selecting the brand of stainless steel, the following requirements governed:

a) the steel must have high resistance to wear in waters containing sand;
b) the steel must be sufficiently plastic and must deform without fracturing, when bent;
c) steel must have adequate impact strength;
d) resistance to corrosion of the steel in water must be not less than that of non-ferrous alloys;
d) steel must insure simplicity of repairs of propeller blades without resorting to heat treatment upon completion of the overhaul.

The stainless steel propellers of a tugboat were examined in drydock after 6 months of service. It was found that the surfaces of the propellers showed virtually no signs of wear, in spite of the severity of the operating conditions.

Casting of the 3-m diameter propeller shape in a mold was done with a teapot laddle; the steel was melted in an arc-type electric furnace.[1]

1. According to data /30/ the 18-8 steel for propellers with a very low carbon content (below 0.03-0.04%) has: σ_v-52,5 kg/mm2; σ_t - 24.5 kg/mm2 40-50%; ψ = 50-60%.

Table 18.

Mechanical properties of stainless steel used in a 3.3 M - diameter propeller after various types of heat treatments.

Austenization		Annealing		Mechanical Properties		
Temperature °C	Exposure hours	Temperature °C	Exposure hours	kg/mm^2	,%	a_k, kgm/cm^2
1000	2	-	-	55.2	12.0	3.2
1000	2	-	-	58.1	25.0	5.0
1100	2	-	-	60.7	21.0	4.3
1100	2	-	-	61.4	32.5	2.9
1150	2	-	-	64.7	21.1	6.8
1150	2	-	-	63.0	17.8	6.4
-	-	600	3	56.2	15.5	2.0
-	-	600	3	49.0	11.5	2.0
-	-	700	3	56.2	18.1	1.5
-	-	700	3	48.2	6.8	2.9
-	-	800	3	55.8	-	1.0
-	-	800	3	54.2	11.3	1.3
-	-	850	3	60.6	24.3	3.6
-	-	850	3	59.2	22.0	2.2
1100	2	600	3	63.0	16.5	2.5
-	2	600	3	65.7	17.8	2.3
-	2	700	3	65.3	19.0	2.5
-	2	700	3	59.5	18.0	4.2
-	2	800	3	59.5	28.2	2.7
-	2	800	3	56.2	10.8	5.3

10. Donald M. Harris in his review /29/ paper furnishes data relating to the following stainless steels used for the fabrication of propellers: chromous with 13% Cr, chrome-nickel designated 18-8 and chrome-manganous-nickel. The chemical composition and mechanical properties are shown in Table 19.

According to this source, chromous steel with 15% Cr is the one most commonly used in the casting of propellers. The advantage of this steel is its high strength. Corrosional stability of chromous steel in sea water cannot be considered good owing to its tendency to develop pitting. However, the corrosional resistance of this steel is certainly higher than those of low-alloy steels. A serious shortcoming of chromous steel is its tendency to develop hair cracks, which form as a result of the disruption of normal processes of heat treatment.

Steel designation 18-8 is ordinarily used in a heat-treated form which insures the formation of austenitic structure; however, the formation of the same structure may also be obtained without thermal treatment through stabilization of the composition through the addition of niobium and tantalum to the steel.

Corrosive resistance of the steel subjected to stabilization is somewhat lower than that of tempered steel, but it is quite adequate for the satisfactory performance of the propeller in sea water. Steel of the 18-8 type shows some tendency toward pitting in still water. Its over-all resistance to corrosion is better than that of manganic brass. An advantage of the 18-8 type steel is also its high resistance to fatigue in sea water. Propellers made of this steel are successfully used in North America (Gulf of Mexico), as well as in inland navigable waters. Such operating conditions, due to corrosive effects (in many cases) of sea water and of industrial wastes, corrosive effects of silt and mechanical effects typical of shallow waters are all deemed to be especially severe.

Chromous-manganic-nickel austenitic steel used in the fabrication of propellers of medium dismensions designed to serve under severe conditions was selected by the American Kennedy firm. Test demonstrated that corrosional resistance of this steel is equal to that of manganese brass.

Table 19

Chemical Compound and Mechanical Properties of Stainless Steel for Screw Propellers

Steel	Characteristic indices	Mechanical Properties							Chemical compound, %.					
		σ_b	σ_m	δ	Contraction	Brinnel hardner H_B	Impact		C	Mn	Si	Cr	Ni	Mo
		kg/mm^2		%			Charpy	Izod						
Chrome (13% Cg)	Minimum	63.3	45.7	18	30	--	—	—	0.15	1.0	1.5	13.25	1.0	0.5
	Typical	67.1	--	25	--	--	--	--						
Chrome-Niclel 18-8	Typical	52.7	24.6	35	55	160	--	70/120	0.04	--	--	18.0	8.0	3.0
Chrome-Manganese	Minimum	59.8	31.6	45	45	--	--	--	0.10	15.0	--	16.0	5.0	--
	Typical	61.9	32.3	56	51	170	98	--						

Chapter III

DOMESTIC STAINLESS STEELS USED IN THE FABRICATION OF NORMAL CLASS SHIPS' PROPELLERS.

Technical specifications for the production of propellers and the conditions under which they are used impose the following requirements on stainless steel. The steel must:

1) have such a corrosional and erosional resistance in sea water that after several years of service the surfaces of the propeller blades should retain their original smoothness and remain free of pits which lower the efficiency of the propeller;

2) contain a minimum amount of costly and scarce components;

3) have a higher strength thatn that of carbon steel and, specifically, to have $\sigma_t \geq$ 30-35 kg/mm^2, at the same time insuring $a_k + 20^\circ \geq$ 3 kgM/cm^2, and adequate plasticity. The fabricating specifications for propellers must require stability of mechanical properties, subsequent to simple heat treatment, and must eliminate the necessity of tempering in liquid mediums which so strongly distort the true shape of the propellers;

4) must have the required fluidity and have no tendency to form hot and cold cracks during casting;

5) must permit the use of welding on minor casting defects without the necessity of preheating the entire castings;

6) must be machineable with the use of tools made of tool steels and alloys readily available to the machine tool industry, and on the machines commonly available for the fabrication of propellers.

High-chrome Steels Without Nickel and With Nickel Content Up to 2%.

Up to the start of research leading up to the commencement of stainless steel propeller production, the nomenclature of domestic stainless steels suitable for casting of shapes was much more limited than that of rolled and forged stainless steels which had already gained widespread acceptance in the industry.

Chrome stainless steels most nearly met the requirements of mechanical properties, content of scarce components and cost, for use in the fabrication of normal class propellers. Depending upon the relative carbon and chrome content, these steels are divided into ferritic and ferrito-martensitic (so-called semi-ferrites), martensitic and ferritic-carbide.

Ferritic steels do not undergo phasal transformations during heat treatment, since they lack the $\alpha \rightleftarrows \gamma$ transformation. Their primary crystal-line structure remains virtually unchanged as a result of heat treatment, consequently, they are characterized by their coarsely-crystalline structure. Such steels tend to have an increasing size of grain with an increase of temperature above 800° and in the course of welding. A certain reduction in size of grain is achieved with the introduction of nitrogen into the liquid steel, or through the acceleration of cooling during the process of crystallization. The size of grain increases sharply with delayed cooling.

Plasticity of chromo-ferritic steel decreases with an increase in chrome content. This is very apparent when the chrome content reaches 16-17%.

According to V. A. Nehendzy /17/, ferritic steels containing 13-14% Cr have σ_B = 30 -40 kg/mm², δ ≈ 20% and ψ ≈ 30%. With a 16-20% Cr content, elongation and necking down drop to 5-10%.

Ferro-chromium steels with less than 14% Cr are plastic and ductile, but are noted for their low corrosive resistance and are therefore suited only for service in low-aggressive mediums (for example, in atmosphere), but unsuited for operations in sea water. Ferro-chromium steels with 16-20% Cr content have much higher corrosion resistance, but low plasticity and ductility.

Ferritic-chrome steels have undesirable casting properties. They have poor fluidity due to the low carbon and high chromium content. Superheating the liquid metal to increase its fluidity results in an increase in primary granulosity, leading to an abrupt drop in ductility and plasticity.

Among the highly-alloyed chromium stainless steels, the most commonly used ones as structural materials are the ferritic-martensitic (semi-ferritic) and the martensitic ones containing a greater proportion of carbon. Among these, the most commonly used ones are the 1Kh13L and 2Kh13L, listed in GOST 2176-57 as "Castings of high-alloy steels with special properties"/24/.

In the course of heat treatment these steels undergo transformations - partial in the semiferritic and complete in the martensitic steels; due to this, a relatively high level of strength, plasticity and ductility is obtained.

The increase in carbon content, as compared with that of ferritic steels, increases their fluidity, while the corrosion resistance is lowered due to the formation of chromous carbides. Carbides reduce the chrome concentration in solid solution because their chrome content is considerably greater than that of carbon. For instance, in the carbide, composition Fe_4C, the chrome content is 17 times greater than that of carbon. Increase in the amount of chromous carbides also lowers the ductility and elasticity of steel.

Because of the undesirable effect of increased carbon content, it is advisable to obtain a martensitic or martensitic-ferritic structure by introducing a certain amount of nickel into the steel, thus also obtaining better corrosion resistance.

In the USSR steels of this type (Table 20) are widely used for the production of castings for hydraulic turbines, though they too have some shortcomings. According to N. D. Vasiliev, they are prone to produce mis-castings.

According to I. R. Krianin and G. I. Bakina /15/, used in large castings, this steel is inclined toward heterogenity manifested by fluctuations in the values of relative elongations, compression and, especially, impact toughness resulting from the liquation of chrome and carbon. Areas of ferrite rich in chrome and chromous carbides can be observed in the castings.

Table 20

Chemical composition of chromous steels with nickel.

Designation of steels	Chemical composition, %							
	C	Si	Mn	Cr	Ni	Ti	S (not over)	P (not over)
	0.17-0.25	0.7-0.9	0.3-0.6	12.0-13.5	0.8-1.0	0.1-0.15	0.3	0.3
	0.20-0.27	0.7	0.3-0.6	12.5-14.5	0.6	-	0.3	0.3

Such liquational phenomena in most cases are not even eliminated by heat treatment consisting of dual or triple air tempering at 1050-1150°; as a result of which, plastic properties are improved only slightly.

Welding up of defects in castings made of this steel is extremely difficult to accomplish, as it can only be made with the castings heated to 300-400°.

A serious defect of these chromous steels, containing 12-14.5% Cr, especially of the 2Kh13L-type steels, is their inclination toward pitting corrosion in sea water, although the overall loss of weight is slight. According to A. A. Babakov /1/, the average depth of corrosive pits in sea water is approximately 0.02 mm per year. However, with a small average rate of corrosion, parts made of this steel sustain deep local damage which radically lowers the strength of the product. Even rolled steel of this consistency, used in drive shafts of vessels, was found to be unsuitable for use in sea water due to the severe pitting of the shafts (even with protective devices installed in the vessels). This corrosion is especially virulent with the growth of calciferous deposits on the surfaces of the steel parts.

More resistant to sea-water corrosion (in the presence of protective devices) is the Kh17N2 steel, containing 16-18% Cr and 2% Ni. It is known that Kh17N2 in the rolled and forged state possesses high strength and plasticity characteristics, subsequent to heat treatment. Nevertheless, it is impossible to obtain such plasticity and toughness properties for this steel in a cast form. The Kh17N2 steel is not included in GOST 2176-57.

The work of casting cast steels containing 16-20% Cr, including Kh17N2, was performed at various times by a number of investigators. For example, we have the research done by K.I. Vaschenko and L.I. Rostovtseva (in collaboration with a steel mill) /4/, who propose a stainless steel 25Kh18L having the following composition: 0.2-0.3% C; 0.8% S; 0.8% Mn; 17-20% Cr. According to them, this steel has a high corrosional resistance, but an extremely low impact strength (a_k 2 kgM/cm^2). Research to establish the possibility of using type Kh17N2 cast steel in the production of propellers was also carried out by the authors, but without positive results. As to steels containing over 19-20% Cr, they, in addition to low impact strength, also have low plasticity. According to N.S. Kreschanovsky /14/, steel containing 0.21-0.22% C; 22% Cr, and 0.1% Ni, with no addition of nitrogen, had an impact strength (after tempering at 860°) of approximately 0.05 kgM/cm^2. Introduction of nitrogen refines the grain and because of it, furnishes a certain (though insufficient) improvement in plastic and strength characteristics. In addition, steels with such high chrome content are noted for their poor flowability.

Chromous Steels With No Nickel.

Structural non-homogeneity of high-chrome steels and the resulting variations of mechanical properties in different sections of a casting, as well as the low corrosional resistance in mediums containing chlorine ions (among them, sea-water, especially polluted water), create the necessity for additional alloying of such steels. A number of elements, including copper, are used for this purpose. Chromous stainless steels alloyed with copper present a number of advantages.

According to N.D. Tomashov /19/, addition of copper radically decreases the rate of corrosion of chromous steels in aggressive surroundings. Anodic inertness of the steel occurs as a result of secondary anodic polarization, produced by the deposition of copper, a cathode, onto the surface of the steel.

According to I.E. Kontorovitch /13/, an addition of even 1% Cu substantially increases corrosional stability of chromous steels and makes them more uniform in hardness and mechanical properties after heat treatment. Y.A. Nekhendzy also points out the beneficial effects of copper which contributes toward creation of more uniform properties in the different sections of a casting.

According to F. F. Khimoushin and A.A. Babakov /2/, additions of 1% Cu to steels with 12-14% Cr and 0.1% C manifests itself chiefly by the fact that various smelts with widely varying compositions acquire approximately the same properties after thermal treatment.

According to [illegible] and G. I. Baboushkina /45/, copper decreases liquation of carbon and phosphorus.

[illegible] of using chromocuprous [illegible] propellers furnished no [illegible] effect of copper was established. With a chrome content of [illegible] 13%, steel containing copper acquires a comparatively high corrosion in sea water, but has a low elasticity and ductility. With a lower chrome content, such steels have sufficiently high plasticity and ductility, but are noted for their poor corrosion resistance in sea water.

Similar results were obtained by A. A. Babakov and F. F. Khimoushin for rolled stainless steel. They determined that steel having 15% Cr and 1% Cu has inadequate corrosion resistance in sea water.

Chrome-Nickel-Cuprous Steel, Designation 1Kh14ND.

Composition and mechanical properties. Research was carried out by A. M. Weingarten, N. P. Lebedev, E. N. Lieberman, E. K. Remizova, and the authors /5/ in order to find a readily available stainless steel, suitable for propellers of the normal class and with a greater sea-water durability than the 1Kh13L and 2Kh13L steels. Considering the improved corrosional stability with concurrent addition of copper and nickel, the research was concentrated on the area of chromous-nickel-cuprous stainless steel.

A number of heats were melted in 40 to 100 kg inductive furnaces and also in 2-3 ton capacity basic arc furnaces, in the course of developing such a composition. The effect of basic component proportions on the mechanical properties was checked for ranges of: carbon from 0.05 to 0.20% silicon from 0.06 to 0.90%; chrome from 12.5 to 15%; nickel from 1.2 to 2%; copper from 1.2 to 2%. The manganese content in all cases amounted to 0.3-0.8%.

It was determined that impact resistance decreases with the increase in carbon content. The lowest level of impact strength corresponded to a 0.2% C content. The trend toward decrease in impact strength can be already observed above a content of 0.11% C. This tendency was particularly pronounced with a combination of an increased carbon content and a Si content above 0.4%.

Variations in chrome content within the limits of 12.5 to 15% had virtually no effect on the mechanical properties. No material effect on the mechanical properties could be observed for variations in nickel and copper contents from 1.2 to 2%.

As a result of this investigation, we proposed a stainless steel designation 1Kh14ND with the following compositions: ≤ 0.1% C; ≤ 0.4% Si; 0.3-0.6% Mn; 13.5-15% Cr; 1.2-1.6% Ni; 1.2-1.6% Cu. The selected lower limit of chromium content (13.5%) for the given carbon content virtually insures the presence of not less than 12-12.5% Cr in the solid solution.

In 2Kh13L type steels, containing up to 0.24% C at the minimum chrome content of 12%, such a condition cannot be achieved, thus accounting for their lower corrosion resistance. An improvement in corrosion resistance of the 1Kh14ND steel in comparison to type 2Kh13L steels is also achieved through the addition of nickel and copper.

It is known that sea water has a depassivating effect on stainless steel, but nickel inhibits this depassivation and renders the steel's potential more positive. The beneficial effect of copper in increasing corrosive resistance has been discussed before. Its effect as an element raising the fluidity of the steel should also be mentioned. Due to the presence of 1.2-1.5% Cu the 1Kh14ND steel has adequate fluidity, in spite of its low carbon content.

The proposed 1Kh14ND steel has the following critical point: $Ac_1 = 710^{\circ}$; $Ac_3 = 850^{\circ}$; $Ar_3 = 260^{\circ}$.

The nature of isothermal disintegration of austenite in this steel is illustrated by the C-shaped curve appearing in Fig. 3. As seen from the sketch, there was no disintegration of austenite while cooling down to 700°. Disintegration begins at 650°. After 9 sec. the quantity of disintegrated austenite amounts to 10%, after 25 sec. it increases to 30%. Additional two-hour exposure at 650° does not add to the quantity of disintegrated austenite. Lowering the temperature of isothermic exposure in the range of 650 to 250° also produces no changes.

With additional lowering of temperature, the quantity of disintegrated austenite increases and becomes 42% at 200°, 70% at 150°, and from 80 to 90% at 100°.

As shown by measurements made on a ballistic installation, at 20° temperature the quantity of residual austenite is 4%. Upon cooling to -70°, no residual austenite could be detected.

A study of the effect of thermal treatment on the mechanical properties of 1Kh14ND steel was made with the following variations:

1) tempering in air from 1000 to 1050° without subsequent annealing;
2) tempering in air from 1000 to 1050° with subsequent annealing at temperatures: 300, 400, 500, 600, 660, 750°.
3) annealing at temperatures 780-[illegible]° without preliminary tempering.

Tests were carried out on specimens cut out from trefoil-shaped stock 40 mm thick.

To furnish comparable data on mechanical properties of different heats, processed at the same temperature, we present as an example data relating to two heats. Their respective chemical compositions are listed in Table 21.

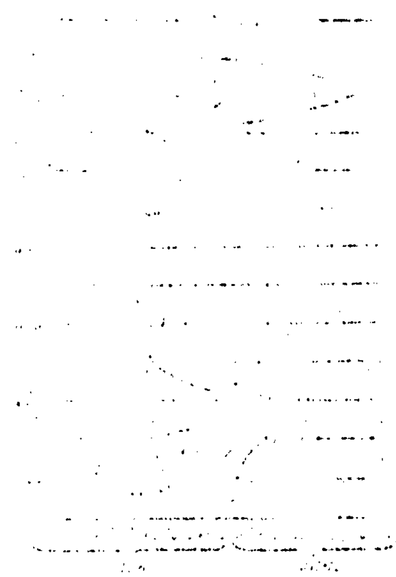


Fig. 3. Diagram of isothermal disintegration of austenite in the 1Kh14ND steel. Preliminary heating to 1000° (figures on the curves denote precent of disintegrated austenite).

Mechanical properties of the steel obtained after thermal treatment, consisting of tempering from 1000° and subsequent tempering at temperatures ranging from 300 to 750°, are shown in Fig. 4. Upon tempering from a temperature of 1050°, the level of mechanical properties remained virtually unchanged. Microstructure of the 1Kh14ND steel in a thermally untreated state and subsequent to various types of heat treatment is shown in Fig. 5-12.

Table 21.

Chemical composition of 1Kh14ND steel meltings used in checking the effects of heat treatment on the mechanical properties

Melting	Chemical composition, %							
	C	Si	Mn	Cr	Ni	Cu	S	P
I	0.06	0.26	0.46	14.05	1.27	1.56	0.025	0.030
II	0.09	0.34	0.42	14.10	1.44	1.57	0.025	0.024

In order to study the nature of structural components, their hardness was measured with a PMT-3 apparatus. The results of measurements appear in Fig. 13.

In a cast, thermally untreated state, the structure of 1Kh14ND steel consists of fine-acicular martensite with areas of chromous ferrite, bordered by carbides of chrome around their perifery. Existence of such a structure insures an adequately high strength and low plasticity and ductility, so that the indicators, in this case, amount to: σ_t = 80 kg/mm^2; v 89 kg/mm^2; = 4%, and a_k = 1.7 kgM/cm^2.

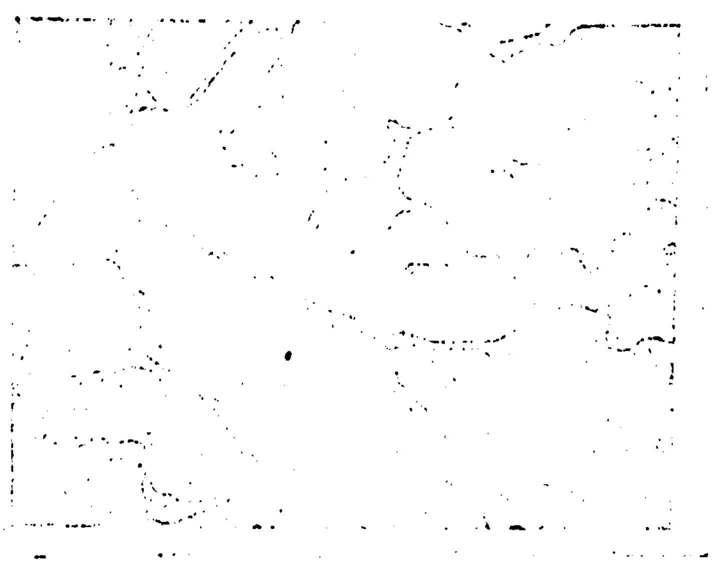


Fig. 5. Microstructure of 1Kh14ND steel in a thermally untreated state: X 300.

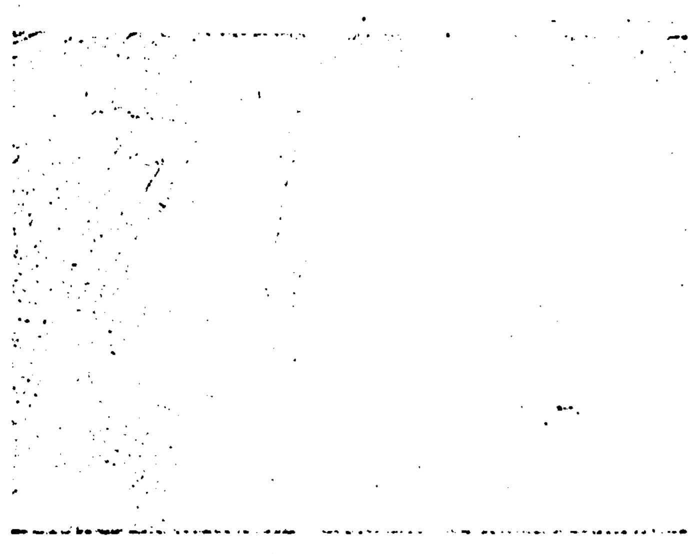


Fig. 6. Microstructure of 1Kh14ND steel after tempering from 1000°; X 300.

