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WELDING OF SHIP STRUCTURES (SELECTED TRANSLATIONS)

G. A. Belchuk, et al

Naval Intelligence Support Center
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PARAGRAPH 18. SOLDERS, FLUXES, AND SHIELDING MEDIA

/Excerpt from Ch. 5--Brazing of Metals in "Svarka sudovykh konstruktsiy (Welding of Ship Structures), a Russian book by [illegible] A. Bel'chuk, K. M. Gatovskiy, V. A. Kokh and V. D. Ma[illegible]evich, 1972, pp 86-90/

The majority of solders are multicomponent alloys based on either nonferrous or rare metals. Pure metals are sometimes used. /86*

The solders are categorized by their melting temperatures (Table 9: solders with melting temperatures below 450° C are classed as soft solders while those with higher melting points as hard solders); /87

by technological characteristics (self-fluxing, cermet-base);

by service properties (refractoriness--heat resistance, vacuum-t[illegible]s, etc.);

by the metal base and major alloying components.

The latter factors usually designate the name of the solder.

Eight low-melting metals, namely mercury (T_m = 38.9° C); gallium (T_m = 29.8° C); indium (T_m = 156.4° C), tin (T_m = 231.9° C); bismuth (T_m = 271.3° C); lead (T_m = 321° C), cadmium (T_m = 321° C) and zinc (T_m = 419° C) are used as the base of a great number of soft solders. /88

Hard brazing solders are based on: aluminum (T_m = 660° C), silver (T_m = 961° C), gold (T_m = 1063° C), copper (T_m = 1083° C), and nickel (T_m = 1453 C).

Self-fluxing brazing solders are generally produced by the addition of fluxing elements--strong deoxidizers (lithium, boron, phosphorus, and sodium) to the basic constituents. The fluxing elements remove oxygen from the oxides and clean the surface from oxide fil . The oxides of the fluxing elements withdraw from the weld and vaporize from the surface; in part, however, they dissipate into the weld.

Cermet solders are made by mixing refractory metal powders with a liquid carrier; by impregnating a refractory metal fiber carcass with a liquid carrier; by mixing refractory metal powders with a low-melting base. The refractory metal is placed into the gap and then wetted with the low-melting carrier for capillary soldering.

Mercury and gallium are used as low-melting carriers for soft cermet solders while silver solders are used as the base for high-melting brazing solders. Copper, nickel, iron, and cobalt powders serve as filler materials.

*Numbers in the margin indicate pagination in the foreign text

Characteristics of Most Commonly Used Solders

TABLE 9

Solder Group	Solder Denomination	Area of Application	Grade	Composition of Solders, %	Soldering (brazing) temp., C	Strength, MPa* shear	Strength, MPa* rupture
	Mercury- and silver-base cermet solders	Copper, silver and titanium parts	-	Hg, 48; Ag, 52	25 (after 3 hr of holding at unsoldering t of 900°C)	-	-
Soft	Tin-lead solders	Copper, brass, steel, and silver	POS50 POSi8	Sn, 50; Pb, 50 Sn, 18; Pb, 82	220 300	35 25	- -
	Zinc solders	Aluminum and AMTs and AMg alloys	P300 P-425A	Zn, 60; Cd, 40 Zn, 65; Al, 20; Cu, 15	340 455	35 170	- -
	Aluminum-base solders	Aluminum and AMTs. AMg and AV alloys	34A P590A	Al, 66; Cu, 28; Si, 6 Al, 89; Cu, 10; Si, 1	550 600	130 -	 -
	Silver-base solders	Copper-, titanium-, iron-, high-temperature stainless steel-base alloys	PSr45 PSr72	Ag, 45; Cu, 30; Zn, 25 Ag, 72; Cu, 28	800 900	230 -	320 300
	Self-fluxing silver-base solders	Stainless steel; copper and titanium alloys	PSr72LMN	Ag, 72; Cu, 26.5; Ni, 1; Li, 0.5	850	-	300
	Self-fluxing copper solder	Copper, molybdenum and tungsten	MF3	Cu, 96; P, 4	850		
Hard	Copper-zinc solders	Copper and its alloys, steel, pig iron	L62 PMTs54	Cu, 62; Zn, 38 Cu, 55; Zn, 45	910 900	- -	320 350
	Copper-nickel solder	Stainless and high-temperature steels	VPR1	Cu, 68.5; Ni, 28; Si, 1.7; Fe, 1.5; B, 0.3	1150	430	-
	Self-fluxing copper-nickel-manganese solder	Same	VPR4	Cu, 34.6; Mn, 35; Li, 0.2; Ni, 28; Si, 1; Fe, 1; B, 0.2	1050	450	-
	Nickel solder	Stainless steels, molybdenum and tungsten	SM60	Ni, 93; Si, 3.5; B, 3.5	1050	-	-
	Nickel-chromium solder	High-temperature steels	SM56	Ni, 75; Cr, 17; Si, 4.5; B, 3.5	1150	-	-