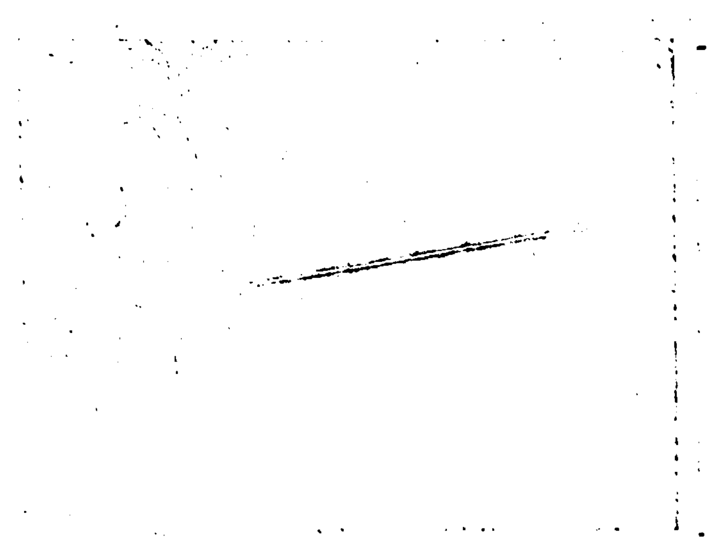


Fig. 7. Microstructure of 1Kh14ND steel after tempering from 1000° and annealing 300°; , X 300.

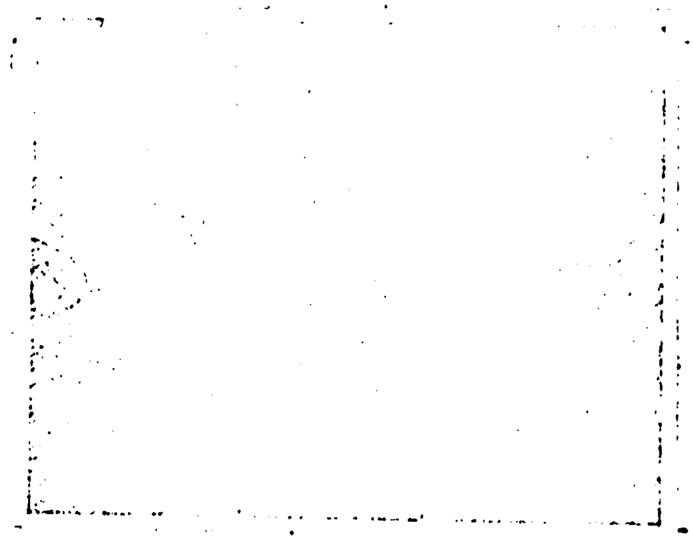


Fig. 8. Microstructure of 1Kh14ND steel after tempering from 1000° and annealing 400° ; X 300 .

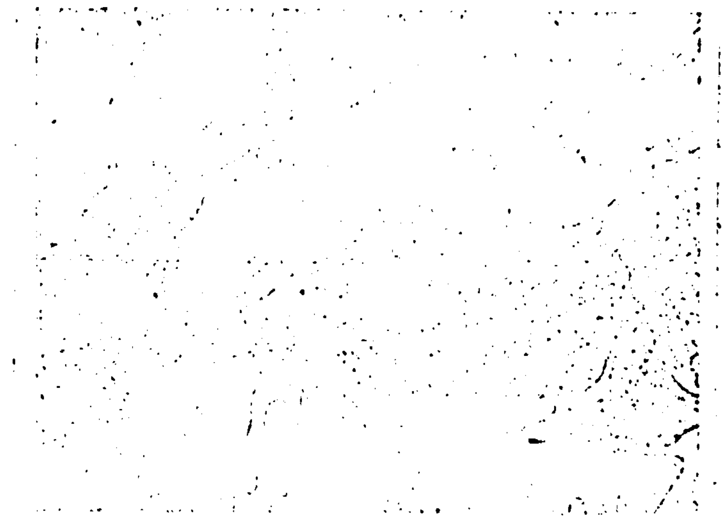


Fig. 9. Microstructure of 1Kh14ND steel after tempering from 1000° and annealing 500° ; X 300.

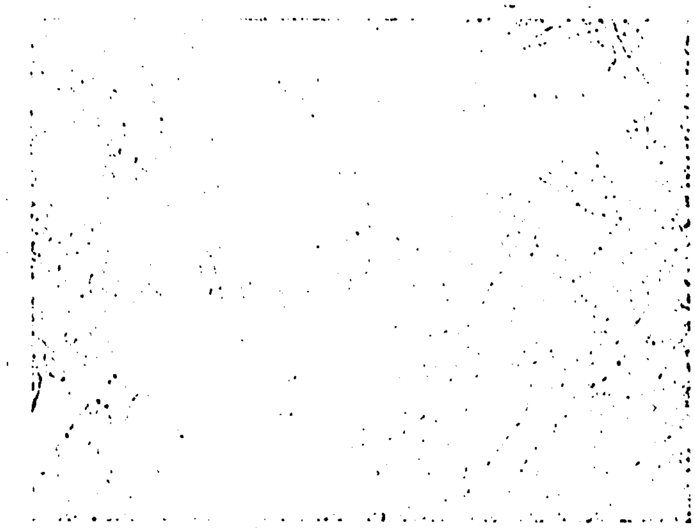


Fig. 10. Microstructure of 1Kh14ND steel after tempering from 1000° and annealing 600° ; X 300.

Fig. 11. Microstructure of 1Kh14ND steel after tempering from 1000° and annealing 680°; X 300.

Fig. 12. Microstructure of 1Kh14ND steel after tempering from 1000° and annealing 750° ; X 300.

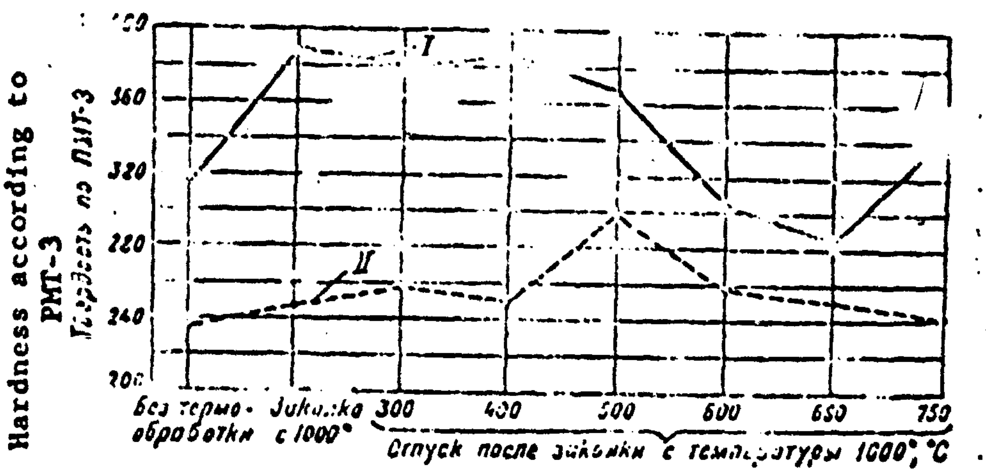


Fig. 13. Effect of thermal treatment process on the microhardness of structural components of 1Kh14ND steel: I - martensite-sorbite; II - ferrite.

Annealing at 600° leads to a further increase in the rate of transformation of martinsite into sorbite and, probably, to coagulation of dispersed copper occlusions. Hardness of ferrite and sorbite decreases. The yield point and ultimate tensile strength are substantially lowered. Elongation, necking down and impact strength values grow higher.

After annealing at 680-700° the structure consists of coagulated sorbite and isolated grains of ferrite. Sorbite hardness drops down to 283 units. The lower values of yield point and tensile strength, highest necking down, elongation and impact strength also develop at the same time.

Increase in the annealing temperature to 750°, that is to 40% above point A_{c1}, probably leads to partial formation of austenite and to its subsequent transformation into martensite during cooling. Hardness, yield point and ultimate tensile strength all increase. Elongation, necking down and impact strength values decrease.

In addition to the above investigation of the effects of annealing temperature on the mechanical properties of 1Kh14ND steel, subsequent to tempering, its mechanical properties were checked only after annealing, with no preliminary tempering. This revealed extremely low values of impact strength, elongation and necking down ($a_k \approx 1$ kgM/cm^2; $\delta \approx 4\%$). It should be said that the use of annealing alone cannot be recommended for the 1Kh14ND steel, not only because of the low resulting mechanical characteristics, but because such a method of heat treatment does not produce a maximum transition of alloying elements into the solid solution and leads to an inferior corrosion resistance, compared to that obtainable through tempering followed by annealing.

During the investigation of 1Kh14ND steel, the effect of cooling rates of tempering and annealing on its mechanical properties were also ascertained. The types of heat treatment and mechanical properties obtained with different rates of cooling are presented in Table 22.

It was determined that the mechanical properties do not differ materially with tempering in water or in air. A reduction in plasticity and in impact strength occurs with additional slowing of cooling process in tempering. This reduction was established at a cooling rate of 70° C/hr. With slower cooling after annealing, the steel shows no tendency to develop annealing brittleness.

Because it is possible for propeller blades to be above water during short periods of time (in cruising unloaded), that is, exposed to the atmosphere at below-zero temperatures (in northern waters), and with consideration of the possibility of the vessel being icebound in winter, tests to determine the impact strength to 1Kh14ND steel were made at a temperature of -10°. The tests were made with specimens cut from trefoil-shaped stock, 40 mm in cross-section, cast of metal taken from production smeltings weighing 3-4 T, liquified in 2 and 3-ton basic electric arc furnaces.

Table 22.

Mechanical properties of [illegible] at various rates of cooling.

Heat treating regime. Tempering	Annealing	σ_B kg/mm²	σ_T kg/mm²	δ %	ψ %	a_k, kg m/cm²
1000°; held 2 hrs.	690°; held 6 hrs;	64.0	79.0	17.0	66.0	9.1-9.0
cooling in water.	air cooling.	59.5	68.5	10.0 (error)	51.0	8.7-9.9
		[illegible]	76.5	19.0	62.0	[illegible]
		65.0	75.5	18.0	65.0	7.1-8.0
As above, but	As above.	65.0	78.0	18.0	60.0	7.4-8.5
air cooling.		62.0	72.0	17.0	64.0	10.7-10.8
		61.5	76.5	19.0	60.0	9.9-10.0
		62.5	72.5	18.0	66.0	8.7-12.5
1000°; held 2 hrs	As above.	58.5	70.0	17.0	55.0	5.0-5.6
cooling with a		58.5	72.0	15.0	46.5	1.2-1.5
furnace at rate		65.5	78.0	17.0	44.0	4.1-5.5
of 70°/hr.		61.5	75.5	19.0	62.0	5.9-5.2
1000°; held 2 hrs	690°; held 6 hrs;	-	-	-	-	12.5
air cooling.	cooling in water.	-	-	-	-	12.5
		-	-	-	-	12.5
		-	-	-	-	12.5
		-	-	-	-	11.1
		-	-	-	-	9.5
		-	-	-	-	9.0-10.5

Table 22, continuation.

Heat treating regime.		σ_b	σ_y	δ	ψ	a_k,
tempering	Annealing	kG/mm^2		%		kGM/cm^2
1000°; held 2 hrs air cooling.	690°; held 6 hrs; air cooling.	-	-	-	-	9.9-11.6
		-	-	-	-	12.3-12.5
		-	-	-	-	10.6-10.7
		-	-	-	-	9.4-9.5
As above.	As above, but cooling with a furnace at rate 60° / hr.	-	-	-	-	8.7-8.9
		-	-	-	-	10.5-11.7
		-	-	-	-	9.4-12.5

Specimens from 31 heats were tested, representing metal used in casting whole propellers and individual blades. Chemical composition of these smeltings and their mechanical properties met the requirements of the specification for 1Kh14ND steel.

Minimum values of impact strength at -10° were as follows: in one melting 3 kgM/cm^2; in two others 3-7 kgM/cm^2 and in 28 others, over 7 kgM/cm^2. In addition, the temperature of critical brittleness (T_k) of the steel[1] was also checked.

1. It was established that the temperature of critical brittleness equals -40° (at that temperature $a_k > 3$ kgM/cm^2).

Because the thickness of the blades and the hubs of large propellers in some places reaches 250 mm, the mechanical properties of 1Kh14ND were checked on specimens cut from thick ingots. Slabs 150, 175 and 250 mm in thickness, as well as a molded blade of variable cross-section, from 40 to 250 mm thick, were cast for use in these tests.

The dimensions and cast weight of slabs and of the molded blade are shown in Table 23.

Table 23.

Dimensions and weights of slabs and of molded blade.

Type of casting	Dimensions	Casting weight, kg.
Slab	150 X 150 X 200	120
"	175 X 250 X 400	270
"	250 X 250 X 500	500
Modeled blade	-	1700

The choice of shape and dimensions of castings for testing was made in view of the need of determining the effect of wall thickness of a casting on the mechanical properties of the steel. In making the molded blade specimen, an effort was made to approximately duplicate the cooling conditions prevailing in castings of propellers in the molds and in the course of their heat treatment. To this end, the approximate ratio of surface of molded blade to its volume duplicated that existing in the basic sections of propellers of large icebreakers.

Specimens for the physical tests were cut out from various sections of the model blade. Patterns for cutting out specimens from thick stock are shown in Fig. 14-17.

Specimen stock was subjected to heat treatment along schedules previously established for 1Kh14ND steel: tempering from 1000°; cooling in air and annealing at 680°, followed by cooling in air.

For slabs 150 mm thick, the following scheme of heat treatment was used:

a) tempering in air from 1000°; exposure at 1000° - 4 hours;

b) two annealings at 680° with cooling in air; first exposure - 6 hours, and the second one - 10 hours.

The slab was cast of steel with the following chemical composition (smelted in 3-ton basic arc electric furnace): 0.07% C; 0.32% Si; 0.49% Mn; 14.40% Cr; 1.62% Ni; 1.48% Cu.

The results of the physical tests are shown in Table 24. As seen from the data, properties of steel on specimens cut from the 150 x 150 x 200 mm slab were sufficiently high and virtually the same as those obtained from specimens made of standard, trefoil-shaped stock of 40 mm cross section.

Typically, the mechanical properties of material from the middle of a casting's section did not differ from those determined at the surface.

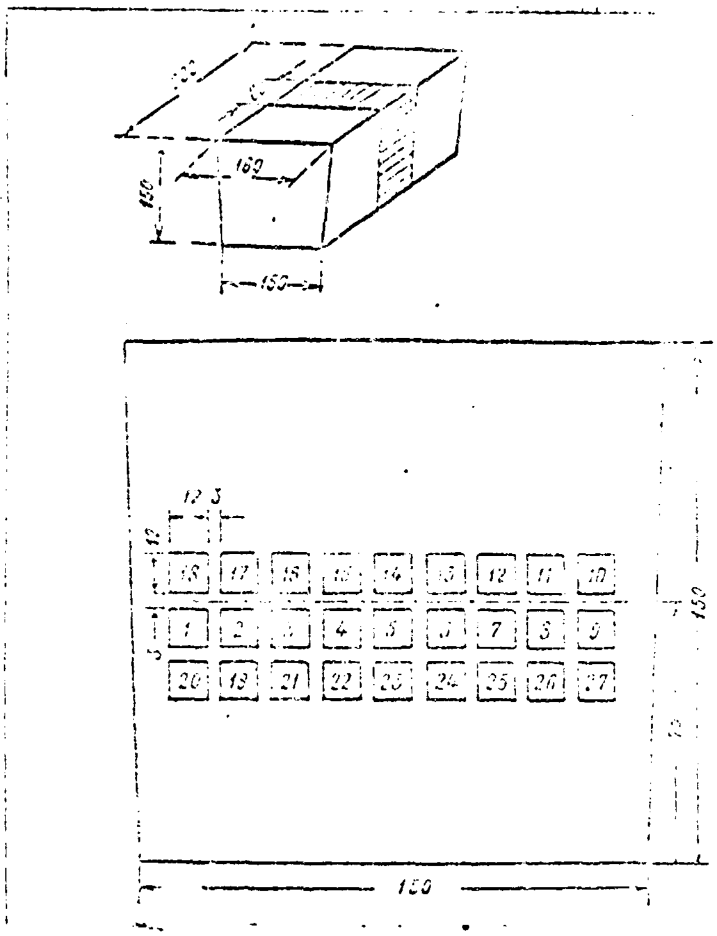


Fig. 14. Scheme for cutting specimens from very thick stock. 150 mm slab thickness

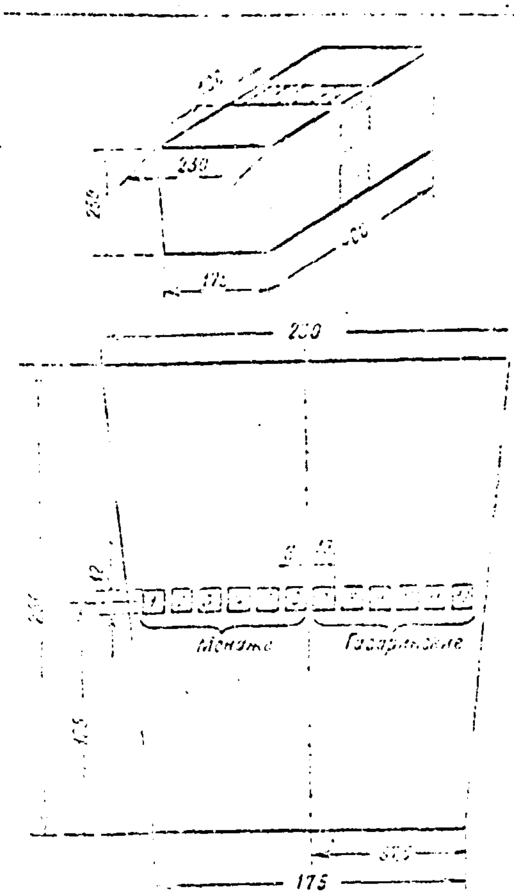


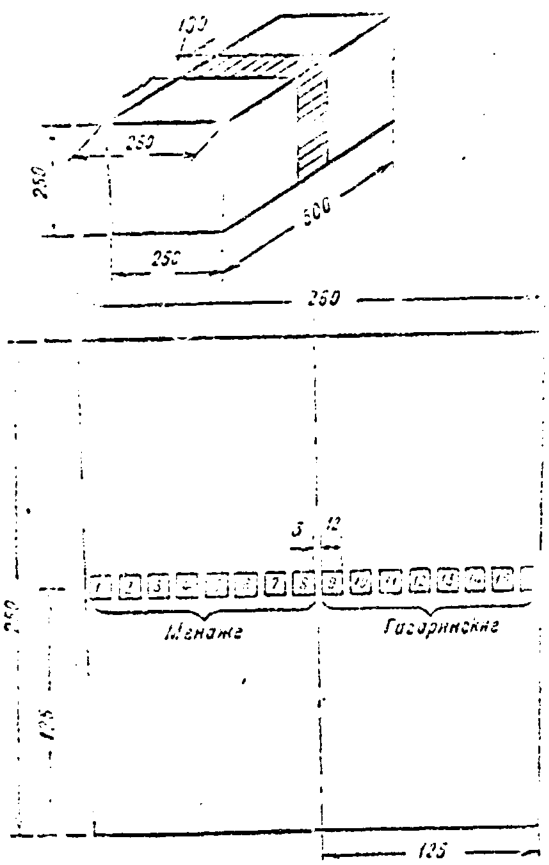
Fig. 15. Scheme for cutting specimens from very thick stock. 250 mm slab.

Stock shown in Fig. 15-17 was cast of steel with the following composition: 0.1% C; 0.32% Si; 0.44% Mn; 14.89% Cr; 1.41% Ni; 1.53% Cu.

Tempering, as in the case of the preceeding smelt, was carried out from 1000° with subsequent air cooling (exposure at 1000° was 4 hours). Only one annealing was used, at 680° held for 10 hours, followed by air cooling.

The results of mechanical tests are shown in Table 25. From this data it is seen that the yield point and ultimate tensile strength of all specimens, both the ones cut from slabs and from the model blade, met the requirements set for trefoil-shaped stock of 40 mm cross-section. Exceptions were the individual deviations typical of large ingots. In all cases the ultimate tension was not less than 64-65 kg/mm^2, with 62 kg/mm^2 - the normal value for this steel, while the yield point was as low as 47-49 only on a few specimens, with 50 kg/mm^2 being normal.

Elongation, necking down and the impact strength values of individual specimens of 250 mm thickness were comparatively low. To improve plastic and ductile properties, the remainder of the cast stock was subjected to a second heat treatment. The cutting pattern for these specimens is shown in Fig. 18 and 19.



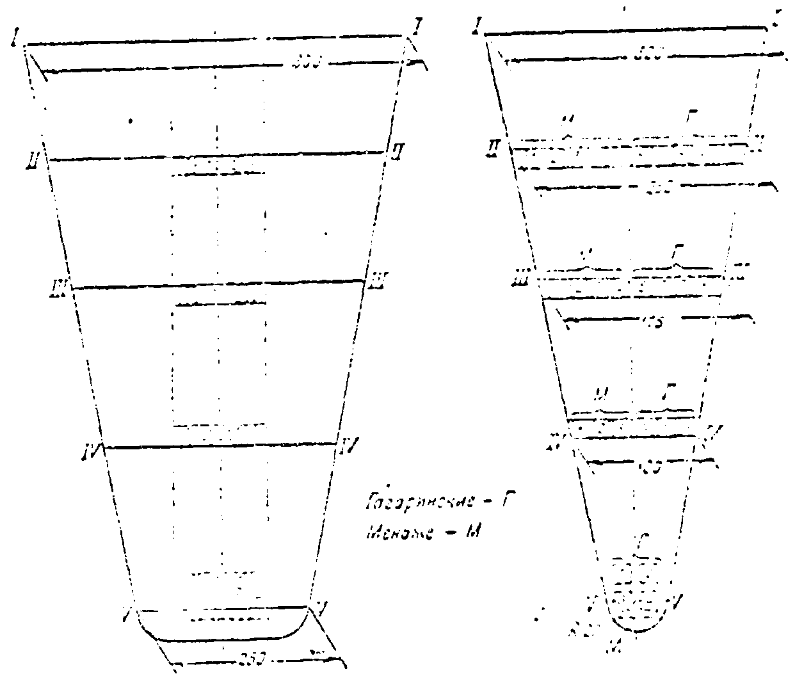


Figure 16. Scheme for cutting specimens from very thick stock. 250 mm slab thickness.

Figure 17. Scheme for cutting specimens from the model blade.

Table 24.

Mechanical properties of specimens made from slabs 150 mm thick.