TRANSLATOR'S NOTE: "MPa" is obviously "meganewton per square meter"

High-temperature brazing solders consist of nickel alloys supplemented with chromium, aluminum, and molybdenum.

Special requirements are placed on solders designed for brazing vacuum-tight seams. This type of soldering is generally done in vacuum. The solders must be free of readily volatile components.

These requirements can be met by a number of silver-base solders.

Soldering fluxes are designed to protect the metal surface from oxidation by air oxygen, clean the surfaces from oxide films and improve the metal's wettability by the solder.

Both the melting temperature and specific weight of the flux are generally lower than those of the solder. The molten flux must, however, be a good wetting agent for the metal. Only a flux with all these properties will be capable of cleaning the metal from oxide films before the solder has been molten to be later displaced by the spreading solder.

Brazing (soldering) fluxes fall into three groups:

1. Fluxes for hard brazing various types of alloys (Table IV), except for aluminum. These fluxes must contain fluoride metals (KF, CaF_2 and others), fluoroborates (KBF_4, $NaBF_4$, etc.) and most certainly--boric anhydride B_2O_3, boric acid H_3BO_3 or prefused borax $Na_2B_4O_7$ (but not $Na_2B_4O_7 \cdot 10H_2O$ which is the formula for unmolten borax). Fluxes are made by the fusing of the constituents and are used in the form of powders or pastes pre-mixed with water, alcohol, or other binders. In /90
some cases the same purpose is served by gaseous fluxes that are produced by soldering as a result of the decomposition of fluoride compounds of ammonium (NH_4F), potassium (KF) or fluoroborate (KBF_4).

2. Fluxes for brazing aluminum and its alloys (see Table 9). They contain metal fluorides and chlorides.

3. Fluxes for soft tin- and lead-base solders (Table 9). The bases here are organic compounds (colophony, Vaseline, etc.), and zinc and ammonium chlorides.

All fluxes, with the exception of those on a pure colophony base, are chemically active with respect to the metals being joined. Flux residues on soldered joints lead to corrosion failures. Soldered parts must, therefore, be thoroughly cleaned from flux.

This particular drawback of soldering with flux as well as other undesirable interactions between the flux and the metal may be eliminated by performing the soldering operation in an inert medium, such as argon or in vacuum (at $1.32\text{-}1.33 \cdot 10^{-2}$ Pa*). In some cases the brazing must be done in an active medium such as hydrogen. This excludes titanium and other metals that actively interact with hydrogen.

*Translator's note: "Pa" obviously identifies "newton per square meter"

TABLE 10

Principal flux grades commonly used for soldering (brazing)