Specimen №	σ_t	σ_y	δ	ψ	a_k
	kg/mm²		%		kgm/cm²
1	-	-	-	-	10.5
2	-	-	-	-	9.0
3	-	-	-	-	9.5
4	-	-	-	-	10.1
5	-	-	-	-	16.3
6	57.0	69.0	19.0	54.5	-
7	56.0	67.0	19.5	59.0	-
8	56.0	70.0	22.0	66.0	-
9	57.0	68.0	18.5	66.0	-
10	-	-	-	-	12.5
11	-	-	-	-	9.9
12	-	-	-	-	9.9
13	-	-	-	-	12.2
14	-	-	-	-	10.1
15	56.0	65.0	17.0	66.0	-
16	56.0	69.0	17.5	62.0	-
17	55.5	68.0	19.0	64.0	-
18	56.0	69.0	19.5	66.0	-
19	-	-	-	-	9.9
20	-	-	-	-	9.9
21	-	-	-	-	10.5

Table 24,

continuation

Specimen №	σ_t	σ_y	δ	ψ	a_k
	kg/mm²		%		kgm/cm²
22	-	-	-	-	10.1
23	54.5	67.5	19.5	59.0	-
24	53.0	67.0	18.0	66.0	-
25	53.0	69.0	17.5	60.0	-
26	53.0	69.0	20.0	62.0	-

Table 25.

Mechanical properties of specimens from 175 and 250 mm slabs and model blade.

Type of stock	Specim. №	σ_t	σ_y	δ	ψ	a_k, kgm/cm² at	
		kg/mm²		%		+20°	−10°
Slab	1	-	-	-	-	-	1.2
250 X 250 X 250	2	-	-	-	-	2.1	-
(fig. 16)	3	-	-	-	-	-	0.9
	4	-	-	-	-	3.4	-
	5	-	-	-	-	-	2.2
	6	-	-	-	-	6.1	-
	9	52.0	67.5	9.7	25.1	-	-
	10	52.5	66.4	8.3	19.1	-	-
	11	-	-	-	-	-	-
	12	55.7	68.3	8.3	19.9	-	-
	13	50.8	67.2	10.0	22.8	-	-
	14	52.8	67.8	15.0	46.2	-	-

Table 25,

Continuation.

Type of stock	Specim. No	σ_s	σ_b	δ	ψ	a_k, Kgm/cm² at	
		KG/mm²		%		+20°	-10°
Modeled blade.	1	-	-	-	-	-	1.0
Specimens taken from	2	-	-	-	-	5.9	-
250 mm cross-sect'n	3	-	-	-	-	-	4.7
(Fig. 17)	4	-	-	-	-	2.0	-
	5	-	-	-	-	-	2.0
	6	52.1	66.2	11.0	25.9	-	-
	7	47.7	66.2	10.0	25.9	-	-
	8	51.6	65.8	8.3	26.3	-	-
	9	48.3	64.8	7.3	37.2	-	-
	10	50.7	64.4	6	27.9	-	-
	11	51.7	65.6	10	26.6	-	-
Slab	1	-	-	-	-	-	1.7
175 X 250 X 400	2	-	-	-	-	5.1	-
(Fig. 15)	3	-	-	-	-	-	6.0
	4	-	-	-	-	-	5.0
	5	-	-	-	-	7.8	-
	6	-	-	-	-	-	5.2
	7	54.3	68.9	10.3	27.1	-	-
	8	52.1	67.2	8.3	22.3	-	-
	9	53.5	66.6	9.7	30.0	-	-
	10	52.3	66.7	9.3	31.2	-	-
	11	53	68.1	12.7	25.6	-	-
	12	53	67.3	17.0	31.8	-	-

Table 25,

Continuation.

Type of stock	Specim. No	σ_b	σ_y	δ	ψ	a_k kgm/cm² at	
		kg/mm²		%		+20°	-10°
Modeled blade, Specimens taken from a section 175 mm thick (fig. 17)	1	-	-	-	-	-	4.5
	2	-	-	-	-	-	6.5
	3	-	-	-	-	-	5.2
	4	-	-	-	-	-	2.6
	5	51.0	65.9	13.3	34.7	-	-
	6	50.7	66.2	15.5	39.0	-	-
	7	48.8	65.2	13.8	36.3	-	-
	8	50.0	66.2	12.7	39.5	-	-
As above, from a section 100 mm thick.	1	-	-	-	-	-	2.5
	2	-	-	-	-	-	5.4
	3	-	-	-	-	-	1.1
	4	47.2	65.7	14.3	41.9	-	-
	5	49.6	66.0	16.3	48.8	-	-
	6	50.1	65.7	13.7	44.3	-	-
As above, from a section 40 mm thick.	1	-	-	-	-	-	8.0
	2	-	-	-	-	-	8.3
	3	46.8	67.9	20.7	50.7	-	-
	4	48.2	65.1	22.7	62.3	-	-
Trefoil	-	67.0	78.5	17.0	48.0	7.9-8.5	-

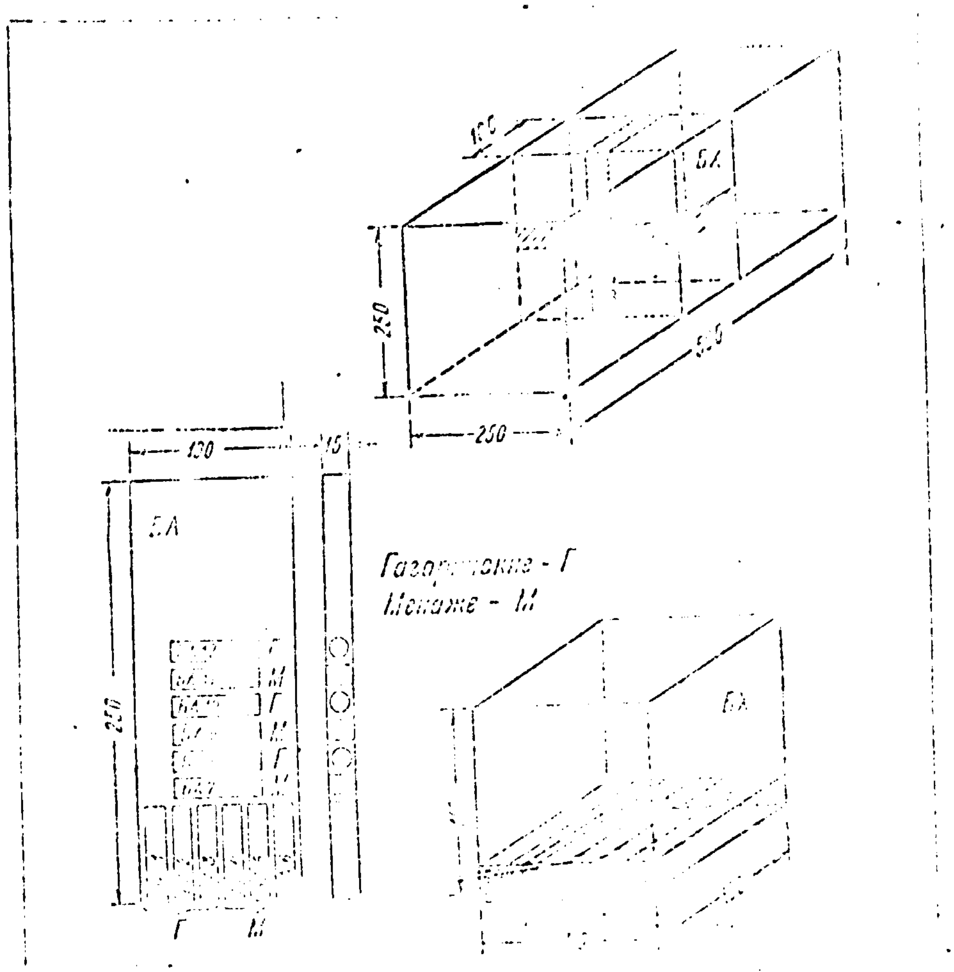


Fig. 18. Schemes for cutting specimens from remnants of slabs 250 mm thick after a repeated heat treatment.

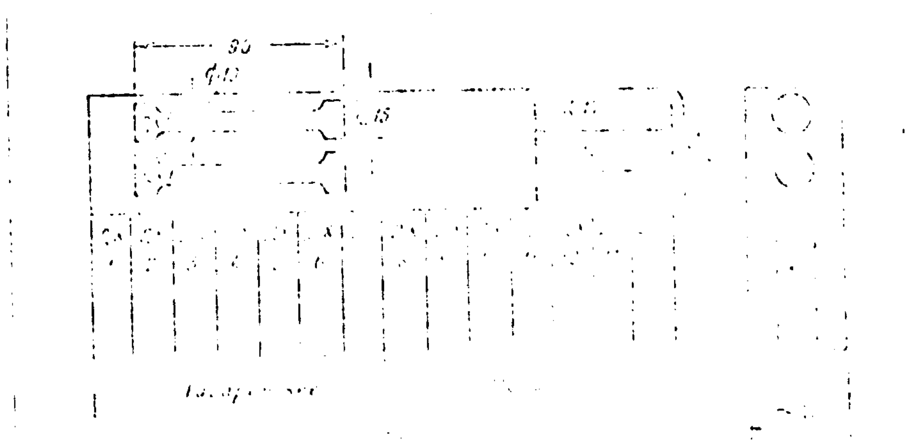


Fig. 19. A scheme for cutting specimens from remnants of slabs 250 mm thick after a repeated heat treatment.

Table 26.

Mechanical properties of specimens cut from slab 250 mm thick after a repeated heat treatment.

Specimen №	σ_t Kg/mm²	σ_v Kg/mm²	δ %	ψ %	a_k, Kgm/cm² at +20°	a_k, Kgm/cm² at -10°
BA 1	49.7	68.8	17.7	61.7	-	-
BA 2	49.1	69.2	20	47.5	-	-
BA 3	49.5	66.8	16.2	46.0	-	-
BA 5	-	-	-	-	-	3.8
BA 6	-	-	-	-	5.9	-
BA 7	-	-	-	-	7.5	-
BA 8	50.7	69.5	15.8	60.8	-	-
BA 9	-	-	-	-	5.6	-
BA10	52.7	68.5	16.2	66.2	-	-
BA11	-	-	-	-	-	2.4
BA12	52.7	71.3	19.2	56.8	-	-
BKh1	-	-	-	-	10.5	-
BKh2	-	-	-	-	-	5.6
BKh3	-	-	-	-	8.8	-
BKh4	52.2	71.7	15.3	54.4	-	-
BKh5	55.3	72.0	15.3	55.3	-	-
BKh6	53.2	72.6	19.3	50.2	-	-
DKh1	51.7	69.7	21.1	56.4	-	-
DKh2	53.3	71.2	17.7	60.3	-	-
DKh3	55.2	72.2	8.0	51.7	-	-
DKh4	53.8	70.8	15.7	51.8	-	-
DKh5	53.2	71.5	16.2	51.4	-	-

Table 26, continued

Specimen No	σ_t Kg/mm²	σ_y	δ %	ψ	a_k, Kgm/cm² at +20°	-10°
DKh6	53.2	71.8	18.8	65.5	-	-
DKh7	52.0	71.5	17.5	62.2	-	-
DKh8	-	-	-	-	11.7	-
DKh9	-	-	-	-	8.3	-
DKh10	-	-	-	-	9.5	-
DKh11	-	-	-	-	-	3.8
DKh12	-	-	-	-	7.6	-
DKh14	-	-	-	-	5.1	-
DKh16	-	-	-	-	7.1	-
DKH17	-	-	-	-	-	7.8

A specimen cut from a slab 250 x 250 mm in cross section, stamped BA, was subjected to a seoond annealing at 660-700° for a period of 10 hours. Specimens stamped BKh and DKh went through a second tempering and annealing. Their mechanical properties after this treatment are shown in Table 26.

From Table 26 it is seen that the elongation, necking down and impact strength indicators have substnatially improved even after the second annealing and had reached the standards set for this type steel, as derived from standard stock of 40 mm thickness. The fact that a second annealing, without preliminary homogenization, materially improved the mechanical properties, proves that the originally obtained lower values are independent of the nature of initial crystalization.

After the first heat treatment, a complete carbide network was observed in the structure along the borders of the ferrite grains and on an appreciable portion of carbides within these grains.

A similar structure can be normally found in specimens having low indexes of impact strength and plasticity. An improvement in these properties can be achieved by resorting to repeat annealing. Typically, the first 150 mm thick slab tested showing high indexes of plasticity and impact strength had been annealed twice.

The possibility of attaining the required levels of impact strength and plasticity through the use of a second annealing at 680°, without a second tempering, was established through considerable practical experience with heat treatment of heats smelted in 2-, 3-, 5-, and 10-ton electric arc furnaces.[1]. The level of mechanical properties of 1Kh14ND steel, determined from 3-4 ton production heats achieved during the last year and a half of a plant's operation is shown in Table 27.

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1. Factors producing the necessity for a second annealing, and the processes in taking place in its course, are discussed in more detail in Chapter V.

Corrosion Resistance of 1Kh14ND Steel. A check was made to determine 1Kh14ND steel's resistance to:

a) flowing stream corrosion;
b) corrosion during immersion in still water, specimens isolated from each other;
c) corrosion in aperture between specimens in contact with each other, immersed in still water.

Flowing stream corrosion tests were made on 145 mm diameter, 1.6-2 mm thick disks (Fig. 20), installed in groups of 3 on a vertical spindle device.

The specimens were rotated at 1400 rpm in a special tank filled with synthetic sea water of a composition similar to that of the Pacific Ocean. Four partitions were installed in the tank, to reduce the motion of water caused by the rotation of the disks. Ebonite sleeves 40 mm high were placed on the spindle to separate the disks from each other. The length of the test (rotation) of samples was 500 hours. To test the effects of welding on corrosional stability some of the disks were cut from previously welded stock.

Tests of corrosion during static immersion in sea water were made on samples 25 mm in diameter and 2.5 mm thick.

Tests of aperture corrosion were also made on specimens having d=25 mm, fastened in pairs with vinyl chloride insulated wire. The gap between specimens was formed because of the loose fit over the total surface. The samples tested consisted both of 1Kh14ND steel in contact with each other and of 1Kh14ND steel samples in contact with more highly alloyed stainless steel and with other materials (LMtsZh 55-3-1 brass; ebonite; carbon steel). The duration of tests ranged from 3500 to 6000 hours.

Results of tests to determine flowing water corrosion resistance of 1Kh14ND steel samples are listed in Table 28 which, for comparison purposes, also gives similar data for carbon steel, LMtsZh 55-3-1 brass used in propellers and for 2Kh13 stainless steel.

Results of tests to determine aperture corrosion of specimens in contact and of corrosion resistance during static immersion, out of contact, are given in Table 29.

Table 27.

Levels of mechanical properties of 1Kh14ND steel obtained from industrial smeltings.

σ_t, kg/mm^2.	≥ 68	≥ 62	≥ 56	> 50	< 50*
number of heats, %.	2.3	22.7	69	95.3	4.7
σ_v, kg/mm^2.	≥ 80	> 74	> 69	≥ 62	< 62*
number of heats, %.	8.5	54.1	90.5	98.8	1.2
δ, %	≥ 21	≥ 19	≥ 17	≥ 15	< 15
number of heats, %.	8.8	28.4	65.6	99.6	0.4
ψ, %	≥ 62	≥ 54	≥ 48	≥ 40	< 40
number of heats, %.	8.7	56.8	72.5	97.5	2.5
a_k, kgM/cm^2 (highest values).	≥ 12	≥ 9.0	≥ 6.0	≥ 3.0	< 3
number of heats, %.	6.2	39.2	85.2	99.4	0.6
a_k, kgM/cm^2 (lowest values).	≥ 12	≥ 9.0	≥ 6.0	> 3.0	< 3
number of heats, %.	1.2	29.2	69.8	99.5	0.5

* Drop in values of elastic limit and ultimate stress obtained only as a result of secondary annealing, made for the purpose of improving the plasticity and ductility.

Tests for flowing water corrosion, the most dangerous one for propellers, demonstrated the resistance of 1Kh14ND stainless steel in sea water to be 25-100 times higher than that of carbon steel, especially noticeable in heats containing over 13% Cr (numbers I and III).[1]

1. The chromium content of these smeltings matches that established for 1Kh14ND steel, while that of number II was lower by 0.6%.

Fig. 20: [illegible] specimen of [illegible] steel after being tested for stream flow corrosion during 500 hours.

A radical difference in the state of the specimens' surfaces was typical. The uncovered portions of the 1Kh14ND steel specimens of heats I and III showed no visible traces of corrosive deterioration, while specimens of carbon and low-alloy steels had very rough surfaces as a result of corrosion (Fig. 20 and 21).

Existence of such roughness on propeller surfaces substantially affects their efficiency.

Specimens from the I and III heats lost less weight than those made of LMtsZh 55-3-1 brass. All specimens of 1Kh14ND steel showed typical evidence of corrosional damage on covered surfaces, under the ebonite inserts.

Similar results were obtained on specimens tested for static immersion. In all cases the uncovered surfaces of the specimens showed no evidence of corrosion. Covered surfaces, in contact, showed well defined apertural corrosion when in contact with specimens of same composition, or in contact with more highly alloyed [illegible] stainless steel. In the case of contact of 1Kh14ND steel specimen with carbon steel no corrosive damage could be observed. When in contact with LMtsZh 55-3-1 brass and carbon steel, the weight loss of 1Kh14ND steel specimen was less than in the absence of contact, since in this case the brass and the carbon steel provided protection to the stainless steel.

Table 28.

Results of tests of specimens to determine corrosive effects of stream flow.

Material	Average weight loss, mg M^2. hr.	Results of visual examination		Remarks
		Exposed surface	Under the ebonite insert	
1Kh14ND steel, Heat I	22.4	No visible local pitting.	Ring-shaped pitting up to 0.25 mm deep.	Chem. Composit'n. 15.5%Cr;1.5%Ni; 1.37%Cu; specimen unwelded.
Heat II	91.6	Pinpoint surface pitting, porosity.	Chain of small pits, up to 0.50 mm deep.	Chem. composit'n. 12.9%Cr;1.4%Ni; 1.57%Cu;specimen unwelded.
Heat III	14.4	No local pitting, isolated pinpoints along the weld.	Small chain of shallow pits.	Chem. composit'n. 14.8%Cr;1.1% Ni;1.55%Cu, welded specimen.
LMtsZh55-3-1brass.	64.7	Dezincing in a thin continuous layer.	Dezincing in thin layer.	Composition as marked.
25L steel	2210	Overall roughness	-	as marked.
2Kh13 steel	not measured.	Pinpoint corrosive damage.	Deep pinpoint corrosion, through specimen in spots.	as marked.

Table 29.

Results of tests for static immersion of specimens placed in contact with each other (aperture corrosion), and specimens not in contact.

Material designat.	Heat	Average weight loss mg m² · hour: out of contact	Average weight loss mg m² · hour: in contact	Material in contact with specimen.	Results of visual inspection of the specimen being tested.
1Kh14ND	A	0.56	-	-	Isolated stains.
		-	5.46	1Kh14ND	Spot corrosion on contact side of the specimens, up to 0.08 mm deep.
	B	6.07	-	-	No damage
		-	8.25	1Kh14ND	Spot corrosion up to 0.09 mm deep only on contact faces of specimens.
	V	2.27	-	-	No damage
		-	13.4	1Kh14ND	Spot corrosion up to 0.04 mm deep only on contact fa-ces of specimens.
	G	-	5.8	1Kh14ND	Spot corrosion only on contact faces.
		-	-	OKh16N4D4T	Groups of pits up to 0.5 mm deep only on contactfaces of specimens.
		-	0.15	LMtsZh 55-5-1 brass.	No damage.
		-	0.04	Carbon steel	No damage.
2Kh15	-	-	29.0	OKh16N4D4T	Corrosional pitting on both faces of specimen. Depth 1.5 mm on contact faces.
Brass	-	-	14.0	1Kh14ND steel	Dezincing.
25L steel	A	53.9	-	-	Evenly distributed corrosion over the entire surface.
	B	-	18.0	1Kh14ND steel	As above.
	V	54.0	-	-	As above

Specimens of 2Kh13 steel showed visible evidence of corrosive damage, not only on the covered surfaces (contact surfaces), but also on the open ones. The nature of the damage itself was noticeably different: specimens were pitted much more deeply on the contact faces. The depth of pitting reached 1.5 mm, while on the 1Kh14ND specimens it did not exceed 0.08-.05 mm.

Corrosion-fatigue resistance of 1 Kh14ND steel. In the course of service, propellers are exposed to the concurrent effects of corrosionally active sea water and stress reversals, that is, they operate under corrosive fatigue conditions.

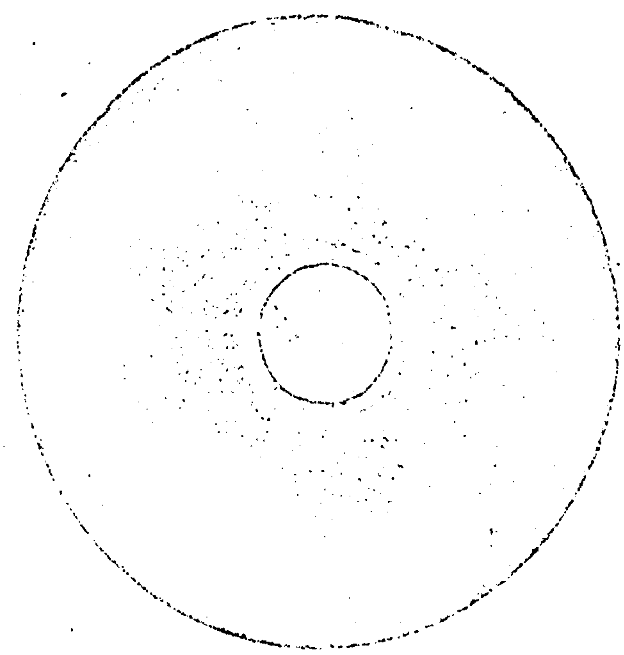


Fig. 21: Disk specimen of carbon steel after being tested for flowing water corrosion during 500 hours.

Due to this, one of the most important properties of material used in propellers is its endurance limit (fatigue limit) for simultaneous effects of load reversal and a corrosive medium on the metal. Today, in some instances of designing propellers for strength (for instance, in designing VRSh), the limit of endurance of the steel under corrosive conditions is a fundamental design consideration.

The limit of corrosive endurance is considered to be that maximum stress which does not yet produce failure due to the effect of a set number of load cycles in a given corrosive medium

Figure 22 shows the resulting curves representing corrosion-fatigue tests made by TsNIIMF associates with the use of methods that they had developed. Tests were carried out on specimens having d = 10 mm. As comparisons, the curves are plotted for 1Kh14ND, 2Kh13N, and 18DGS steels.

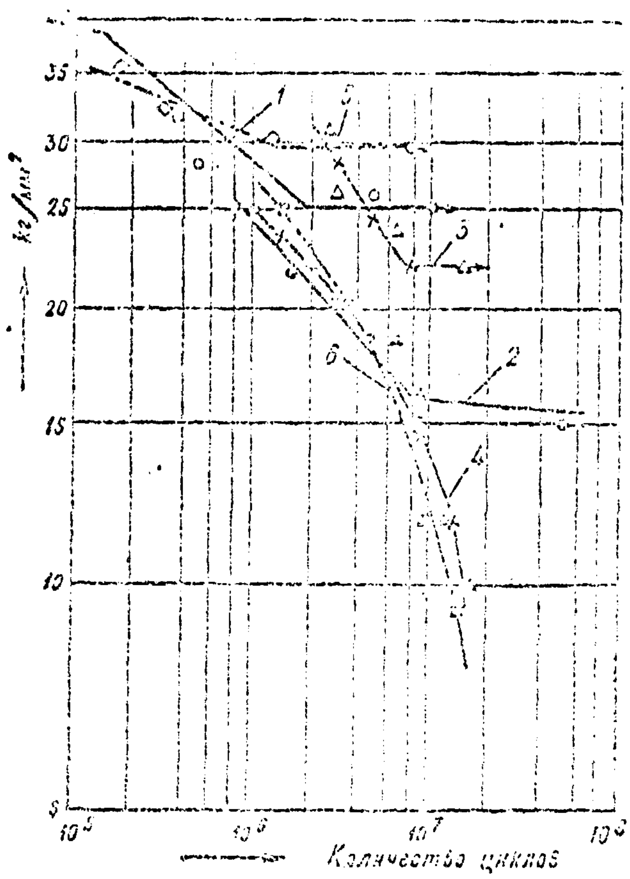


Fig. 22. Results of comparative corrosion-fatigue tests of 1Kh14ND, 2Kh13N and 18DCS steels.

1 - 1Kh14ND tested in air;

2 - 1Kh14ND in a 3% solution of NaCl;

3 - 2Kh13N tested in air;

4 - 2Kh13N in a 3% solution of NaCl;

5 - 18 DGS in air;

6 - 18 DGS in a 3% solution of NaCl.

Specimens of the 2Kh13N and 18DGS steels were cut out of the blades of a hydraulic turbine, while the 1Kh14ND specimens, from a 60 mm thick ingot.

As seen from this data, the limit of corrosional endurance of 1Kh14ND steel during tests based on 10^7 cycles is 25 kg/mm2 in air and 16 kg/mm^2 in a 3% solution of NaCl. The 2Kh13N steel tested on the basis of 10^7 cycles in air had an endurance limit of 22 kg/mm^2. During tests in a 3% NaCl solution and an increased number of cycles, the limit of fatigue indicators were radically lower (no endurance base), as was the case with the 18 DGS structural steel. Probably this indicated low corrosional endurance of the 2Kh13N specimens, cut from the blades, is attributable not only to its composition, but to the specific character of its crystalization in large castings.

Endurance of 1Kh14ND steel under the effects of cavitation. In practice there are known cases of extremely rapid breakdown of propellers due to the destructive action of cavitation. This damage can be averted chiefly through adoption of structural measures (change in the shape of the propeller, in the outline of the vessel's stern, etc.), however, an improvement in the propeller's resistance to the effects of cavitation can to a certain extent be achieved through the adoption of more durable material.

Many investigators have studied the nature of cavitational damage. The most thorough exposition of this problem appears in L. A. Glickman's book Corrosive-Mechanical Strength of Metals[7]. According to this study, the deterioration results from the mechanical action of "hydraulic impacts" produced by the closure of cavitational bubbles on the surface of the metal, as well as by the corrosional process.

It is considered established that corrosion, acting in combination with cyclic mechanical influences, causes destruction of metals.

The extent of the metal's resistance to cavitational effects depends on a number of factors, including the composition of the metal. Brasses, bronzes and stainless steels, especially austenitic ones, are much more resistant to such damage than cast iron and carbon steels. Materials having greater hardness and strength present better resistance to effects of cavitation at equal levels of corrosional resistance.

Endurance tests made by Prof. L. A. Glickman and candidate of technical science Y. E. Zobachev, on a magnetostrictive vibrator demonstrated a higher resistance of 1Kh14ND steel as compared to carbon steel and LMtsZh 55-3-1 brass (Table 30). It was typical of 1Kh14ND steel that, after tempering at 1000° with a hardness N_V = 388, it had a considerably better resistance to cavitational damage than was the case after tempering and annealing at a hardness N_V = 217.

Results of natural tests of propellers made of 1Kh14ND steel. The 1Kh14ND stainless steel has been widely used during the last few years for the fabrication of normal class propellers.

Propellers cast of this type of steel are being used in the atomic-powered icebreaker LENIN, ships of the SLAVA whaling flotilla, the diesel-electric ships OB and LENA, which participated in Antarctic expeditions, in new domestic-built whaling ships and in a number of overhauled ships of our merchant marine. The maximum diameter of a unit-cast propeller made of 1Kh14ND steel was 5.2 M.

Of much interest are the results of inspections of propellers made of 1Kh14ND steel for use on 500-hp seagoing tugs, operating in the Black, Baltic, and Barents Seas. The propellers were examined after different lengths of service, ranging from one to six years.

Operating conditions differed. Some of the tugs cruised in ice-filled waters for a long period of time. A few of the propellers showed evidence of impact on rocks; there were dents and chips along the edges of the blades. However, none of the propeller , including theones which have been in service for six years at the time of the inspection, showed any visible evidence of corrosional deterioration.

As a comparison, the propeller of the same type of tug, made of 25L carbon steel was examined at the same time. This propeller showed corrosional pitting 3-4 mm deep, after only some seven months of service in the Barents Sea.

Table 30.

Comparative resistance to cavitational destruction in sea water of carbon steel, LMtsZh 55-3-1 brass and 1Kh14ND steel.

Material	Specimen's weight loss, mg.			
	1-st hour	2-nd hour	3-rd hour	Total in 3 hour test.
Carbon steel (0.31% C). . .	47.9 55.4	85.4 89.4	65.0 60.0	198.1 204.8
LMtsZh 55-3-1 brass. . . .	41.8 42.8	58.3 58.3	57.5 55.3	157.6 156.6
1Kh14ND steel after tempering in air from 1000° (N_V = 388)	9.7 8.0	12.0 16.0	14.0 10.0	35.7 34.0
after tempering in air and annealing 680° (N_V = 217)	17.1 17.0	31.0 30.5	47.3 27.6	95.4 75.1

Similar findings were made during inspection of assembled propellers of the diesel-electric ships OB and LENA after cruising one and three years respectively in the Antarctic.

The comparatively high sea water corrosion resistance of propellers made of 1Kh14ND steel, together with the beneficial effects of its composition's properties can to a large extent be attributed to the beneficial action of the protection system installed in the vessels, and to the protective action of the outlines of the stern portion of the hull, built of structural steels whose potential is much lower than that of 1Kh14ND steel.

Uses of 1Kh14ND steel. In a number of seas, especially during pro tracted inactive periods, there is a formation of marine growth over the submerged parts of a ship, including the propellers. Stainless steel propellers are likewise subject to this type of growth. Narrow apertures (gaps) form between the layer of marine growth and the surfaces of the blades. Due to stagnation of sea water in these gaps, and the lack of free access of oxygen needed for the maintenance of the inhibiting layer on the surface of the stainless steel, there arises a favorable medium of development of corrosive processes. As a result of aperture corrosion, damage in the form of pitted areas, or individual spots, appears on these surfaces. The number and extent of these blemishes varies widely, depending upon the aperture corrosion tendency of the material.

In steel not strongly inclined toward aperture corrison the damage may be insignificant, but in steels susceptible to such corrosion it may be of very significant magnitude.

Tests indicate that machined plates (quality of machining $\nabla\nabla 6$) of 1Kh14ND steel, continuously immersed in the Black Sea for six months were covered with calciferous deposits several millimeters thick. After removal of the deposits, individual pits approximately 0.5 mm deep could be observed on the surfaces of the plates. This, as well as the results of the laboratory tests described above, confirm the tendency of 1Kh14ND steel toward aperture corrosion.

The presence of such individual pits on the surfaces of normal class propellers is acceptable and does not materially reduce their operational properties. These propellers have unfinished surfaces and, in accordance with standing specifications, isolated rough spots and shallow pits of appreciable dimensions are permitted on the surfaces of such blades.

The situation is different in the case of certain propellers of the highest class, the surfaces of whose blades must be ground or polished, according to standard specifications; presence of corrosional pits 0.5-1.0 mm deep on such surfaces is inadmissible.

Because of the possibility of an extended lay-over of ships, the probability of formation of marine growth on highest class propellers and a resultant situation favorable to aperture corrosion should be considered. Apertural corrosion can also occur in the clearances between the propeller and shaft (if the latter is made of stainless steel) and between the propeller and its fairing. Consequently, the fabrication of highest type propellers for particularly critical service conditions, preference should be given to stainless steels having a better apertural corrosion resistance than that of 1Kh14ND.

It should be noted that 1Kh14ND steel, in addition to being suitable for normal class propellers, can also be used in those propellers of the highest class which do not require especially high standards of blade finish, such as propellers of certain merchant and service vessels. The probability of wider utilization of 1Kh14ND steel in the production of other propellers of the highest class can only be established upon the accumulation of more practical experience with propellers made of this steel on high-speed vessels.

CHAPTER IV

DOMESTIC STAINLESS STEELS USED FOR THE PRODUCTION OF THE HIGHEST CLASS SHIPS' PROPELLERS.

Stainless steel of high durability for use in propellers of the highest class must be able to meet the following basic requirements:

1) have a yield point in tension and compression not less than (preferably somewhat higher than) those of high-strength brass (LAMtsZh 67-5-2-2 type) and alloyed aluminum bronzes for use in propellers (that is, σ_t = 25-30 kg/mm^2), and at the same time have adequate plasticity and toughness;

2) have corrosion resistance in still and in flowing sea water not lower than that of brasses and bronzes used in propellers;

3) have a minimum tendency toward corrosional pitting of the blade and hub surfaces of propellers;

4) have no tendency toward intercrystalline corrosion or corrosional cracking under propeller service conditions;

5) be able to resist cavitational damage better than the brasses and bronzes used in propeller;

6) contain no significant quantities of expensive and scarce components (nickel, molibdenum, etc.);

7) possess good casting properties (fluidity, freedom from cracking, etc.). permitting casting of propellers in accordance with ordinary technical procedures. Mechanical properties and corrosional resistance must be obtainable through heat treatment not requiring cooling subsequent to tempering in liquid mediums. Should permit the repair of casting flaws by normal welding procedures, without resorting to preheating;

8) must permit machining of propellers with the use of available machine tools and the use of cutting tools made of materials available to the industry.

With regard to corrosive resistance, the above requirements are also met by a number of stainless steels listed in GOST 2176-57 for castings of high-alloy steel (Kh18N9TL, Kh18N12M3TL, Kh25N19C21, etc.). However, these have the following important faults, making them unsuitable for use in propellers. These steels:

a) have low strength characteristics; guaranteed yield point of the Kh18N9TL steel is 20 kg/mm^2 and those of the Kh18N12M3TL and Kh25N19C2L steels 22 and 24 kg/mm^2 respectively;

b) they contain a large amount of nickel (8-20%); in addition, Kh18N12M3TL steel has 3-4% Mo.

Literature mentions instances of the use of Kh25N5 type stainless steel for the production of the highest class propellers. However, this steel has low flowability, due to its high chrome content, which complicates production due to the required addition of 35-40% ferrochrome in the course of casting.

According to Y. A. Nehendzy, Kh25N5 steel is brittle in untreated form, due to separation of σ -phases and carbides. Experience has shown that castings made of this steel have low plasticity and ductility, as well as comparatively low strength. For example, steel with the following chemical composition was smelted in a 3-ton arc furnace: 0.11% C; 1.80% Si; 0.65% Mn; 23-25% Cr; 5.37% Ni; 0.30% Ti; 0.21% V. In order to obtain the optimum mechanical properties, a number of heat treatments were tried out. Results of mechanical tests after various types of heat treatment (Table 31), demonstrate that with all the various cycles of tempering in air and in water, and with use of annealing, the impact strength was within limits of 1-2 kgM/cm^2.

From available information, steel of the 25-5 type is also not used abroad to any extent in the fabrication of propellers.

Table 31.

Mechanical properties of Kh25N5 type steel.

Heat treatment regime	σ_t, kg/mm^2	σ_T, kg/mm^2	δ, %	a_k, kgM/cm^2
Cast state (without any heat treatment)	54.9 55.2	54.9 57.5	3.7 3.7	[illegible] 1.8
Tempering in air from 950°	-	6?.5 62.5	8.0 2.5	1.0 [illegible]
As above, from 1000°	50.5 52.5	65.0 64.5	7.0 10.0	1.0 1.0
As above, from 1150°	48.8	69.8	8.7	1.0
Tempering in air from 1150° draw 680°	51.0 48.7	69.1 70.0	10.0 10.[illegible]	[illegible] 1.0

Heat treatment regime	[illegible]	[illegible]	[illegible]	[illegible]
Tempering in air from 1200°	[illegible] 58.9	70.5 [illegible]	[illegible]	[illegible]
Tempering in water from 1200°.	[illegible]	[illegible]	16.0 15.6	[illegible] 1.6

CHROME-NICKEL-CUPROUS STAINLESS STEELS
OKh17N3G4D2T and OKh16N4D4T

Structure and Mechanical Properties. A number of investigators have made attempts to find the stainless steels best suited for use in highest class propellers, ones having a minimum tendency toward pitting and apertural corrosion in sea water.

As a result of research carried out by the authors in collaboration with Sc. candidate A. M. Weingarten and V. K. Koupriancva, a new austenitic-ferritic steel has been developed, desiganted OKh17N3G4D2T, and an adjustment made in the composition of dispersionally reinforced OKh16N4D4T steel with an increase of up to 0.1% in carbon content.[1] The chemical composition and mechanical properties of these steels are presented in Tables 32 and 33.

1. Dr. of Sc. L. A. Glickman and Candidates of Sc. Y.E. Zobachev and L. N. Souproun and Engr. E. N. Kostrov participated in the work.

Steel designated OKh17N3G4D2T is of the austeno-ferritic type. The amount of austenite is within 55-70%.

In a cast state, with no heat treatment, the microstructure of this steel consists of austenite, ferrite and a considerable amount of carbides along the borders of the ferritic granules (Fig. 23). The carbides become dissolved upon heating to 1000-1050° under austenization (Fig. 24).

Table 32.

Chemical composition of OKh17N3G4D2T and OKh16N4D4T stainless steels.

Steel Designation	Chemical composition, %						
	C	Si	Mn	Cr	Ni	Cu	Ti
OKh17N3G4D2T	$\leqslant$ 0.1	0.7-1.6	3.2-4.2	16.5-18.5	2.6-3.2	2.0-3.0	0.10-0.25
OKh16N4D4T	$\leqslant$ 0.1	0.4	0.6-1.0	15.0-17.0	3.6-4.2	3.6-4.2	0.05-0.15

Table 33.

Mechanical properties of OKh17N3G4D2T and OKh16N4D4T stainless steels

Steel Designation	Mechanical Properties, at least				
	σ_t	σ_v	δ	ψ	a_k,
	kg / mm^2		%		kgM/cm^2
OKh17N3G4D2T	50	70	16	-	5
OKh16N4D4T	60	85	12	55	5

Annealing to 500° produces no visible changes in the structure of the austenized specimen. Further heating to 550-600° produces a considerable fall-out of carbides around the ferrite granules (Fig. 25), and the component whose nature is so-far insufficiently well understood. With the raising of heat treatment temperature to 800° there begins a partial dissolution of carbides located around the ferritic granules (Fig. 26).

The nature of the change in mechanical properties obtained as a result of austenization in air and subsequent drawing of the tempered steel is shown in Table 34. The chemical composition of the steel, smelted in an inductive furnace, is as follows: 0.09% C; 0.70% Si; 3.80% Mn; 17.72% Cr; 2.66% Ni; 2.40% Cu; 0.18% Ti.

An extensive history of testing OKh17N3G4D2T steel shows that, within the limits of its prescribed chemical composition, sufficiently stable mechanical properties are obtained, virtually identical to those appearing in Table 34. There is evident a certain improvement in the mechanical properties of production smeltings made in electrical furnaces, compared to those made in the laboratory, using inductance furnaces.

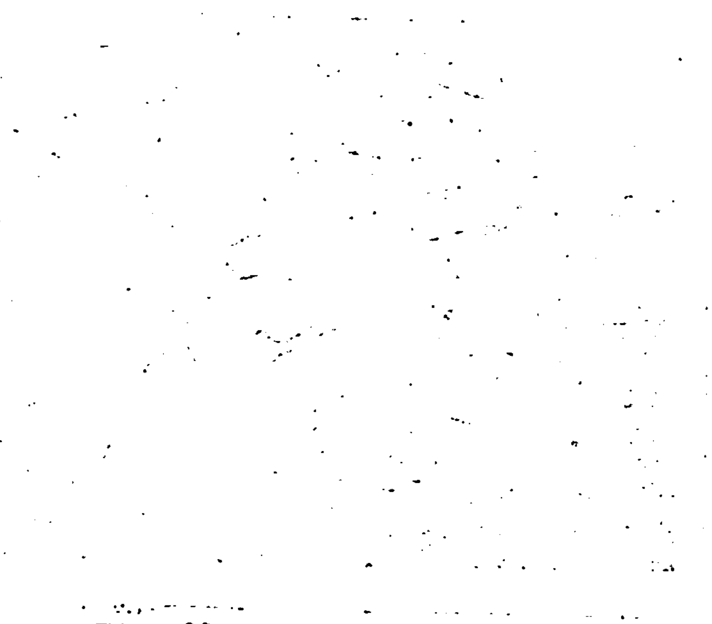


Fig. 23: Microstructure of OKh17N3G4D2T steel in a cast state; X 300

Fig. 24: Microstructure of OKh17N3G4D2T steel after austenization from 1000°; X 300.

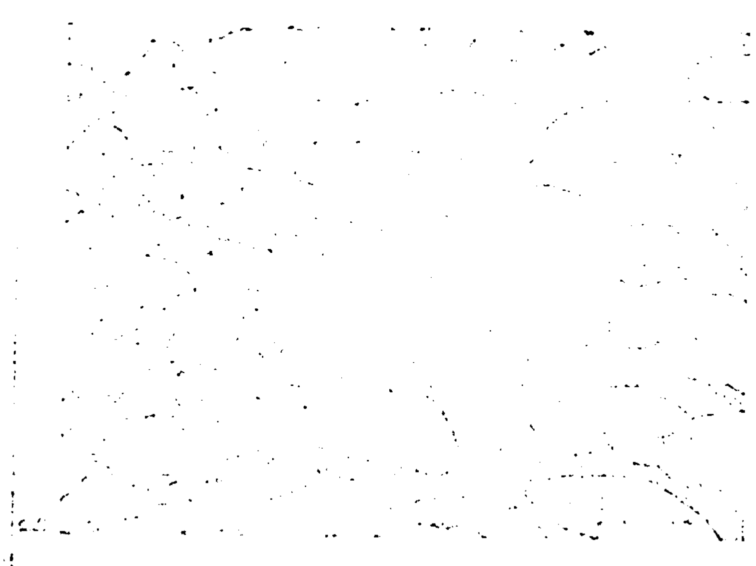


Fig. 25: Microstructure of OKh17N3G4D2T steel after austenization from 1000° & drawing 550-600°; X 300.

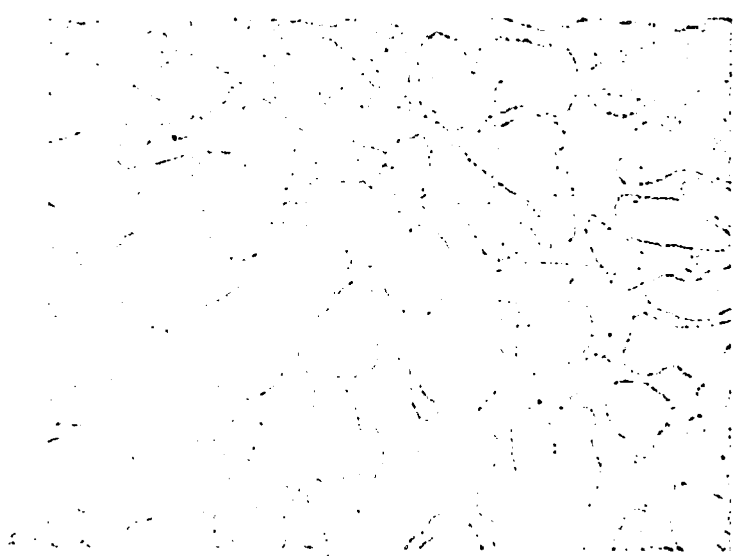


Fig. 26: Microstructure of OKh17N3G4D2T steel after austenization from 1000° & drawing 800°; X-300.

As seen from Table 34, change in mechanical properties due to heat treatment fully corresponds to the structural transformations of the steel. Maximum plastic and ductile properties are shown by the steel after austenization without subsequent annealing, or with annealing to 500°; at that time the structure consists of austenite and ferrite. No carbidic separations can be observed along the edges of the ferritic granules.

Table 34.

Change in mechanical properties of [illegible] steel after various heat treatment processes.

Heat treatment regime	Mechanical properties				
	σ_t, kg/mm^2	σ_v, kg/mm^2	δ, %	a_k, kgM/cm^2	Hardness, Brinell H_B
Cast state (without heat treatment)	- 33.1	83.5 82.2	24.3 15.6	7.9 5.4	207 217
Austenization in air from 1000°	33.0 34.0	77.0 84.5	35.0 29.0	16.8 18.1	197 170
As above and annealing 450°	34.8 34.5	86.8 86.8	24.0 24.5	12.4 12.5	197 -
As above and annealing 500°	37.8 34.8	85.9 78.4	25.3 26.3	15.8	197 207
As above and annealing 600°	68.8 68.4	91.2 84.3	4.2 2.5	0.8 0.9	285 302
As above and annealing 680°	84.9 85.9	84.9 89.9	0.8 3.3	1.0 1.1	302 302
As above and annealing 750°	69.5 67.3	98.7 93.7	10.7 10.0	1.5 1.6	285 -
As above and annealing 800°	54.8 58.1	96.1 96.1	12.2 10.8	2.8 1.8	285 -

An abrupt increase in strength properties and decline in plasticity and ductility takes place upon annealing from 600°, when considerable carbidic separations form around the ferritic granules; the hardness increases drastically at the same time (from 197-207 to 285-302 H_B).

An additional increase in annealing temperature up to 800° produces a partial dissolution of carbides, due to this there is a certain increase in plasticity. However, their complete dissolution (as upon heating to 1000-1050°) does not take place. The plasticity and ductility remain at a low level.

A repeated austenization with heating up to 1020-1050° produces the dissolution of carbides and restores the plasticity and ductility.

Mechanical properties of CKh17N5G4D2 steel smeltings made in an inductive furnace of [illegible] kg capacity.

Melting No	Mechanical Properties			
	σ_t, kg/mm^2	σ_y, kg/mm^2	δ, %	a_k, kgM/cm^2
I	29.9 - 34.6	76.3 - 84.5	20.0 - 25.7	16.8 - 19.5
II	32.4 - 34.1	72.3 - 76.6	23.3 - 29.7	11.6 - 15.4
III	32.6 - 34.5	78.7 - 90.2	23.3 - 24.3	13.8 - 14.4
IV	29.3 - 31.8	78.5 - 85.2	20.8 - 28.0	9.3 - 13.8
V	31.5 - 32.7	72.8 - 73.5	30.3 - 32.3	10.8 - 13.9
VI	37.3	76.0	18.3	6.6

Table 36.