1 Применяемые припои, основной металл и марка флюса				2 Характеристики флюса	
3 Группа припоев	4 Характеристика припоев	5 Основной металл	6 Марка флюса	7 Состав, %	8 Интервал температур пайки, °C
9 Твердые	10 На основе меди, серебра, никеля	11 Нержавеющие и жаропрочные сплавы и стали, молибден, вольфрам	12 № 200	13 B_2O_3 — 60 $Na_2B_4O_7$ — 22 CaF_2 — 18	14 850—1150
	15 То же	16 Конструкционные углеродистые и низколегированные стали, медь и ее сплавы, чугун, титановые сплавы	17 № 209	18 KF — 42 B_2O_3 — 35 KBF_4 — 23	19 600—900
20 Твердые и мягкие	21 На основе цинка и алюминия	22 Алюминий и его сплавы	23 31А	24 LiCl — 32 KCl — 50 NaF — 10 $ZnCl_2$ — 8	25 420—500
26 Мягкие	27 На основе олова, свинца	28 Медь, латунь, луженая сталь	29 Канифольно-спиртовой	30 Канифоль — 30 Спирт — 70	31 150—300
		32 Хромоникелевая нержавеющая сталь	33 ЛМ-1	34 H_2O — 100 см³ Спирт — 400 см³ Канифоль — 300 г	35 210—250
		36 Углеродистые и низколегированные стали, медь, никель и их сплавы	—	37 $ZnCl_2$ — 48 NH_4Cl — 12 H_2O — 40	38 150—320

1--solders, base metal and flux grade; 2--flux characteristics; 3--solder groups; 4--solder characteristics; 5--base metal; 6--flux grade; 7--composition, %; 8--soldering (brazing) temperature range, °C; 9--hard; 10--copper-base, silver base, nickel base; 11--stainless and high-temperature alloys and steels, molybdenum, tungsten; 12--No 200; 13--B_2O_3, 60; $Na_2B_4O_7$, 22; CaF_2, 18; 14--850-1150; 15--same; 16--constructional carbon and low-alloy steels, copper and its alloys, pig iron, titanium alloys; 17--No 209; 18--KF, 42; B_2O_3, 35; KBF_4, 23; 19--600-900; 20--hard and soft; 21--zinc-base,

aluminum-base; 22--aluminum and its alloys; 23--34A; 24--LiCl, 32; KCl, 50; NaF, 10; $ZnCl_2$, 8; 25--420-500; 26--soft; 27--tin-base, lead-base; 28--copper, brass, lead-coated steel; 29--colophony-alcohol; 30--colophony, 30; alcohol, 70; 31--150-300; 32--Cr-Ni stainless steel; 33-LM-1; 34--H_2O, 100 cm^3; alcohol, 400 cm^3; colophony, 300 g; 35--240-250; 36--carbon and low-alloy steels, copper, nickel and their alloys; 37--$ZnCl_2$, 48; NH_4Cl, 12; H_2O, 40; 38--150-320

PARAGRAPH 37. WELDING MATERIALS FOR ARC AND ELECTROSLAG WELDING OF STEELS*

[Excerpt from Ch. 8--Metallurgical Processes in Welding. Welding Materials in "Svarka sudovykh konstruktsiy" (Welding of Ship Structures), a Russian book by G. A. Bel'chuk, K. M. Gatovskiy, V. A. Kokh, and V. D. Matskevich, 1972, pp 159-170]

Electrodes, filler rods and wire, shielding gases and fluxes are integrated into a single concept--welding materials. They perform diverse metallurgical and technological functions. /159**

The metallurgical functions include:

shielding the weld from the atmosphere;
metal alloying and deoxidation;
metal refining--removal of sulfur, phosphorus, oxide inclusions and slag;
innoculation--refining the primary weld structure.

The technological functions include:

providing stability of arc or electroslag processes, filling-in filler metal into the opening between the parts to be joined;
shaping the weld surface.

Welding electrodes are made in two forms: consumable and nonconsumable. The former are designed to produce the weld arc and the latter--for maintaining the arc or the slag process and serve as filler (weld) metal.

Nonconsumable electrodes are made from refractory materials, such as graphite, tungsten, and zirconium.

Tungsten electrodes are made from pure tungsten and tungsten with additions of thorium, lanthanium, and yttrium oxides.

Addition of thorium (ThO_2), lanthanum (La_2O_3), yttrium (Y_2O_3) oxides to tungsten in amounts ranging from 1.0 to 2.5% markedly increases the emissive power of tungsten as a cathode.*** This enhances the /160 electrode's stability (ability to retain its pointed shape at maximum currents for longer periods) in dcsp**** or ac welding.

*Information on materials designed for nonferrous metals and alloys is dealt with in another chapter discussing the welding technology of these materials.

**Numbers in the margin indicate pagination in the foreign text

***Thorium is a radioactive element; thoriated cathodes are, therefore, replaced--wherever possible--with lanthanized or yittriated cathodes

****Translator's Note: Dcsp welding stands for direct current, straight polarity welding

Chemical composition of certain welding wire grades TABLE 17

1 Марка проволоки по ГОСТ 2246-70	2 Химический состав, % по массе									
	3 Углерод	4 Кремний	5 Марганец	6 Хром	7 Никель	8 Молибден	9 Титан	10 Сера, не более	11 Фосфор, не более	12 Прочие элементы
				Цинкоуглеродистая проволока						
14 Св-08	13 Не более 0,10	43 Не более 0,03	18 0,35–0,60	44 Не более 0,15	19 Не более 0,30	—	—	0,040	0,040	42 Алюминий, не более 0,01
16 Св-08А	» » 0,10	» » 0,03	0,35–0,60	» » 0,12	» » 0,25	—	—	0,030	0,030	Алюминий, не более 0,01 42
17 Св-08АА	» » 0,10	» » 0,03	0,35–0,60	» » 0,10	» » 0,25	—	—	0,020	0,020	Алюминий, не более 0,01 42
20 Св-08ГА	» » 0,10	» » 0,03	0,80–1,10	» » 0,10	» » 0,25	—	—	0,025	0,030	—
21 Св-10ГА	» » 0,12	» » 0,03	1,00–1,30	» » 0,20	» » 0,30	—	—	0,030	0,030	—
				Легированная проволока 33		40				
22 Св-08ГС	Не более 0,10	0,60–0,[illegible]	1,10–1,70	Не более 0,20	Не более 0,25	—	—	0,025	0,030	—
23 Св-08ГСМТ	0,05–0,11	0,[illegible]–0,[illegible]	2,0–2,[illegible]	39 » » 0,20	» » 0,25	—	—	0,025	0,030	—
24 Св-18ХГСА	Не более 0,12	0,[illegible]–0,[illegible]	0,[illegible]–1,[illegible]	» » 0,20	0,90–1,[illegible]	—	—	0,025	0,030	—
25 Св-08ГСМТ	0,[illegible]–0,[illegible]	0,[illegible]–0,[illegible]	1,[illegible]–1,[illegible]	» » 0,30	Не более 0,[illegible]	0,[illegible]–0,[illegible]	0,05–0,12	0,025	0,030	—
26 Св-08ГСМФА	0,12–0,18	0,[illegible]–0,[illegible]	0,[illegible]–1,[illegible]	» » 0,30	» » 0,[illegible]	—	0,05–0,20	0,025	0,025	Алюминий 0,20–0,5[illegible]; 45 ниобий 0,05–0,[illegible]% 46
27 Св-20ГСТЮА	0,17–0,23	0,60–0,[illegible]	0,90–1,20	» » 0,30	» » 0,40	—	0,10–0,20	0,025	0,025	церий, не менее 0,4 47 Алюминий 0,20–0,50; церий 0,30–0,45 48
28 Св-10ХГМ	35 Не более 0,12	0,12–0,35	0,4–0,70	4,00–5,50	» » 0,50	0,4–0,6	» —	0,025	0,03	49 —
				Высоколегированная проволока 41						
Св-10Х11Н23М2Ф	0,08–0,13	0,30–0,60	0,35–0,65	10,50–12,00	0,60–1,10	1,00–1,30	—	0,025	0,030	Ванадий 0,25–0,50, вольфрам 1,00–1,40 56 51
30 Св-04Х19Н9	Не более 0,06	0,30–1,00	1,00–2,00	18,00–20,00	8,00–10,00	—	—	0,018	0,025	—
31 Св-08Х19Н10Ф2С2	» » 0,10	1,[illegible]–1,[illegible]	1,00–2,00	18,00–20,00	8,00–10,00	—	—	0,025	0,030	Ванадий 1,80–2,40 52
32 Св-04Х19Н11М3	» » 0,06	Не более 0,60	1,00–2,00	18,00–20,00	10,00–12,00	2,00–3,00	—	0,016	0,025	—
Св-07Х25Н13	» » 0,07	0,30–1,00	1,00–2,00	23,00–26,50	12,00–14,00	—	—	0,018	0,025	—
33 Св-10Х16Н25АМ6	0,08–0,12	Не более 0,60	1,00–2,00	15,00–17,00	24,00–27,00	5,50–7,00	—	0,018	0,025	Азот 0,10–0,20 53
34		21								