Mechanical properties of CKh17N5G4D2T steel smeltings made in an arc-type furnace of 2 - 3 T capacity.

Melting No	Mechanical Properties			
	σ_t, kg/mm^2	σ_y, kg/mm^2	δ, %	a_k, kgM/cm^2
I	36	74.5	23	20.4 - 20.7
II	46	82.5	16	14.5 - 17.0
III	34.3 - 36.1	70 - 79.2	17.0 - 28.0	10.4 - 16.0
IV	42.0	82.0	20.0	6.9
V	36	79.5	21.0	11.5 - 11.7
VI	35.0	96.5	17.5	6.2 - 7.6

Table 37.

Magnitude of mechanical properties of CKh17N5G4D2T steel from production heats, melted in an electric arc 0.5 T furnace.

σ_t, kg/mm^2 number of heats %	50 8.8	45 50.4	40 84.8	30 100	30 0
σ_y, kg/mm^2 number of heats,%	85 47.8	80 69.6	75 80.4	70 97.8	70 2.2
δ, % number of heats, %	30 19.5	25 25.9	20 66.0	15 97.8	15 2.2
a_k, kgM/cm^2 number of heats, %	15 20.5	12 47.5	9 70.5	6 98.5	6 1.5

A C-shaped curve of isothermal transformation of austenite during the cooling process of OKh17N3G4D2T steel is shown in fig. 27. As seen from this curve, in cooling from 1000 to 6000°, there is no disintegration of austenite and it begins only at 550°. At that temperature the amount of disintegrated austenite reaches 30%, then it remains vietually unchaged in cooling down to 100°.

The mechanical properties of this steel are sufficiently stable after heat treatment consisting of austenization in air from 1020-1050°. This temperature is held from 3 to 5-6 hours, depending upon the size of the propeller. Mechanical properties of runs smelted in induction-type 100-kg furnace are listed in table 35; of those smelted in 2-3 ton electric arc furnace, in table 36, while the level of mechanical properties of a large number of production heats from a 0.5-ton furnace are in table 37.

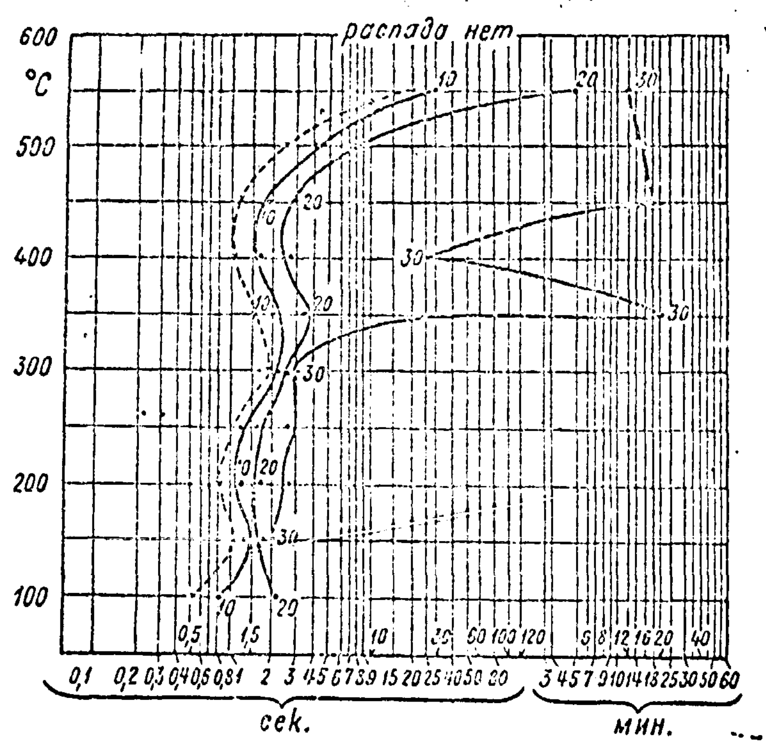


Fig. 27: Diagram of isothermal disintegration of austenite of OKh17N3G4D2T steel (figures on the curves represent the percent of disintegrated austenite).

Mechanical properties were determined on specimens cut from trefoil-shaped test bars 40 mm thick, as specified by GOST for formed steel castings. Test stock slabs 150 and 100 mm thick were case for use in determining mechanical properties of large cross-sections, specimens for mechanical tests were cut directly from them. The shapes and dimensions of slabs and locations of specimens' cut-outs were similar to those shown in fig. 14.

Heat treatment of the slabs consisted of austenization in air from 1020-1050°. Because of the initial austenization was accomplished at a short time-lab (about 1.5 h), a second austenization was carried out and held at 1020-1050° for 5 hours was carried on.

Mechanical properties were checked along the entire section in order to determine the tempering of this steel and the effects of initial crystalization in the various areas of the slab. Specimens 1 and 10 were taken from the edges of the slab and 5 and 6 from the center. The remainder were located between the edges and the center. The results obtained are presented in Table 38.

Comparing the results obtained from tests of specimens cut from trefoil and from large-section slabs, it can be noted that they do not differ much.

Assuring adequate stability of mechanical properties for given intervals of chemical composition, this steel's properties change materially with deviations, especially in chrome content. An increase in chrome content over 18.5-19% normally lowers the impact strength. There were a number of heats in which, with increase in Chrome above 19%, the impact strength fell to -3 kgM/cm^2.

A decrease in both silicon and chrome content likewise has an adverse effect. For instance, Heat No. 1364, made in a 3-ton arc furnace, had 0.41% Si instead of the specified minimum of 0.70 - 0.60%. The impact strength was 3.5 kgM/cm^2 and a repeated heat treatment resulted in no improvement. Steel of Heat No. 114, containing 16.2% Cr and 0.50% Si also had an inadequate impact strength ($a_k \approx$ 3.5 kgm/cm^2) at high yield point values.

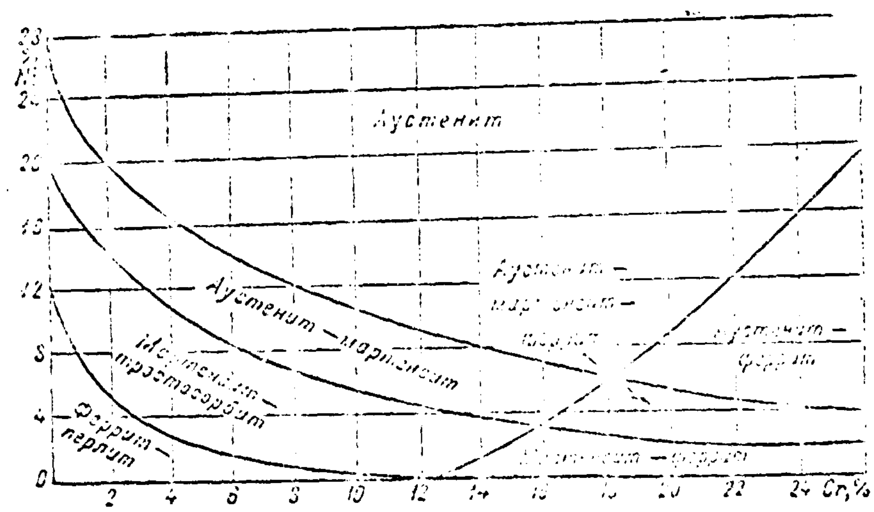


Fig. 28: Structural diagram of ferro-chrome-nickel steels (according to Mauer and Sherrer).

Decline of impact strength with an increase in chrome content above 19%, or with a drop in manganese content down to 2%, is probably attributable to the reduction in the quantity of austenite. But in the case of simultaneous reduction of chrome to 16% and of silicon to 0.5%, in accordance with Mauer's structural diagram (Fig. 28), the steel changes from austenitic-ferritic to austenitic-martensitic-ferritic. It is evidently this formation of martensite which causes a decline in impact strength.

Table 55.

Mechanical properties of 0Kh17N5G4D2T steel obtained from specimens cut from slabs.

Thickness of slab, mm.	Specimen No.	Mechanical properties			
		σ_t, kg/mm^2	σ_y, kg/mm^2	δ,%	a_k, kgM/cm^2
100	1	-	-	-	11.4
	2	-	-	-	13.1
	3	-	-	-	15.5
	4	-	-	-	13.5
	5	-	-	-	15.5
	10	53.3	77.2	25.7	-
100	9	52.7	82.5	20.0	-
	8	52.5	76.5	16.7	-
	7	52.9	82.9	19.2	-
	6	53.6	85.8	26.0	-
150	1	53.8	76.7	15.6	-
	2	55.7	72.7	-	-
	3	55.6	75.0	15.5	-
	4	56.0	85.2	25.5	-
	5	56.5	76.0	16.7	-
	6	-	-	-	8.8
	7	-	-	-	10.6
	8	-	-	-	6.9
	9	-	-	-	9.4
	10	-	-	-	[illegible]

Because of the above, maintenance of limits of chemical composition analysis is prerequisite to the attainment of required mechanical properties. Wide limits of the specified chemical composition with relation to silicon, manganese and chrome greatly simplify the problem. As to nickel and copper, meeting the specified limits (2.6-3.2% Ni; 2.0-3.0% Cu) usually produces no difficulties, since these elements virtually do not burn out in the process of smelting.

OKh17N3G4D2T steel, due to a high content of manganese (3.2-4.2%) silicon (up to 1.6%) and copper (up to 3%), in the presence of chrome in the amount of 16.5-18.5%, has a flowability considerably higher than that of 1Kh18N9T steel, and especially of Kh25N5 steel. Experience has demonstrated that, with a loose fit of the upper and lower half-molds overflows of considerable length and of 1-2 mm thickness can be formed along the "seam," clearly demonstrating the actual high flowability.

A substantial number of highest class proepllers, with diameters ranging from 700 to 2600 mm and cast weights from 150 up to 4500 kg, have been cast in OKh17N3G4D2T steel. Their service history over a period of several years has shown that this steel possesses a number of advantages, as compared with brass (especially over LMtsZh 55-3-1 brass).

For example, on a ship in which brass propellers deteriorated rapidly due to dezincing, OKh17N3G4D2T stainless steel ones did not deteriorate. One of the ships was used for testing comparative corrosion resistance of propellers made of various steels, under severe service conditions. To this end, in replacing propellers, one 1Kh18N9T and one OKh17N3G4D2T steel propellers were installed simultaneously. Condition of the blade surfaces of both propellers was found to be similar after a year-and-a-half of service. This test carried out under natural operating conditions confirmed results of laboratory experiments, thus it follows that OKh17N3G4D2T steel, with approximately 6% less nickel than 1Kh18N9T steel, also possesses sufficient resistance to corrosion in sea water. (It should be noted that, to a large extent, these propellers were shielded by protection devices installed in the vessel, as well as by the hull itself).

However, for a number of highly-stressed highest class propellers the strength provided by OKh17N3G4D2T steel ($\sigma_t \geq 30$ kg/mm^2) is inadequate. A highly corrosion-resistant stainless steel with $\sigma_t \geq 50$ kg/mm^2 is required for the production of such propellers. Dispersionally strengthened (intermetallic) high-strength and highly durable stainless steels, which have recently attained wide usage abroad, could be used for such purposes in this country. There are known chrome-nickel stainless steels, additionally alloyed with copper, aluminum, molibdenum, vanadium and other components.

Based on requirements for the highest technological properties and a maximum economy in scarce components, OKh16N4D4T steel should be recommended. This steel is the only one dispersionally strengthened and has a $\sigma_t \geq 60$ kg/mm^2; it can be used for both the fabrication of highest class propellers and for normal class ones, subject to special loadings.

There is published data relative to stainless steel, close in composition to OKh16N4D4T steel, with an extremely low carbon content (not over 0.07%). Actually, production of steel with such a low carbon content is very difficult. OKh16N4D4T steel, containing up to 0.10% C is much simpler to produce.

In order to select the optimum composition with a greater amount of carbon, tests were made to determine the affects of: manganese (from 0.6 to 3%); chrome (from 15-20%) and silicon (from 0.2 to 1.5%). Variation in the manganese content was made to establish the possibility of a maximum decrease of nickel content. The effects of varying the chrome and silicon contents were checked to insure attainment of optimal mechanical properties.

It was found that an increase in chrome content above 17.5% greatly increases the amount of ferrite. The structure becomes austenitic-ferritic instead of martensitic, leading to a radical drop of strength characteristics. Of significance are the mechanical properties (obtained as a result of tempering in air) of three smeltings, differing solely in their chrome content. Compositions of these steels and their mechanical proerties are shown in Table 39.

Table 39.

Effect of chrome on mechanical properties.

Heat No.	Chemical composition, %							Mechanical properties		
	C	Si	Mn	Cr	Ni	Cu	Ti	σ_t, kg/mm^2	σ_y, kg/mm^2	δ,%
I	0.08	0.71	1.05	18.55	3.74	4.17	0.07	44.8 48.1	98.0 92.3	18.[illegible] 16.0
II	0.07	0.85	1.12	17.42	4.36	4.25	0.12	65.5 66.6	92.8 95.2	14.5 15.4
III	[illegible]	[illegible]91	1.25	15.95	3.95	4.25	0.14	80.2 75.5	107.2 107.8	6.7 8.0

Substitution of manganese in place of nickel gave no positive results. In the course of this research, it was found that silicon content in excess of 0.4% has an adverse effect on the impact strength (according to published data, the silicon content was allowed to reach 1%). With an Si content 0.7-0.9%, usualy $a_k \leq 4.5$ kgm/cm^2, with most of the specimens showing $a_k \leq 4$ kgm/cm^2. With a silicon content of 0.4-0.5%, $a_k = 4.5$-5.5 kgm/cm^2, while individual specimens had an $a_k \geq 6$ kgm/cm^2. In six heats, made in a 100 kg capacity inductive furnace, 90 of the 94 specimens tested had a yield point $\sigma_t \geqq 65$ kg/mm^2 at the above mentioned impact strength and only 4 of them had $\sigma_t = 59.6$-64.9 kg/mm^2; 93 specimens had $\sigma_v \geqq 85$ kg/mm^2 and only one had a σ_v below that level.

Change in mechanical properties at different annealing temperatures in the course of dispersional hardening process can be traced from the results of mechanical tests (Table 40) of specimens of heat having the following chemical composition: 0.08% C; 0.91% Si; 1.25% Mn; 15.9 Cr; 3.95% Ni; 4.25% Cu; 0.14% Ti.

Table 40.

Effect of annealing on the mechanical properties of OKh16N4D4T steel.

Heat treatment process		Mechanical properties			
Tempering	Drawing	σ_t, kg/mm^2	σ_v, kg/mm^2	δ, %	a_k, kgm/cm^2
1050-1070°; held for 2 hours; cooling in air.	-	80.2 75.6	107.2 107.8	6.7 8.0	3.5 3.3
As above	200°-6 hrs.	85.8 82.3	108.5 107.5	10.8 11.3	3.8 3.6
" "	300°-6 hrs.	91.7 92.0	113.7 112.5	8.2 10.2	1.8 3.0
" "	500°-6 hrs.	99.0 98.9	114.2 110.0	- -	0.9 0.9
" "	550°-6 hrs.	79.3 78.3	97.8 98.5	14.3 15.3	4.4 4.1
" "	600°-6 hrs.	71.8 70.5	96.1 96.1	14.3 14.3	3.8 4.2

As a result of dispersional hardening, with an annealing temperature of 500°, the strength characteristics attain their maximum values and impact toughness decreases. With a rise in annealing temperature to 550°, the process of coagulation of the dispersed phase begins. Due to this the strength characteristics decline sharply while plasticity and ductility increase.

Critical points have been determined for OKh16N4D4T steels: $Ac_1 = 600°$; $Ac_3 = 795°$. Structure of this steel after tempering is shown in Fig. 29 and after annealing in the interval 580-620°, in Fig. 30.

The mechanical properties of OKh16N4D4T steel were checked both on specimens cut out of trefoil-shaped bars with 40 mm cross-section and from those taken from large-section slabs. Slabs 100 and 150 mm thick and a model blade of varying cross-section, from 40 to 250 mm thick were cast for this purpose. The shapes and dimensions of these stocks, as well as the locations at which the test specimens were cut out, are similar to those shown in fig. 14-16.

Mechanical properties obtained by testing specimens made from trefoil-shaped stock, poured from a production heat of 3.5 tons, appear in table 41. From this data it is seen that the figures for elongation, reduction of section and impact strength are somewhat higher after two annealings.

The general level of properties of steel smelted in a 3-ton electric arc furnace was higher than that produced in a 100-kg inductive furnace.

Properties obtained by testing specimens cut out of large sections, after tempering and one annealing per schedule adopted for specimen No. 1, table 41, are shown in table 42. As seen from this data, extremely low values for elongation and reduction of section take place in sections 100 and 150 mm thick. In order to improve these characteristics, the effect of two temperings and two annealings was carried out.

The mechanical properties obtained from 100, 150 and 250 mm sections after one tempering and two annealings and after two temperings and two annealings are shown in table 43.

An analysis of mechanical properties tests of OKh16N4D4T steel leads to the following conclusions:

1) the following mechanical properties are obtained from tests of specimens cut out of trefoil-shaped stock, after one tempering in air from 1040 to 1070° and annealing at 600-620°: $\sigma_t > 62$ kg/mm^2; $\sigma_v > 85$ kg/mm^2; $\delta > 12\%$; $\psi > 35\%$; $a_k > 3$ kgm/cm^2. The elongation, reduction of section and impact strength figures become somewhat higher after a second annealing;

2) on specimens taken from 100 and 150 mm thick slab sections, after one tempering in air from 1040-1070° and one annealing at 600-620°, low values of elongation (δ = 4-8%), reduction of section (ψ = 4-13.5%), and impact strength (a_k = 2.1-5.9 kgm/cm^2) are obtained. The use of a second annealing improves these properties appreciably. Even for a 250 mm section the impact strength reaches 3.0-6.2 kgm/cm^2. With two temperings and one annealing, elongation and impact strength values for 100 and 150 mm sections are low, but they increase substantially after a second annealing ($\delta \approx 11.4$ - 14.0%; $a_k \approx 3.0$-5.4 kgm/cm^2).

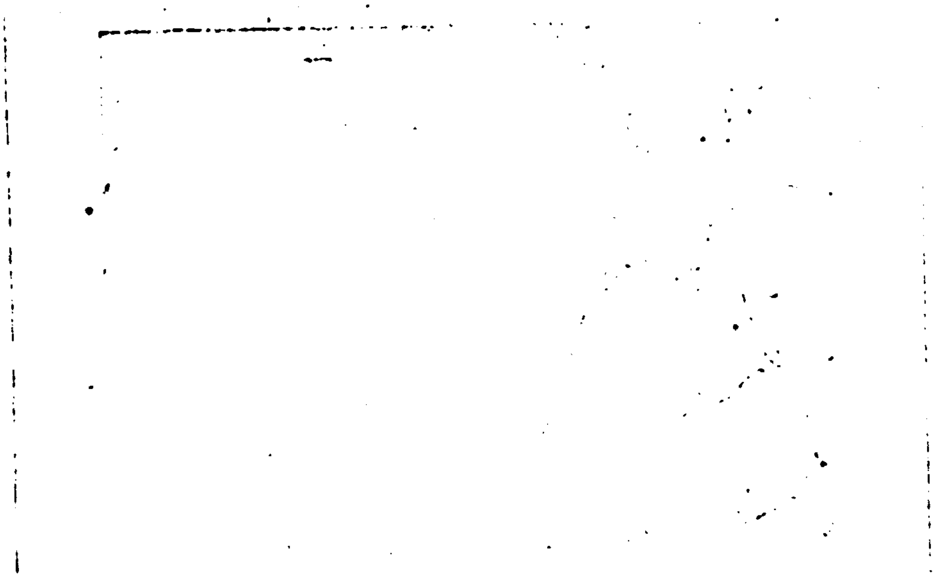


Fig. 29: Microstructure of OKh16N4D4T steel after tempering followed by air cooling from 1050°; X 300.

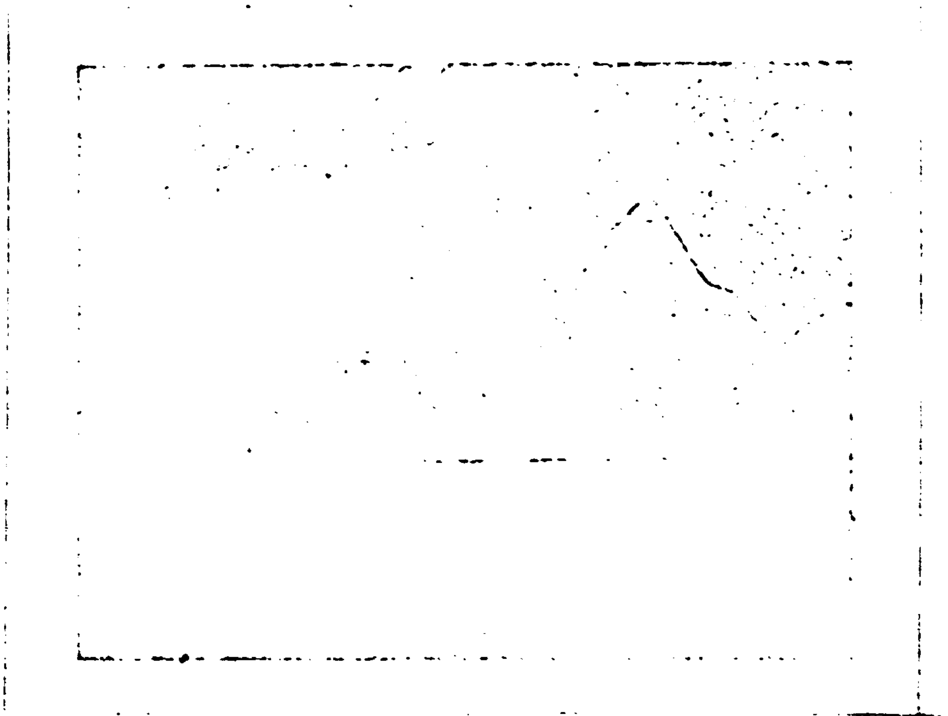


Fig. 30: Microstructure of OKh16N4D4T steel after tempering and annealing at 580-620° temperature; X 300.

Mechanical properties of OKhl6N4D4T steel as determined on trefoil - - shaped stock specimens.