NOTES: 1. Chemical elements contained in the wire metal are denoted as follows: A--nitrogen (only in high-alloy wire); B--niobium; V--tungsten; G--manganese; D--copper; M--molybdenum; N--nickel; S--silicon; T--titanium: F--vanadium; Kh-chromium; Ts--zirconium; Yu--aluminum;

2. Letter A at the end of the arbitrary symbols of low-carbon and alloy wire grades indicates a higher metal purity relative to sulfur and phosphorus contents. In the wire grade Sv-08AA the double AA indicates lower contents of sulfur and phosphorus as compared to the wire grade Sv-08A.

NOTE: Commas in the figures mean decimal points.

1--wire grade acc. to GOST 2246-70; 2--chemical composition, % by mass; 3--carbon; 4--silicon; 5--manganese; 6--chromium; 7--nickel; 8--molybdenum; 9--titanium; 10--sulfur, no more than; 11--phosphorus, no more than; 12--other elements;

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13--low carbon wire; 14--Sv-08; 15--no more than 0.10; 16--Sv-08A; 17--Sv-08AA; 18--no more than 0.015; 19--no more than 0.030; 20--Sv-08GA; 21--Sv-10G2; 22--Sv-08GS; 23--Sv-08G2S; 24--Sv-10GN; 25--Sv-08GSMT; 26--Sv-15GSTYUTSA; 27--Sv-20GSTYUA; 28--Sv-10Kh5M; 29--Sv-10Kh11NVMF; 30--Sv-04Kh19N9; 31--Sv-08Kh19N9F2S2; 32--Sv-04Kh19N11M3; 33--Sv-07Kh25N13; 34--Sv-10Kh16N25AM6; 35--no more than 0.12; 36--no more than 0.06; 37--no more than 0.60; 38--alloy wire; 39--no more than 0.20; 40--no more than 0.25; 41--high alloy wire; 42--aluminum, no more than 0.01; 43--no more than 0.03; 45--aluminum 0.20-0.50; 46--zirconium 0.05-0.15; 47--cerium, no less than 0.4; 48--aluminum 0.20-0.50; 49--cerium 0.30-0.45; 50--0.25-0.50; 51--tungsten 1.00-1.40; 52--vanadium 1.80-2.40; 53--nitrogen 0.10-0.20

Consumable electrodes. Consumable electrodes will take bare steel wire of continuous cross section, bare powder wire (for automatic and semiautomatic submerged welding, gas shielded welding, unshielded welding, electroslag welding), or steel rods with special coverings as rod-type electrodes for manual metal-arc welding.

Welding wire of continuous cross section for welding steels is made to conform with GOST 2246-70 for "steel welding wire." The specifications regulate the diameters, technical requirements, markings and chemical compositions for 77 wire grades, including testing procedures and storage regulations.

All wire grades are classed into three groups: low-carbon (6 grades), alloyed (30 grades), and high-alloy (41 grades). The designation begins with letters Sv indicating that the wire is designed for welding. The next portion of the designation consists of commonly used digits identifying the alloying components in the steel and numbers indicating the approximate contents of these components.

Table 17 cites the compositions of some of the wire grades used in shipbuilding.

Sv-20GSYuT and Sv-15GSTYuTs welding wire grades are designed for metal-arc welding without additional shielding of the molten metal from the atmosphere. The former provides the weld metal with mechanical properties conforming to those of E50-type rod electrodes while the latter—to those of E42 electrodes (see Table 18 for electrode classification and properties). All other wire grades are used in various welding procedures with additional shielding of the weld from open air.

Electrodes for manual metal-arc welding are rods made from welding wire covered with a layer of a special material. The coverings are designed to enhance arcing stability, form combined gas-slag shields and promote alloying and refining of the metal.