Specimen No.	Heat treatment regime		Mechanical properties				
	Tempering from 1040-1070° in air.	Annealing	σ_t, kg/mm^2	σ_y, kg/mm^2	δ, %	ψ, %	a_k, kgM/cm^2
1	Exposure 5 hrs.	610°-7 hrs.	69.4 68.5	92.8 94.0	16.0 12.7	49.5 41.8	6.0 6.2
2	Same	Same	66.2 68.8	95.3 95.1	16.0 14.3	53.3 51.4	7.0 7.2
3	Same	Same	65.5 68.0	94.5 94.3	13.7 11.0	44.7 37.7	5.2 5.4
4	Exposure 3 hrs.	First one: 610°-5 hrs.;	68.0	90.0	17.0	51.0	9.9
		Second one: 610°-6 hrs.	71.0	93.5	20.0	51.0	9.4
		First one: 610°-5 hrs.;	67.0	93.5	15.0	52.5	8.65
		Second one: 640°-6 hrs.	67.0	92.0	17.0	51.0	8.6
5	Same	First one: 610°-5 hrs;	74.5	90.5	16.2	51.7	6.7
		Second one: 580°-6 hrs.	73.5	90.0	17.3	55.5	7.0

Table 42.

Mechanical properties of OKhl6N4D4T steel as determined in large sections after one tempering and one annealing

Locations where specimens cut out of blade.	Mechanical Properties				
	σ_t	σ_y	δ	ψ	a_k, kgM/cm^2
	kg/mm^2		%		
150 mm sect.	68.0-69.2	88.7-92.5	4.8-8.4	8.8- 13.5	3.5-5.9
100 mm sect.	85.9-87.4	98.4-100.2	3.6-5.6	4.0- 8.7	2.1-2.3
40 mm sect.	84.4- 89.5	101.3-110.2	9.8-14.8	19.0-41.5	3.5-4.4

Table 43.

Mechanical properties of OKh16N4D4T steel in large cross-sections under various regimes of heat treatment.

Heat treatment regime	Spec't Locations in blades	σ_t	σ_V	δ	ψ	a_k, kgM/cm²
		kg/mm²		%		
Heating to 1040 – 1070°; tempering in air. First draw at 600-620°; held 7 hrs. Second draw at 600-620°; held 8 hrs.	100mm sect'n	65.8-66.4	86.5-92.7	16.6-16.8	36.0-55.0	4.7-5.6
	150mm sect'n.	64.8-65.9	86.6-89.2	7.8-7.0	19.8	5.2-6.7
	250mm sect'n.	60.5-63.0	88.0-90.5	8.4-12.6	13.5-23.5	3.0-6.2
Two temperings in air. Heating to 1040-1070°. Exposure first one 5 hrs, second, 3 hrs. Draw at 600-620°; exposure 8 hrs.	150mm sect'n	70.2-71.5	97.0	8.4-12.4	22.5-30.7	2.8-3.2
Same and a second annealing at 580-600°; exposure 6 hrs.	150mm sect'n	69.3-75.0	91.4-92.0	13.8-14.0	23.1-33.9	3.0-5.0
	100mm sect'n	72.6-76.5	91.8-92.9	11.4-13.4	-	[illegible].4-5.4
	40 mm sect'n	73.5-81.0	93.6-95.0	13.6-15.2	35.3-40.6	[illegible].8-7.9

The above data was verified on a second production heat. The rules established during the study of production heats were similar to those ones determined in laboratory studies. This confirmed the comparative stability of this steel's mechanical properties.

Corrosion resistance, resistance to the effects of cavitation and corrosion fatigue resistance of OKh17N3G4D2T and of OKh16N4D4T steels.

Corrosion resistance of the above steels was checked by the same methods that were used in the case of 1Kh14ND steel. The results of these tests are listed in table 44. For comparison purposes, data relating to 25L carbon steel, SKhL-4 structural steel, stainless steels 1Kh14ND, 2Kh13,

OKh18N9T and of brasses are also tabulated. From this table it is seen that resistance to contact corrosion of OKh17N3G4D2T and OKh16N4D4T steels is higher than those of brass and/2Kh13 stainless steels.
1Kh14ND

Samples of OKh17N3G4D2T and OKh16N4D4T steels had insignficant weight losses (same as all stainless steels) and, most important, only slight pitting; actually they performed in the same manner as 1Kh18N9T steel ones.

But samples of 1Kh14ND and especially of 2Kh13 steel showed heavy local corrosional damage, with a relatively small overall loss of weight. For instance, the depth of some corrosional pitting in 2Kh13 steel reached 1.5 mm. Tests to determine stream flow corrosion and that resulting from immersion in still water, without contact, showed small weight losses (less than those of LMtsZh 55-3-1 brasses) and a total absence of pitting on the exposed surfaces.

Resistance of OKh17N3G4D2T and OKh16N4DT steels to the effects of cavitation was checked, as for 1Kh14ND steel, on a magnetostrictional vibrator. The results are shown in table 45.

Comparing the results of these tests with corresponding data relating to brass and 1Kh14ND stainless steel (after tempering and annealing) shown in table 29, it can be stated tht OKh17N3G4D2T and OKh16N4D4T steels have a much higher resistance, especially in comparison to LMtsZh 55-3-1 brass.

Results of corrosional fatigue resistance tests of stainless steels are presented in graphic form (fig. 31). These tests have shown that the greatest corrosional endurance in a 3% solution of NaCl is that of the OKh17N3G4D2T steel (29 kg/mm^2). Under the same conditions OKh16N4D4T steel's limit of endurance is 18, and that of 1Kh14ND - 16 kg/mm^2.

Results of performance tests of propellers made of OKh17N3G4D2T steel. Propellers made of this steel have been serving in vessels since 1956. Inspections of these propellers were made after 1-3.5 years of cruising in the Black and Barents Seas.

During this period there was a recorded case of one of the propellers striking a floating log. Due to the relatively high strength and toughness of the material, the edges of the blades, though deformed by the impact, did not break; the damaged propeller was straightened out and put back into service.

All propellers of OKh17N3G4D2T steel in service are of the highest class category and were formerly made of brass. None of the propellers examined showed any trace of corrosional or cavitational damage, while at the same time, a number of similar propellers made of LMtsZh 55-3-1 brass had to be taken out of service after a short period of time due to dezincing and physical damage sustained as a result of the low-strength characteristics of the brass.

Table 44.

Summarized comparative data of corrosion resistance tests of OKh17N3G4D2T, OKh16N4D4T, 1Kh14ND, 2Kh13, OKh18N9T stainless steels, 25L, SKhL-4 carbon steels and of brass.

Material investigated	Type of test in synthetic sea water.			
	Stream flow corrosion	Corrosion in still water, in absence of contact.	Aperture corrosion in still water immersion of specimens in contact with each other,	
	Specific loss of weight mg/M^2· hour		Material placed in contact with test specimen	Specific loss of weight of tested material
25L	2120.0	55.22	Brass LMtsZh 55-3-1	79.1
			25L	55.0
			1Kh14ND	56.0
			OKh17N3G4D2T	63.4
			OKh18N9T	72.0
			Ebonite	40.0
SKhL-4	-	-	OKh16N4D4T	50.0
Brass LMtsZh 55-3-1	64.7	14.5	25L	0.615
			1Kh14ND	14.2 ob
			OKh18N9T	17.9 ob
			OKh16N4D4T	8.3 ob
			OKh17N3G4D2T	13.27 ob
1Kh14ND	57.0	2,57	25L	0.042
			Brass LMtsZh 55-3-1	0.153
			1Kh14ND	8.47 **
			OKh17N3G4D2T	10.0 **
			OKh18N9T	14.6 **
			Ebonite	5.38 **

Table 44,

Continuation.

Material investigated.	Type of test in synthetic sea water			
	Stream flow corrosion.	Corrosion in still water, in absence of contact.	Aperture corrosion in still water immersion of specimens in contact with each other.	
	Specific loss of weight mg/M^2· hour		Material placed in contact with test specimen.	Specific loss of weight of tested material.
2Kh13	-	-	OKh16N4D4T	28.5 ***
OKh17N3G4D2T	12.43	4.24	25L	0.056
			Brass:	
			LMtsZh 55-3-1	0.112
			LMts 58-1	0
			LO 62-1	1.33
			1Kh14ND	0.077 *
			OKh17N3G4D2T	3.165 *
			OKh18N9T	4.514
			Ebonite	1.69 *
OKh16N4D4T	8.4	-	2Kh13	None found
			1Kh14ND	None found
			Brass:	
			LMtsZh 55-3-1	0.5
OKh18N9T	3.3	0.18	25L	0.070
			Brass:	
			LMtsZh 55-3-1	0.042
			1Kh14ND	0.504
			OKh17N3G4D2T	0.214
			OKh18N9T	0.899 *
			Ebonite	0.77

Remarks:

1. Spedimens which, in addition to general weight loss, had sustained a visually apparent pitted corrosion having a depth of:
   less than 0.1 mm are marked (*),
   from o.1 to 0.5 mm " (**),
   from o.5 to 1.5 mm " (***).
2. Specimens which, in addition to loss of weight, had visible dezincing, are marked thus (ob).

Table 45.

Resistance of OKh17N3G4D2T and OKh16N4D4T stainless steels to damage caused by cavitational effects.

Steel designation	Specimen's loss of weight, mg			
	1-st hour	2-nd hour	3-rd hour	Total for 3 hours of testing
OKh17N3G4D2T	13.0	24.0	18.0	55.0
OKh16N4D4T	6.6	19.6	8.4	34.6

Table 46.

Characteristics ofprincipal materials used in propellers.

Designation of Characteristic	Carbon steel	Brass		Stainless Steel		
	25L	LMtsZh55-3-1	LAMtsZh67-5-2-2 (68-5.5-2-2)*	1N14MD	OKh17N3G4D2T	OKh16N4D4T
σ_t, kg/mm^2	≥24	≥20	(≥25)*	≥50	≥50	≥60
σ_v, " "	≥45	≥48	≥62(55)*	≥62	≥70	≥85
δ, %	19	20	≥12(16)*	15	15	12
ψ, %	30	-	-	40	-	55
a_k at 20°, kgM/cm^2 . .	4.0	7-8	5-7	≥5.0	≥6.0	≥5.0
Limit of corrosional endurance in synthetic sea water, kg/mm^2	5.0	11.0	15.0	16.0	29.0	18.0
Loss of weight (corrosion) in synthetic sea water mg/ m^2· hour						
A. Still water immersion of samples: with no contact. . . .	55.2	14.0	3.3	2.57	4.2	-
contact with same material	-	-	-	8.47	3.2	-
B. Flowing jet corrosn with rotation of samples(D 145 mm) 1400 r.p.m.	2120	64.7	-	57.0	12.4	8.4
Intercrystalline cor.			No tendency.			
Weight loss due to cavitation (tested on a magnetostrictional vibrator for 3 hrs)mg.	200	157.0	58.7	55.0	55.0	34.6
Specific gravity. . .	7.8	8.5	7.7	7.85	7.85	7.85

* Values in parentheses are for LAMtsZh68-5.5-2-2 brass.

CHAPTER V

TECHNOLOGICAL FEATURES OF CASTING PROPELLERS IN STAINLESS STEELS.

The techniques of casting propellers in stainless steel basically differ very little from the familiar techniques of molding and casting used in the production of propellers made of other metals, covered in sufficient detail in technical literature (for instance, (16)). Consequently, only special features of casting propellers of stainless steel will be discussed below.

Molding Materials. Completed laboratory research and practical experience in casting propellers of stainless steel have shown the chromomagnesitic mix to be the best fettling in the preparation of molds.

Acid molding materials (quartz sand), or semi-acid ones (chamotte) cause the formation of a chemical crust on the surface of the castings. Crust also forms on the surfaces of massive castings of stainless steel produced by the precise casting method utilizing melting models. Covers for the molds were made of ground quarts and ethyl silicate. It is known that such covering is especially strong and forms an even, smooth surface, one that is not eroded by the metal and which keeps it from penetrating the pores of the mold. Therefore it can be stated that, in this case, incrustation on the surfaces of the casting were of chemical, rather than mechanical nature.

Use of other basic materials, particularly that of magnesite, gave no positive results.

To secure a cleaner surface, it is recommended that the chromomagnesitic molds be coated with titanium oxide paint. Above all, the use of this paint must be recommended for covering the cores of propeller hubs, in cases where metallic pipes are used as cores.

Sometimes, due to lack of chromomagnesite at the foundries, quartz sand is employed and such molds should also be covered with titaneum paint. This tends to somewhat insulate the stainless steel from acid molding materials and reduces the probability of low-melting oxides being deposited along the metal-mold demarkation. However, coating with paint does not insulate the mold completely and the cleanliness of the castings' surfaces is inferior to that obtained with the use of chromomagnesitic mixes.

At foundries employed in casting stainless steel parts, to save on chromomagnesite, molds made of quartz sand are lined with chromomagnesitic paste of sour cream consistency. This method has so far not been used in the manufacture of propellers.

Table 47 lists the consistencies of chromamagnesitic pastes and of paint used in casting stainless steel propellers.

The selection of binder (cement or water glass) is governed purely by practical considerations. The advantage of water glass over cement is that molds made of a mixture based on water glass harden much faster, when blown through with carbon dioxide. Cleanness of the casting's surfaces is not affected by the type of binder chosen (provided the binders satisfy the technical requirements).

There existed an erroneous belief that use of cement-based mixes in some cases produces gas pits on the surfaces of castings. Long-term experience of one of our foundries indicates that use of cement results in an absence of gas pitting and furnishes the required quality of surface.

Table 47.

Composition and properties of chromomagnesitic pastes and paint made of titanium oxide for propeller molds

Raw materials (composition in parts by weight)	Physical-mechanical prperties		
	Moisture,%	Permeability to gas.	Raw compressive strength kg/cm^2.
Paste on a base of water glass			
Powdered chromomagnesite - 100; water glass (spe.grav.1.48-1.52; module 2.1-2.2)* - 6.5 ÷ 7.5; water to required moistness...	5.0-6.5	25	0.28-0.30
Paste on a cement base			
Powdered chromomagnesite - 100; cement (mark 400-500) - 15; water to required moistness...	7.0-8.0	25	0.25-0.35
Paint			
Titanium oxide** and waterglass, diluted in water (25% water glass to 75% water)	-	-	-

* In using water glass with a module above 2.2, a 10% solution of NaOH should be introduced for its reduction, in an amount which produces a module of 2.1-2.2 .

** Titanium oxide is added in the amount which produces a paint of 1.7-1.8 specific gravity.

Chromomagnesitic powder is usually obtained by grinding tailings of chromomagnesitic brick. The brick or powder are roasted at temperatures above 900°. If stored for a long time, these materials should receive a second roasting.

Depending upon the standard technique for the preparation of molds, various requirements are applied relative to the size of grain of the chromomagnesitic powder. In preparing a paste based on water glass and blowing the mold out with carbon dioxide gas, coarse-ground powder gives the best results, furnishing the required gas permeability of the mold, thus insuring good penetration of the carbon dioxide gas. When the smoothest possible surface is required, a finer grind should be used.

Ordinarily, all material passing a 1.5 mm mesh sieve is used in the preparation of the molding compound. Sometimes an even finer grind is used. Recent experience has demonstrated that a much finer surface of castings can be produced with use of chromomagnesite passed through a sieve with 0.5-0.8 mm openings.

Method employed in molding one-piece propellers and individual blades. Fabrication of forms for one piece propellers and for individual blades, cast in stainless steel, is accomplished in the same manner as for similar castings made of other metals.

The following methods of preparation of forms for stainless steel one-piece propellers are currently most commonly used: sweep molding; core box molding; from a complete pattern; from an adjustable blade pattern (this pattern consists of only one blade and the adjacent sector of the hub). Casting from meltable patterns and into skin forms is so far only in the development stage and has not been employed in actual production of stainless steel propellers.

Forms for casting individual blades of sectionalized propellers are ordinarily molded on a clean pattern or in core boxes.

It should be noted that the method of sweep molding, in spite of its improvement during the last few years, still fails to produce castings with dimensional tolerances that satisfy GOST specification 8054-59 (propellers). Deviations in the pitch of the propellers usually exceed the allowable and are corrected on highest class propellers by machining off considerable surplus allowances, amounting to 8-12 mm per face. On normal class propellers, cast without allowance for machine finish, correction of pitch is made by setting the propeller, or by manual cutting and building up. Execution of such corrections leads to a considerable expenditure of time and labor. For this reason, lately, sweep molding in casting stainless steel propellers has been replaced more and more by methods which result in a greater precision of castings: molding on a complete pattern, core box molding, or molding on an adjustable blade pattern.

Molding on a complete metallic pattern results in the greatest precision of casting, but the complexity and length of time required for the fabrication of such forms limits their application to mass production. Molding in cores or on adjustable patterns is employed when a single casting is called for. Molding on cores is satisfactory in cases where the preparation can be accomplished with the aid of molding machines; when the preparation is to be accomplished manually, the wooden rigging gets out of admustment rapidly, so that if, for some reason, preparation of core molds cannot be made on machines, it is advisable to do the molding on a transposable blade pattern. The rig used to fabricate molds by this method is shown in fig. 32 and consists of a metal spindle 3 installed in socket 4 and of a wooden or metallic blade pattern, complete with a sector of the hub, 1. The hub sector is provided with metal eyes which fit on the spindle, permitting the assembly to rotate around it. The centerline of the spindle coinsides with that of the propeller. The required rotational angle of the blade about the spindle is rigidly fixed by the locking device 2. The number of fixed positions of the blade around the perifery of the spindle equals the number of blades of the propeller.

A pressure layer is first molded on the surface of the blade pattern, secured in its required position, this is followed by pressure packing on a removal section of the absorbing layer. Upon completion of its molding, this piece is taken off and the blade pattern rotated about the spindle through the required angle. For propellers using three blades, the angle is 120°, 90° for four-blade propellers, etc. After the blade pattern has been secured in its new position, a second blade is pressure molded, etc.

Repetitive molding on the pattern results in relatively high accuracy of reproduction, due to the sturdy construction of the angle of turn retaining device and the true vertical position of the pivot. Depending upon the size of an order, the blade pattern may be made of metal or wood.

Metal patterns are castings made of sweep molds. The pattern, cast with allowances, is machined to obtain the required geometry and surface finish. To simplify the machining, these patterns are made of aluminum or brass alloys.

The necessity of making all equipment of metal, rather than of wood, is sometimes dictated by strength considerations. For instance, adequqate strength of thin-blade propeller patterns (with outer edge thicknesses down to 10-12 mm) may be obtained only through the use of metal patterns.

Use of a swinging blade simplifies the molding of outline of the pressure suface in the area AB of the propeller edge (fig. 33). In contour molding this part of the form can only be made with the addition of metal patterns ("undercuts", shown by dotted lines), shaped out after rounding off the pressure surface. To simplify the molding, these areas of the pressure surface are sometimes straightened out, leading to an excessive allowance which must be subsequently removed by manual cutting.

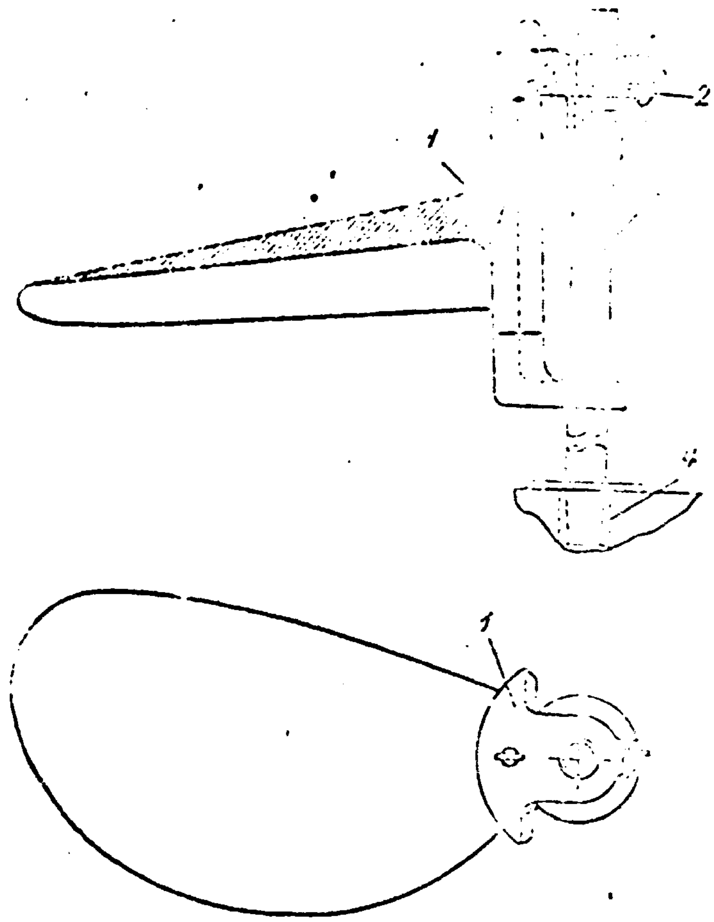
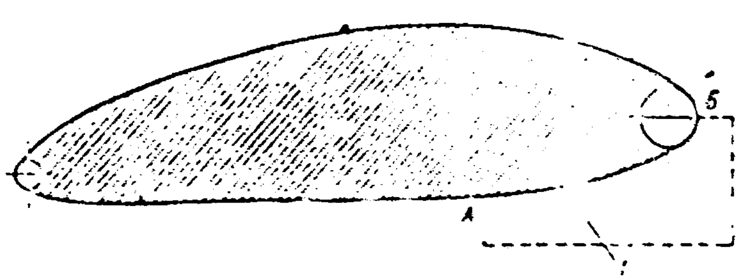


Fig. 32: Transposable blade pattern.

Fig. 33: Cross-section of blade.



The labor of molding on a duplicate blade, or on a complete pattern, is considerably (20-30%) less than that connected with contour molding. The necessity of making a "false" blade is eliminated. The complicated operation of rounding off the bottom ridges is replaced by the less laborious process of tamp packing.

Use of a pattern in lieu of a sweep mold has a number of other advantages. First it should be noted that it results in higher quality finishes of surfaces, due to packing rather than pointing up of the pressure surface. The surfaces of the mold are also better on the vacuum faces. In sweep molding the form is packed on the "false" sand blade which, because of certain inevitable uneveness of compaction, commonly leads to local roughnesses in the upper part of the mold. Tamp packing of the suction surface on a pattern (especially a metal one) prevents the occurence of such defects impossible.

The method under consideration should gain wide acceptance in the production of cast-in-block stainless steel propellers, calling for the use of more perfect techniques resulting in precision castings.

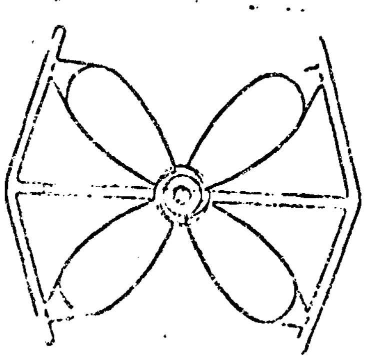
In the development of molding techniques suitable for stainless steel propellers, because of the particular casting properties of these steels and employment of chromomagnesitic pastes with higher heat conductivity, the approach to the selection of a pouring scheme must differ somewhat from that used in casting a carbon steel propeller. For cast-in-block propellers these peculiarities can be summarized as follows.

The rate of filling the mold must, as a rule, be more rapid. This is especially important in filling the outer sections of blades having blade thicknesses less than 10-12 mm. In filling these areas, in addition to the overall gravimetric speed of casting, linear speed of advance of the metal through these sections is extremely important. It is desirable to have the metal enter such locations in its hottest state. Due to this, the method of siphoning the pour through the hub, used in casting carbon steel propellers, is not acceptable for stainless steel ones, with diameters over 3 M (especially with the use of 1Kh14ND steel which has a lower flowability than 0Kh17N3G4D2T and 0Kh16N4D4T steels).

When the pour is made through the hub, metal enters the outermost sections of the blades in its coldest state. To eliminate this fault, it is best to introduce the metal directly into the blades. This routing can be accomplished by locating the feeders along the trailing edge in the central and outer portions (fig. 34), or at the tips of the blades (fig. 35 and 36). The first scheme is recommended for wide-bladed propellers with a large pitch, the other ones, for narrow-bladed propellers.

Feeders. Slit-type feeders are recommended, to insure dispersed delivery of metal, thus reducing local overheating. Cross-sections of the feeders at their points of juncture with the propeller casting must be considerably larger than the normal cross-section of the flow gate system, to minimize spouting of metal upon its entry into the mold cavity. At the

Fig. 34: Casting scheme for a wide-bladed propellar.



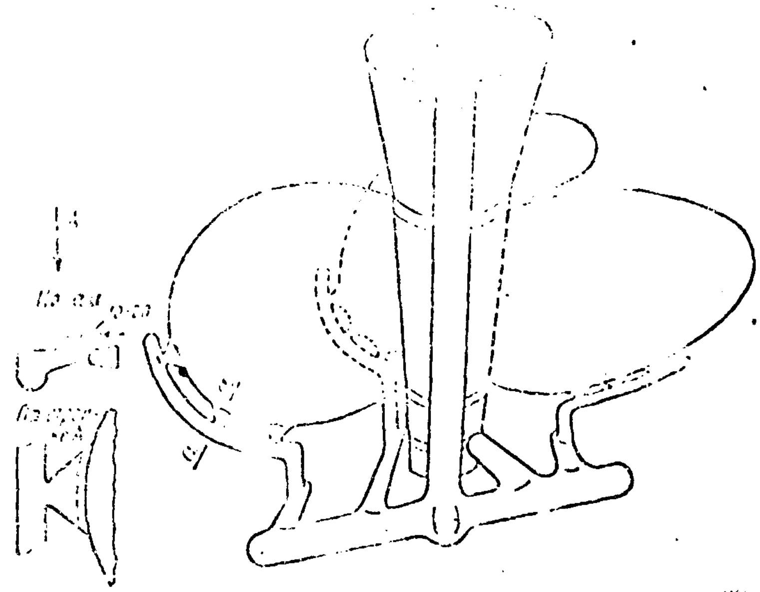


Fig. 35: Casting scheme for pouring a narrow-blade propeller, weighing less than 4 tm tons.

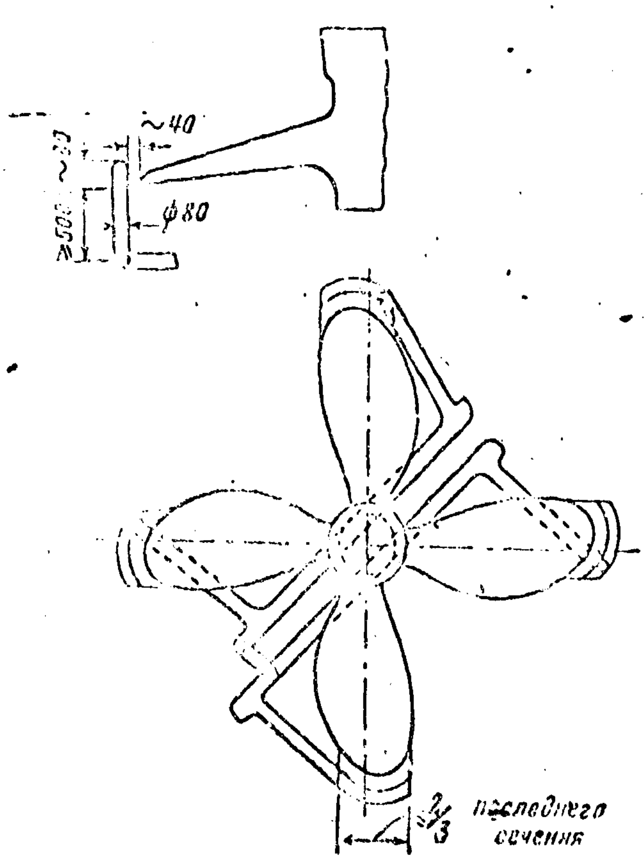


Fig. 36: Casting scheme of a system for pouring a narrow-bladed propeller weighing over 4 tons.

same time, the maximum dimension of the feeder at its point of juncture with the blade must not exceed the thickness of the latter, measured at a distance of 10-20 mm from its extreme outer edge. To preclude the breaking off of the feeder together with a portion of the blade, it should be "grooved," as shown in fig. 34.

In casting narrow-bladed propellers of less than 3 M diameter and with a minimum blade thickness greater than 10 mm, delivery of metal by siphoning through the hub usually results in successful filling of the mold. This method of delivery is simpler and is conseqeuntly widely used. The risers and casting runs should, as a rule, be made of ceramic material.

In determining the dimensions of casting systems, in addition to the above factors, rapid filling of the mold to preclude its scorching should be considered. Because of this, the casting time of even large propellers with a cast weight of 8-10 T, must not exceed 100-120 seconds. The following weight rates for pouring unit-cast propellers are used in practice: 20-25 kg/sec for propellers with cast weights below 1 T and 40-55 kg/sec for propellers weighing 2-4 T. The above rates are achieved by pouring through one inlet of the stopper arrangement. Propellers with cast weight of over 4T are normally cast through two stoppers. In that case the weight rate of pouring is 60-85 kg/sec., depending upon the total weight of the propeller.

The molding scheme and pouring system for casting individual blades of large assembled propellers is shown in fig. 37. When the casting weight is over 4 T, the pour is usually made through two stoppers from a single laddle or from two laddles, simultaneously. The pouring system indicated by dotted lines introduces the metal through the edge and is ordinarily used only for casting propellers having blades of over 2.5 M diameter, with blade edge thicknesses of 12-14 mm.

Ordinarily, to simplify the lay-out of the casting system when the blades are very thick, the metal is fed only through the flanges. Although this insures complete filling of the mold, it still cannot be considered best practice, since it heats up the flanges and induces the formation of shrinkage pores. Delivery of metal only to the flange with an insufficient head dimension is especially dangerous (there are actual known cases of formation of hot cracks in the region of the flange). In this type of scheme the metal is forced to travel over the entire mold.

More logical is the decentralized, simultaneous delivery of metal, both to the edges and to the flange of the blade, this shortens materially the path taken by the metal through the form cavity and contributes to a more uniform rate of cooling of the casting.

Blades of heavy-duty propellers, especially those of icebreakers, should be cast in a vertical, rather than a horizontal position. Only with vertical casting, with the flange up, can the shrinkage friability be largely eliminated by the ferrostatic pressure. This type of porosity can be found in almost any section of a blade cast in a horizontal position. Existance of shrinkage friability in the most highly stressed base section of a blade is especially dangerous. Vertical position of the blade during casting also insures the exclusion of non-metallic occlusions from the body of the casting.

The dimensions of the heads for casting propellers and individual stainless steel blades are so far determined in the same manner as that used in the case of carbon steel castings. Preheating of the heads with exothermic mixes has recently gained wide acceptance.

One of the most vital and complicated problems of the entire technical complex relating to the production of unit-cast stainless steel propellers is the estimate of proper allowance for distortion of the propeller's pitch, made in the course of preparing the mold. Experience shows that, even in casting from the same pattern, there is insufficient accuracy of reproduction of shape and dimensions of blades in a propeller casting. Change in the nature of distortion due to variations in the disk ratios of a propeller is so far not adequately determined. However, as a result of processing a large volume of statistical data covering the dimensional dispersions of propeller castings, it was possible to establish the approximate magnitude of distortion which must be taken into consideration in designing the molding equipment.

It is currently considered an established fact that the pitch of narrow-bladed, unit-cast propellers, with a disk ratio approximating 0.6, is reduced somewhat in the first and second sections and increases, beginning with the third-fourth one, as a result of differential deformations due to cooling in the mold, or in the course of heat treatment. In view of this the pattern should be made with a distortion of pitch.

For example, for a propeller of a 3.3 M diameter, with a disk ratio of 0.45, in making a model of a blade duplicate the following coefficients of distortion of pitch were adopted, by sections:

first and second	(+1.0) ÷ (+1.5) %
third one	0 %
fourth	- 1.0 %
fifth and sixth	- 1.5 %
seventh	(-1.0) ÷ (-1.5) %

However, the nature of pitch distortion of different propellers is not always the same. There are figures for individual narrow-blade propellers with diameters of 2 M, which show that the increase in pitch in the outer sections of the blades reaches 4-5% as a result of warp.

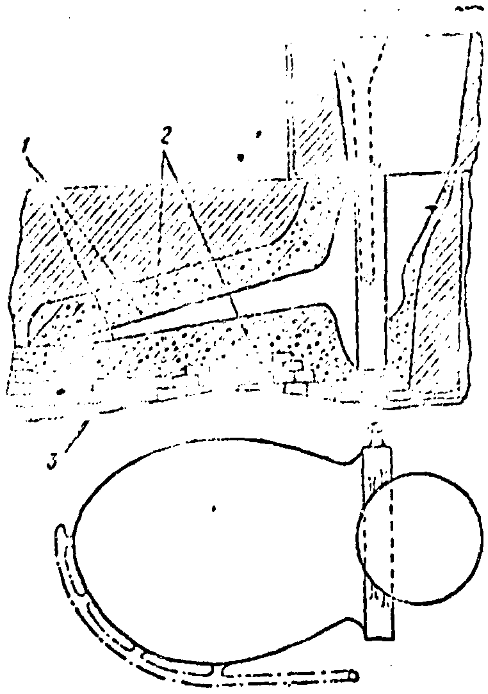
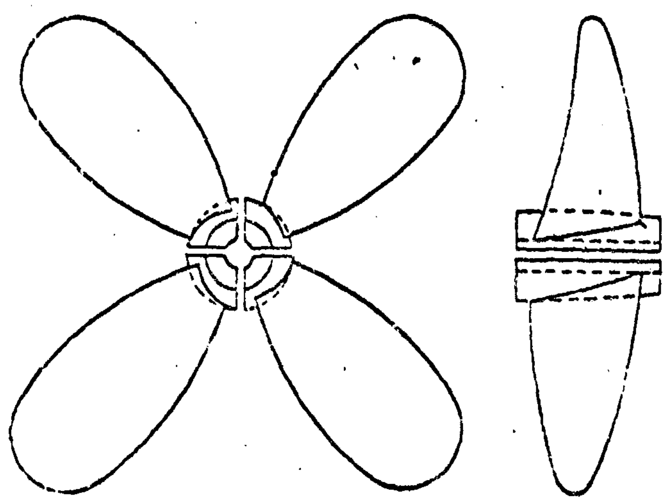


Fig. 37: Mold and pouring arrangement for individual blades of assembled propellers:

1 - chromomagnesitic mix; 2 - rapid-drying mix; 3 - brick base.

Fig. 38: Assembly scheme of individual blades in preparation for welding.



The nature of pitch distortion of wide bladed propellers, with disk ratios approaching unity, has not been sufficiently established. According to individual available figures, the pitch of these propellers is reduced as a result of warping. This reduction approximates 1.5-2% in the outer sections of the blades and becomes smaller in sections located closer to the hub, becoming 0.25-0.50% in the first and second sections of the blade.

The abundance of factors influencing the magnitude of pitch of the propeller casting and difficulty to properly estimate the deviation account for the fact that a large number of propellers of even the normal class (for which specifications permit deviations in pitch of up to 3%) require straightening due to excessive deviation. This corrective process is difficult and not always successful.

Propellers of the highest class (with allowable pitch deviations not over 1.5%) are cast with substantial machining allowances. The allowance is normally set so as to insure the ability to eliminate casting discrepancies by machining. The allowance must be made greater than the minimum required for cutting in producing the required surface finish.

All these difficulties related to attainment of proper pitch for the finished propeller are to a large extent eliminated in the production of ordinary assembled propellers and adjustable pitch ones, consisting of individually cast blades attached to the hub by mechanical means. However, assembled propellers, because of the larger diameter of their hub, have inferior hydrodynamic characteristics and a lower efficiency, so that their field of application is limited and their cast tonnage represents a diminishing part of the total for all propeller production. Adjustable, variable pitch propellers have not yet attained wide applications.

Considering that production difficulties connected with monolithic propellers stem from large dimensions and complexity of shape of the castings, there is a strong probability of widened use of welded propellers (cast in parts and subsequently assembled by electric arc welding, according to the scheme illustrated by fig. 38). This method of fabrication is in the development stage. At present, according to A. Y. Zelichenko /11/, active production of welded propellers is limited to small-size carbon steel ones. The technique of producing such propellers calls for welding stamped blades to a cast as a unit hub.

In examining the maze of problems connected with the obtainment of requisite propeller quality, it is necessary to pause for an examination of specific casting surface defects peculiar to stainless steel ones.

Defects commonly occurring in blade surfaces can be divided into two basic groups.

In the first one are the non-fusions and waviness caused by pouring cold metal and pouring through a casting system which does not provide linear velocity of metal propagation within the mold cavity. Normally these defects are located in the outer sections of the blades, near their edges. With the use of casting systems insuring delivery of metal to the blades and permitting filling at the requisite rate and at the specified temperature, these defects do not occur.

In the second group of defects are the gas pockets in the surfaces. The fundamental reason for their occurrence is inadequate drying out of the mold. Because of the low gas permeability of chromomagnesitic mixes, the danger of getting this type of flaw is great and is especially intensified if casting is done with cold metal. These defects are normally located in the lower (compression) surface. The opinion that this type of flaw occurs only with the use of cement is erroneous, since experience has demonstrated that similar defects occur also with the use of other binders, specifically, dextrene and water glass.

Fig. 39 shows gas porosity located chiefly in the edges of blades of a propeller made of 1Kh14ND steel, poured into a mold of chromomagnesitic mix, with dextrene used as binder. The predominant distribution of porosity in the edges of the outermost section of the blade is attributable to the fact that, in drying out the mold with portable driers inserted through the hub, this portion of the blade was not adequately dehydrated.

Typical is the over-all superficial gas rash (fig. 40) on the compressed surfaces of the propeller casting whose mold became damp during the 80-hour interval between the completion of dry-out and the pour. A brief secondary drying with a portable drier did not succeed in removing the newly accumulated moisture.

Typical also are the defects on the surface of special slabs, cast of 1Kh14ND steel. Chromomagnesite was used as fettling: in one mold - on a water glass and in the other one, on a cement base. Both molds were subjected only to a surface dry-out penetrating 10-15 mm. Because of such inadequate drying, both castings had a wrinkled surface typical of such cases, shown in fig. 41.

To eliminate the occurrence of this type of defect, it is necessary to insure adequate drying of the molds. In blowing the mold through with carbon dioxide, it is necessary to use an additional drying in a kiln, or with portable driers. Thermal drying of the molds after a brief blowing-through with carbon dioxide materially increases the strength of the mold by removing the moisture.

According to data of A. G. Doukor, E. V. Ivanov and P. M. Sitchev /9/, sandy mixes on a water glass base, after blowing through with gas for 45 seconds, have a compressive strength of 8.5 kg/cm^2. The same mix had a strength of 64.0 kg/cm^2 oven air dry-out lasting 15 minutes.

Fig. 39: Gas pores on edge of propeller blade cast in a mold with chromomagnesitic lining and dextrene base.

Fig. 40: Gas pores on the pressure surface of a propeller, cast in a damp mold.

Fig. 41: Wrinkled surface of a plate cast in an insufficiently dried mold.

Smelting of steel: heat treatment of castings; cutting off surplus allowances and welding of defects. Founding of stainless steels is done in basic electric arc furnaces or in inductive furnaces. Smelting of 1Kh14ND, OKh17N3G4D2T and OKh16N4D4T steel designations is in no way different from that of comparable stainless steels.

Temperature of liquid steel in the laddle must be at least 1540° by thermocouple, which insures the requisite flowability and creates favorable conditions for the elimination of non-metallic inclusions which polute the steel and render it suceptible to local corrosional damage. A check showed that a casting temperature of 1540-1600° results in the highest level of mechanical properties of 1Kh14ND, OKh17N3G4D2T and OKh16N4D4T steels.

Castings of propellers and of individual blades are subjected to heat treatment with schedules depending upon the steel designations.

Heat treatment of 1Kh14ND steel consists of tempering with air cooling and of one or two drawings. The heat-up for tempering is carried out to 980-1020°. The temperature is held at this level for 4-6 hours, depending upon the thickness of the casting. For propellers having especially thick blades (in the order of 250 mm), it is well to use two temperings with an exposure of 5-6 hours after the temperature is stabilized, in each case.

Due to the nature of isothermal breakdown of austenitic 1Kh14ND steel (see fig. 3), cooling of castings must be carried out to a temperature below 100°. If the cooling is stopped above 100°, there remains a considerable amount of undecomposed austenite; in that case, the structure consists of martensite and austenite and products of their incompleted transformation. A single drawing of steel having such a structure leads to a transformation of martensite, formed in the process of tempering, into sorbite. The residual austenite is transformed probably into secondary martensite or trostomartensite. Presence of martensite or trostomartensite after one drawing is evidently the cause of lowered plasticity and impact strength of the metal of many heats. Concurrently, there is an increase in ultimate tensile strength and yield points. The following data is typical.

Two ingots of 1Kh14ND steel were heated to 1000° and held at that temperature for 2 hours. Both were then cooled in air, one to 15-20° and the other one to 300°, after which both were drawn at 690°, the normal temperature for this steel, for a period of 6 hours. Mechanical properties tests indicated that specimens taken from the ingot cooled down to 300° has an ultimate tensile strength of 92.0 kg/mm^2 and a hardness of 269-277 H_B; while their impact strength did not exceed 1.5 kgm/cm^2. At the same time, specimens taken from the ingot cooled to 15-20° after annealing had an ultimate tensile strength under 74 kg/mm^2, hardness of 215 H_B and an impact strength of over 9 kgm/cm^2. Requisite properties could not be obtained from the metal of the castings which had not undergone complete cooling in heat treatment, even in an extended exposure in the drawing (up to 30 hours).

Greater hardness and lower ductility o ten occur in thick sections of a casting, where incomplete curing in the tempering may take place, even in cases when the thinner sections of the casting had ample time to cool.

Measurements of hardness made on massive blades, from 15 to 200 mm thick, have shown that, as a result of incomplete cooling in the process of heat treatment of massive sections, their hardness after one drawing at 670-700°, held for 30 hours, was as high as 300 H_B, while the hardness in the thin sections, completely cooled in tempering, was no higher than 230 H_B. This leads to the conclusion that one drawing is not sufficient with existance of residual austenite at the end of heat treatment.

A second drawing substantially changes the level of mechanical properties. Hardness and strength indicators are considerably lowered. This is explained by the fact that after a second drawing, the secondary martensite is transformed into sorbite and the sorbite formed in the process of the first drawing is subjected to further coagulation.

In order to increase stability of mechanical properties in the heat treatment of massive propellers, and especially of propeller blades for icebreakers, the use of two drawings with simultaneous adherence to cooling of massive portions of the casting to a temperature below 100° is recommended.

Hardness of castings should be checked along with testing of specimen plates, to maintain quality control through the heat treatment of the product.

Existance of 255 H_B, or higher, hardness in 1Kh14ND steel is a sure indication of the fact that elongation, reduction of section and impact strength figures will be unsatisfactory; the required properties are firmly assured at a hardness of 240 H_B and lower (the best hardness range is 202-236 H_B).

Castings made of 0Kh17N3G4D2T steel are subject to austenization only upon being cooled in air from 1020-1060° temperature level. Massive castings should also undergo double austenization. Exposure at a temperature 1020-1060° should be 4-6 hours.

0Kh16N4D4T steel castings up to 200 mm thick should undergo one tempering from 1040-1070°, followed by atmospheric cooling, and two drawing cycles at a temperature 600-620°. Two temperings and two drawings are recommended for castings over 200 mm thick.

Cooling of castings after drawing should be done in air for all three of the above steel designations.

Removal of allowances and sprues is made with an oxyacetylene torch. Before removal of the excess material, massive castings of 1Kh14ND and 0Kh16N4D4T steels should be drawn at 700-730°, followed by cooling in a furnace for removal of casting stresses and drawing of martensite, thus reducing the danger of cracking in the process of cutting off excess metal.

The preliminary drawing is often omitted in the case of smaller castings and preparations limited to taking precautions normally reducing the danger of cracking. To this end, the cutting is done indoors to protect the casting from drafts. The cutting itself is performed rapidly, without interruptions, so as to avoid repetitive heating and cooling of the work.

Welding of defects must as a rule be made prior to heat treating the casting. Only correction of minor defects is permitted after completion of heat treatment. Should major defects appear and have to be repaired by welding after the completion of a full cycle of heat treatment, the casting must undergo a repeat treatment consisting of tempering and annealing, or only of annealing.

Welding of defects in 1Kh14ND steel castings is made with S_V0Kh14 electrodes complying with GOST 2246-54, their coating consisting of (parts by weight):

Marble (GOST 4416-48)	57.5
Ferromanganese Mn0 and Mn1 (GOST 4755-49)	2.5
Fluorspar (GOST 4421-48)	33.5
Ferrosilicon Si 75 (GOST 1415-49)	5.0
Ferrotitanit Ti0 and Ti 1 (GOST 4761-57)	2.5
Bentonite (GOST 3226-49)	1.0
Class A water glass; spe. grav. 1.34-1.36 (GOST 4419-48) . .	45-52

Lacking S_V0Kh14 rod, S_V1Kh13 GOST 2246-54 rod may be used. This type of rod containing more carbon (up to 0.15%) than the 1Kh14ND steel, and less chrome (12.0-14.0%), which may lower the corrosional resistance of the welds. To improve the corrosional resistance of the weld metal, additional chrome, copper and nickel are added to the coating of the S_V1Kh13 wire electrodes. Chrome is introduced in an amount which will produce a content of at least 12% in the solid solution of the weld and copper and nickel in amounts of not less than 1.0% of each.

Defects in castings of 0Kh17N3G4D2T and 0Kh16N4D4T steels, found before heat treatment and afterwards, as well as minor defects in castings of 1Kh14ND steel discovered after heat treatment, are welded with S_V0Kh18N9 - GOST 2246-54 wire electrodes. The consistency of their coating is the same as that of S_V0Kh14 electrodes.

CHAPTER VI

SPECIAL FEATURES OF MECHANICAL FINISHING OF STAINLESS STEEL PROPELLERS.

Mechanical finishing of stainless steel propellers (one-piece and assembled), does not differ materially from similar operations on structural steel propellers, or on copper-base non-ferrous alloy ones, neither in the character or the sequence of operations, nor in the type of machine tools required.

However, machinability of stainless steels is inferior to that of other mentioned materials. This requires modifications in cutting schedules, design of cutting tools, choice of tool steels and hard alloys for tools and a general stiffening of the system: lathe - fitting - propeller stock - cutting tool.

Inferior machinability of stainless steels (compared to structural, low-alloy steels, carbon steels and, especially, copper-based non-ferrous alloys) is a consequence of the following basic peculiarities of their physical-mechanical properties;

1) low thermal conductivity of austenitic steel, lowering heat disipation and thus causing local overheating of both the part being cut and the tool;

2) greater tendency of austenitic steel toward impact hardening, leading to substantial toughening of the layer being cut and the formation of a stepped cutting. Proneness to vibration during the cutting process;

3) greater friction at the point of contact of the tool with the work, due to the presence of hard carbides in the structure of some stainless steels and greater adhesion to the metal of the cutting tool;

4) increase in toughness and hardness at raised temperatures;

5) higher resistance to formation (at cutting temperatures) of oxide films, which prevent binding between the work and the cutting tool at their point of contact.

Because of the above characteristics of the material, machining of stainless steel propellers calls for:

1) use of a tool with a cutting edge made of fast-cutting steel, or or higher-strength hard alloys;

2) stiffening of the system, lathe-fitting-propeller casting-tool (reinforcing of clamps for holding the work and the tool, increased rigidity of the chucks and cutting tool holder, reduction in cutter sweep, etc.);

3) greater cooling capacity for cooling the tool;

4) better dressing of the tool's cutting edge with total absence of flaws (dents, clogging, etc.), cutting edges for tools and milling cutters for finishing stainless steel must be ground to a sharp edge;

5) avoidance of impact on the tool in machining; very accurate centering of multi-blade tools in the lathe.

There is a need for additional automation in a number of finishing steps which are often accomplished manually in finishing non-ferrous alloy propellers.

The technique of finishing propellers made of non-ferrous alloys and of structural steel, and the equipment and devices employed, is described in sufficient detail in certain papers (for instance /10/), therefore this chapter discusses only the results of research relating to the machinability of stainless steels recommended for use in propellers and clarifies certain features of finishing techniques. Considering the limited amount of available data relating to production of stainless steel propellers, the authors naturally do not lay claim to complete clarification of all the problems involved.

Machinability of stainless steels used in propellers. As mentioned previously, three stainless steels are recommended for the casting of propellers - 1Kh14ND, 0Kh17N3G4D2T and 0Kh16N4D4T. Relative machinability of these steels has been established (and, as a basic of comparison, that of mark 30 carbon steel and of austenitic stainless steel designation 1Kh18N9T), These tests were made in the laboratory of the machine building technological department of the M. I. Kalinin Leningrad Polytechnical Institute (by A. V. Schegolev, P. P. Zagretsky and V. A. Skragan). Cutting speed, permitted by a tool of a given durability, and the effort exerted in the process of cutting were determined in the course of this study.

1. Establishment of comparative machinability of stainless steels through determination of allowable cutting speed V_{60}. Allowable cutting speed for a given tool life of 60 minutes (V_{60}) was determined by facing a number of disks (D_{max} = 290-300; thickness H = 100-150 mm) on a lathe.

The facing out was made with through cutters made of mark P-18 rapid-cutting steel, 20 x 30 mm in cross-section. Geometry of the cutters was controlled by table-mounted angle gages. Variations in the angle of cut was within allowable limits of ($\pm$ 1°). Before proceeding with the tests, the cutters were calibrated by the method of a longitudinal cut run on a lathe. Carbon steel stock mark 40 was used for this test and was machined at a cutting speed of 42 M/min, a feed of 0.3 mm/rev., depth of cut 2 mm and a total run of 400 M. Wear on the leading edge of the cutter was determined upon the completion of machining with the aid of a microscope. This calibration showed that all the cutters selected had virtually the same amount of wear, substantiating their identical cutting capacity. Hardness of the heat treated cutters was within the limits R_c = 62-64.

Machining of the test disks was done on a surfacing lathe with a stepless rotary speed control ranging from 23 to 400 rpm. The rotary speed was selected so that in all experiments blunting of the cutter would take place during the first pass under the condition

$$R_n \leqq 2 R_o$$

Where R_n - radius of blunting, mm; R_o - radius of cut hole, mm.

The diameter of blunting was measured with a sliding caliper with an accuracy of 0.05 mm.

In carrying out the first tests it was determined that the commonly accepted indication of the cutter's blunting - appearance of a bright streak on the machined surface - was useless in the case of stainless steels due to difficulty of determining the moment when such a streak first appears. Therefore, the external appearance of the cuttings was chosen as an indicator of cutter blunting.

In observing the machining of stainless steel disks, it was determined from the wear on the cutter and appearance of the chip that the instance of destruction of the cutting edge of the tool was marked by formation of a divided (bifurcated) chip with a typical black streak on the undercut side. Transition from a coiling to a bifurcated cutting occurs during a fraction of a second, followed by a catastrophic wearing out of the tool. During the machining of the carbon steel disks, the most visible indication of blunting was the color of the cutting. At the moment of destruction of the cutting edge of the tool, the cutting turned blue (iridescent) in addition to the appearance of the bright streak.

From test data for each type of steel, graphs were drawn on logarithmic scale, with the number of revolutions of the disks per minute (m) plotted on the ordinate and the radius of blunting R_n in mm for a given pass along the abscissal axis.

Angles α (inclinations of the functional lines with respect to the abscissal axis) were determined from the graphs and then from the expression $m_o = \frac{tg\alpha + 1}{tg\alpha - 1}$ was determined the quantity m_o, inverse of the relative durability index, m in the formula

$$V = \frac{C}{T^m} = \frac{C}{T^{\frac{1}{m_o}}}; \qquad V_{60} = \frac{C}{60^{\frac{1}{m_o}}} \text{ m/ min,}$$

where

V - cutting speed;

C - constant coefficient;

T - time for complete blunting of the cutter, min.;

m - relative durability index.

The constant coefficient C is determined from the formula

$$C = V_n \sqrt{\frac{R_n}{S_n (t_0 + 1)}},$$

where

V_n - cutting speed corresponding to the instant of blunting of the cutter, M / min.;

R_n - blunting radius, mm;

S - feed, mm/rev.;

n - r.p.m.

After determining the above values for each steel, permissible cutting speed for a given tool life of 60 min (V_{60}). Then by dividing the permissible speed V_{60} of each one of the stainless steels investigated by the permissible speed V_{60} of mark 30 carbon steel, the coefficient of machinability K_v, of stainless steels was determined.

Table 48 lists the results of determination of permissible cutting speeds for a given 60 min. tool life, and also the coefficient of comparative machinability K_v of stainless steels.

Table 48.

Permissible cutting speeds for turning stainless steels at a given tool life of 60 minutes.

Steel Designation	tg α	Constant coefficient C	Permissible cutting speed V_{60}, M/min	Relative machinability coefficient, K_v
Carbon steel 30	1.25	102	67	1.0
1Kh14ND	1.25	61.5	40	0.6
0Kh16N4D4T	1.37	44	24.4	0.36
0Kh17N3G4D2T	1.29	37.5	22.8	0.34
1Kh18N9T	1.33	32.7	18.6	0.28

Of all stainless steels investigated, stainless steel mark 1Kh14ND has the best machinability (for turning on a lathe).

2. Investigation of comparative machinability of stainless steels through determination of cutting force. The vertical component of the cutting force is a criterion of machinability characterizing the energy output and the forces acting on the work, tool and lathe. For steels of the same type, the cutting force depends principally on the ultimate tensile strength and the hardness. Increase in the values of the above properties causes an increase in the cutting force. In machining stainless steels, an important effect of the cutting force may also be produced by secondary hardness resulting from the cold hardening of the surface layer of the metal being machined.

Cutters used in facing tests were also used in measuring cutting forces. Rings made of steels being tested were secured to the chuck and machined.

Table 49.

Comparative machinability of stainless steels, on the basis of the required cutting force.

Steel Designation	Cutting force P_z, kg.	Proportional force C_{Pz}	Coefficient of machnability K_p
Mark 30 carbon steel	160	150	1.0
1Kh14ND	162	152	1.01
OKh16N4D4T	196	177.5	1.15
OKh17N3G4D2T.	168	157	1.05
OKh18N9T.	186	174	1.16

The proportional force was computed from formula

$$C_{Pz} = \frac{P_z}{S^{y_p} \; t^{x_p}} ,$$

in which $y_p = 0.75$ and $x_p = 1$ (for OKh16N4D4T steel, $y_p = 0.85$).

The coefficient of machinability K_p was computed from formula

$$K_p = \frac{C_{Pz} \text{ (of invest. steel)}}{C_{Pz} \text{ (of mark 30 steel)}}$$

Data presented in table 49 shows a relatively small variation in cutting force between carbon and stainless steels.

The vertical cutting force was measured with a three-component, automatically recording lathe dynamometer. Measurement of cutting force P_z was in accordance with the following regimes: cutting speed V = 20 M/min; depth of cut t = 3 mm; feeds S:0.15; 0.3; 0.58 mm/rev.

Table 49 lists the determined cutting forces P_z, proportional cutting forces Cp_z and the coefficients of machinability Kp for the investigating steels (at a feed of 0.3 mm/rev).

3. Determination of comparative machinability of stainless steels in milling. This investigation was made with 1Kh18N9T and OKh17N3G4D2T steels. Ingots measuring 100 x 100 x 300 mm were subjected to this type of machining. The work was done on a vertical milling machine with a facing miller of 250 mm diameter, with one or two cutters. The milling cutters were made of high-seed steel. Special precautions were taken to insure precision of installation when two cutters were used; the allowable play could not exceed 0.05 mm.

These tests showed that in milling, OKh17N3G4D2T steel is easier to machine than 1Kh18N9T steel; this is expressed in terms of an approximately 35% higher durability of the cutting tool.

Features of the technical process of machining propellers made of stainless steel. Table 50 enumerates the basic operations of machining a one-piece stainless steel propeller (based on experience of a plant specializing in the manufacture of propellers made of various materials); and lists the basic instructions covering the machines and tools involved.

Table 50.

The Basic operations in machining stainless steel propellers

PP No.	Name of combined machining operations*	Machine Type	Cutting Tool	Remarks
1	Remove excess	Vertical - boring and turning.	Passing and cutoff cutters with VK8 hard alloy blades.	To eliminate vibration and excessive wear on cutters, rigidity of cutter proper and of holder in carriadge must be increased.**
2	Drill and bore cut cone-shaped hole in hub. Face hub.	Turning and vertical boring lathes.	Spiral drills and cutters with VK8 hard alloy blades.	To eliminate displacement of cutter in boring cone-shaped opening, boring chuck.**

Table 50, Continuation.

pp No.	Name of combined machining operations.*	Machine Type	Cutting Tool	Remarks
3	Milling contours (edges) of the blades.	Specialized Duplicate--milling, or hydraulic duplicate mill'g (if former not available).	Milling cutters with VK8 hard alloy blades.	Must be done only by mechanical means.(even in case of one-of-a kind production).Shaping of contours with pneumatic chippers must not be allowed.
4	Milling surfaces of blades.	Electro, or hydro duplicate milling.	As above.	Strongly recommended is the use of duplicating machines permitting uninterrupted milling of leading and trailing blade surfaces, without repositioning the propeller casting. Two milling cutters secured to working head concurrently.
5	Milling fillets at transition points, blade to hub, and of hub outside surfaces	Electro duplicate milling.	As above	-
6	Cutting keyway grooves in hub.	Small propellers - broaching lathes. Large ones - special portable milling machines.	Broaches and milling cutters.	Because of cutter displacement due to inadequate rigidity of chuck and carrier of a grooving machine, their use is not recommended.
7	Manual finish (Machinists) operations: dressing, buffing, polish.	-	Chisels, grinding wheels,"Durex" wheels, felt disks.	"Durex" emery wheels must be steel finishing type.

* The list of operations does not include lay-out, fitting-up and static and dynamic balancing, since they in no way differ from similar operations involved in production of propellers of other materials.

** This means increasing in rigidity or change in design, as compared with that employed in machining brass propellers.

For mechanical finishing of stainless steel propellers, use of belt-type buffing machines is highly recommended. This equipment can be used for finishing blade surfaces after milling (for removal of ridges) as well as on the rough surfaces of blades for removal of casting scale and other roughness present on cast surfaces. Their cost and operating expense are low; the machines operate without the use of master forms (belt position is governed by the shape of the castings). Belt-type buffing machines are widely used in finishing the blades of gas and steam turbines made of stainless and heat-resistant steels.

Tables 51 and 52 present data pertaining to machining schedules used in finishing an experimental propeller of the highest class, cast of austeno-ferritic steel.

...steel.

Table 51.

Cutting schedules used in machining an austeno-ferritic steel propeller.

Name of Operation	Tool	Cutting Schedule		
		V, M/min	S, mm/rev	t, mm
Removal of excess	Cut-off tool with a VK8 blade.	4.5-9.0	0.1 (Manually)	-
Facing hub (forward).	Facing tool with a VK8 blade.	- 40	0.26	3
Boring recess in hub.	As above.	25	0.26	3
Boring cone-shaped hole through hub, to size.	Cutter on bracket carrier, VK8 blade.	3.8- 21	0.26	0.3-3.0
Facing hub (aft)	Facing tool with a VK8 blade.	25.2-47	0.25-0.5	0.5-3.0
Turning hub for threading.	As above.	34-45	0.2 -0.5	0.5-3.0
Cutting thread inside hub.	Thread cutter with VK8 blade.	3.1	4.0	0.1

Table 52.

Schedules used in milling austeno-ferritic steel propellers.

Name of operation	Tool	Cutting Schedule.		
		t, mm	S, mm/tooth	V M/min
Milling of leading and trailing blade surfaces (On hydro-duplicating machine).	Special milling cutter with VK8 blades.	3 - 5	0.3	33
Milling exterior surfaces of hub and the fillets at point of transition from hub to blade. (On electric duplicating machine).	Special milling cutter.	6 -10	0.25	31

From data supplied by A. Sh. Shifrine /20/, tables 53 and 54 present a list of tool material designations for blades of cutters and milling cutters, and cutting schedules for chromous stainless steels of martensitic type and chrome-nickel austenitic stainless steels. In using this data for finishing propellers of 1Kh14ND, OKh17N3G4D2T and OKh16N4D4T stainless steels, consideration should be given to the relative machinability of these steels compared with that of 1Kh18N9T-type steel (see table 48).

Table 55 presents data relating to cutting schedules and material for the cutting tools based on experience with machining of OKh17N3G4D2T austeno-ferritic steel parts.

Table 53.

Schedules for machining of stainless steels and material of cutters used.

Stainless steel Designation	Type of Turning.	Cutter Blade Material.	Cutting Schedule.		
			V, M/min	S, mm/rev	t, mm
Chromous (Martensitic)	On crust Finishing	VK8, T15K6 T15K6	150-400. 150-400	To 1.6 0.1-0.3	To 8 To 3
Crome-nickel austenitic.	On crust Finishing	VK4, VK8 T30K4	75-90 200-250	0.4-0.6 0.2-0.4	To 7 0.5-1.0

Table 54.

Milling Schedule for Stainless Steels.

Stainless Steel Mark	Cutting Blade Mater'l	Type of Milling	Cutting Schedule.				
			V, M/min	S_z mm/tooth	S mm/min	t, mm	B, mm
1Kh13, 2Kh13	VK8	Rough facing	100–110	-	160–200	6	-
		Finish facing	165	-	220	0.5	-
	P9	Facing	50–65	To 0.2	320	3–7	75
	P9	Cylindrical	17.5	0.12	72	5–6	32
	P18	Disk type	25	0.11	100	5	-
			47	0.06	105	2	-
	P18, P9	Profile	20–35	0.11–0.05	60	5–14	-
1Kh18N9T	P18	Facing	25	0.1–0.2	-	3–7	75
	P9	Cylindrical	35	0.1–0.2	-	2–8	-

Table 55.

Cutting Schedules and Tools for Machining 0Kh17N3G4D2T steel Parts.

Title of machine operation	Type of cutting tool	Cutting Schedules		
		V, M/min	t, mm	S mm/rev
Removal of excess	Cutters with blades of T15K6 and T5K10 alloys	9.42	-	0.2–0.5
Rough turning	Cutters with T15K6 alloy blades.	23–25	4–5	0.3–0.35
	Same but of VK8	22		0.8
Finishing	Cutters with T15K6 alloy blades.	~ 40	0.5–1.0	0.15–0.2
Milling	Milling cutters with T15K6 alloy blades.	32	4.5–6.0	50 mm/min
Boring	Drill, rapid-cutting P18 steel	5.1	-	0.1
Machining on grooving lathe.	Rough stripping, cutters with T15K6 alloy blades; Finish cutters-P18 steel	1.5	-	-

CHAPTER VII

QUALITATIVE REQUIREMENTS APPLICABLE TO THE PRODUCTION OF STAINLESS STEEL PROPELLERS.

Table 47 furnished the chemical composition and mechanical property standards of stainless steels used in casting propellers. The following data relates to fundamental qualitative requirements for finished stainless steel propellers according to GOST 8054-59, covering standards for surface finishes and dimension and shape tolerances.

Required surface finishes of blades and hubs. Table 56 presents the standards relating to surface finish of blades and hubs of machined propellers, according to GOST 8054-59.

These requirements do not apply to casting defects remaining after machining, accepted under the terms of contract specifications.

Table 57 lists criteria of acceptance of casting defects on finished propeller surfaces.

Tolerances in dimensions and parameters. These tolerances for propellers, according to GOST 8054-59, are given in table 58.

According to the above specification, measurements of propeller pitch and of blade thickness must be checked at not less than 5 radiuses (0.3R; 0.5R; 0.7R; 0.8R; and 0.95R), indicated on the drawings and at not less than 3 points at each section outside the area of the edges. According to specifications, the pitch of stainless steel propellers of the highest class must be checked at each section shown on the drawings (outside the area of the edges).

Checks of blade thicknesses must be made at the same locations as the checks for pitch accuracy.

Length of sections must be measured on the same radii that are used in checking pitch and thickness. By agreement with customer, an increased deviation in pitch is permitted if it is caused by a corresponding change in propeller diameter.

Tolerance in pitch, thickness and length of blade sections on inner radii up to 0.4R inclusive may be 50% greater than those given in table 58.

Requirements related to local pitch do not cover propellers with a pitch of 1 M and less, nor do they apply to sections of propellers with a pitch in excess of 1 M, limited by a central angle of 25° and less.

Table 56.

Standard requirements for surface finish of blades and hubs of propellers.

Diameter of Propeller, mm	Propeller Class: Highest	Propeller Class: Normal
Surface finish of blades on radii greater than 0.3 R of propeller		
300 - 1000	$\nabla 5$	$\nabla 3$
>1000	$\nabla 4$	$\nabla 1$
Surface finish on blade surfaces on radii less than or equal to 0.3R of propeller and of the hub.		
300 - 1000	$\nabla 4$	$\nabla 1$
>1000	$\nabla 3$	500

Remarks:
1. 500 - roughness, not in excess of 500 mk.
2. surface finish of hubs for assembled highest class propellers must be 3, and that of normal class, 500. Edges of highest class propeller blades must have a finish equal in quality to that of the blade, but not less than 3, while edges of blades of normal class propellers must have a 3 finish. Surface finish of hubs for variable pitch propellers is in accordance with requirements of contract specifications.

Table 57.

Casting Defects on Finished Propellers, Not Requiring Corrections.

Location of defect.	Type of defect.	Highest Class Brass and stainless steel	Normal Class Stainless and carbon steels.
Blade surface	Gas and slag cavity	Diameter and depth from 0.5 to 1 mm – not over 1 per 100 cm^2 on each face of blade.	Diameter and depth from 0.5 to 2 mm – not more than 2 in area of 100 cm^2 on each face of blade.
		Diameter and depth over 1 and up to 2 mm – not over 1 in area of 200 cm^2 on each face of blade.	Diameter and depth over 2 and to 5 mm – no more than 1 in 100 cm^2 area in each face of blade.
	Local roughness in form of creases, wrinkles, waviness and black spots.	–	Depth up to 1.5 mm over whole surface, but not having continuous character.
Exterior and faces of hub.	Isolated gas and slag cavities	Up to 1 mm deep; up to 2 mm in diameter.	Up to 2 mm deep; up to 5 mm in diam.
	Local roughness in form of creases, wrinkles, wavuness and black spots.	–	Up to 1.5 mm deep over whole surface, but not having continuous character.

Remarks:

1. Gas and slag cavities less than 0.5 mm in depth and diameter are permitted on blade and hub surfaces; in stainless steel highest class propellers – not over 10 per 200 cm^2 and on brass propellers – 2 to 5 per 200 cm^2 on one face; on propellers of normal class, no limitation, provided they do not form a continuous run over an entire face.

2. By diameter of a cavity is meant its largest diameter at the surface.

Tolerances in dimensions [illegible] of propel[illegible]

Name of dimension or parameter checked.	[illegible] from specified [illegible] on propeller drawing.	
	[illegible] Class.	Normal Class.
Radius of propeller	±(0.2% + 0.5mm)	±([illegible]5% + 0.5mm)
Length of blade section	±(1.0% + 1 mm)	±(1.5% + 1 mm)
Pitch of propeller	± 1.0 %	± 2.0 %
Pitch of blade	± 1.5 %	± 2.5 %
Pitch of section.	± 2.0 %	± 3.0 %
Local pitch	± 2.5 %	± 3.5 %
Thickness of blade section.	+(4.0% + 2.0 mm) −(2.5% + 1.5 mm)	+(6.0% + 2.5 mm) −(3.0% + 2.0 mm)
Relative location of blade axes on propeller circumference (deviation in % of propeller diameter).	±(0.5% + 4.0 mm)	±(0.5% + 5.0 mm)
Location of blade along axis of the propeller at points on 0.5R and 0.95R (in % of propeller diameter)	±(0.5% + 3.0 mm)	±(0.4% + 5.0 mm)
Location of blade axes along propeller's axis between two different blades at a point on 0.5R of propeller (in % of propeller diameter)	0.5% + 2.0 mm	0.4% + 2.0 mm
Weight of propeller (without fairing) in %.	± 4.0%	± 5.0%
Weight of service and spare blades of assembled propellers (deviation in % of the lightest of the blades)	2.0%	2.0%

Deviations in blade thicknesses within the allowable must be evenly distributed on the surface. The spacing of individual deviations must be 80 - 100 times greater than the size of the deviation.

The cone-shaped opening in the hub must have its diameters checked by the paint indication test; the number of paint spots on the conical surface must not be greater than one per [illegible] mm area, by agreement with the customer, it is permissible to machine the cone-shaped opening in the hub to fit the cone on the shaft. By similar agreement, it is also permissible to machine the conical opening and recessed keyways with allowances for the final fit-up.

Static and dynamic balancing; marking, packing and shipment of propellers. Static balancing of propellers must be carried out in accordance with a prescribed sequence. Dynamic balancing is done in accordance with the special instructions set forth in the technical contract specifications. In the matter of regulations for static and dynamic balancing, marking, packing and shipping, stainless steel propellers are treated in the same manner as those made of other materials.

The above operations are regulated by the general rules of GOST 8054-59, or by individual contract specifications.