The following materials are used for electrode coverings:

gas-forming--organic compounds (starch, meal, dextrin) and inorganic compounds (carbonate compounds--marble, magnesite);

alloying elements and deoxidizer-elements. silicon, manganese,, aluminum, titanium, etc. (alloys of these elements with iron--ferroalloys are commonly used).

ionizing compounds containing elements with low-ionization potentials: /162
potassium, sodium, calcium (feldspar, mica, granite, chalk);

slag-forming--ores (iron, manganese, titanium), minerals (feldspar, silica, granite, marble, etc.);

fluxing additions (fluxes)--fluorspan CaF_2, titanium dioxide TiO_2;

binders--aqueous solutions of sodium silicates--$n(Na_2O) \times m(SiO_2)$, potassium silicates--$n(K_2O)m(SiO_2)$ and liquid gases.

Many of the listed materials perform several functions at the same time.

The electrode covering technology involves the following operations:

The welding wire supplied in coils is cleaned, straightened, cut into rods with the use of special equipment. The constituents of the coverings are dried, quality-inspected, processed through rough and medium crushers, pulverized in ball mills and screened through sieves with a mesh number ranging from 80 per cm^2 (for ferroalloys) to $3000/cm^2$ (for powders).

This kind of pulverization affords high chemical reaction rates to form gases and slag and total completion of the process within the short electrode melting time.

The pulverized ferroalloys are put through a passivation* procedure.

The constituents are then mixed in given proportions and mixed again with liquid glass. The paste is applied to the rods by dipping (in manual production) or by special presses (specialized mass production). For the former case the viscosity of the paste is that of sour cream and for the latter case--that of modeling clay.

The covered electrodes are dried at normal temperatures for 20-48 hrs (or at 40-50° C for 2-4 hrs), and then fired for about 1/2 hr at 150-200° C for electrodes with organic compounds in the coverings and at 300-400° C for those without organic compounds.

The fired electrodes are sorted into batches, sampled for certification tests to conform with GOST 9466-60 specifications for "Electrodes for Metal-Arc Welding and Hard Facing of Steels."

*Passivation is explained in terms of formation of oxide films on the surface of ferroalloys to protect them from oxidation during the fabrication of electrodes.

The finished electrodes are packed in bundles weighing 3-8 kg each and wrapped in moistureproof paper. Each package is furnished with a plant certificate indicating the grade and designation of the electrodes as well as the technological, mechanical properties, and chemical composition of the weld metal*.

Electrode classification. Electrodes (Table 18) designed for manual arc welding are classed by /163

the material to be welded;
chemical composition of both the covering and the weld metal;
the mechanical properties of the weld metal.

Electrodes for welding constructional carbon and low-alloy and heat-resistant steels are made to conform with GOST 9467-60 specifications.

For carbon steels the classification is based on the mechanical properties of the weld metal; for the other steels--on both the chemical composition and mechanical properties that will be attained after a specific treatment.

Electrodes for constructional carbon and low-alloy steels come under electrode types identified as E34, E42, E42A and so forth up to E145. Letter E stands for "electrode;" the numbers indicate the minimum tensile strength of the weld metal (34 corresponds to 340 MPa, and so forth); the letter A indicates higher plasticity and notch toughness of the weld metal.

Electrodes for welding heat resistant steels are identified as EKhM, EKh2MFB and so forth. The letters and numbers following letter E indicate the chemical composition of the weld metal.

GOST 9467-60 specifies four types of coverings: organic, denoted by letter O; acid-ore--by R; rutile--by T and calcium-fluoride--by F. The coverings owe their names to the properties and constituents of covering base, which, in turn, determines the metallurgical properties.

Organic compounds form the base of organic coverings (40-50%).

Acid-ore coverings contain up to 33% manganese or iron ore: MnO_2--pyrolusite, Fe_2O_3--hematite. Some of them are supplemented with up to 37% of ilmenite (a titanium) concentrate that contains: about 38% TiO_2 and about 52% FeO; the balance represents admixtures. When heated, the ores give off some of the oxygen by oxidizing the metal. To combine this oxygen, P-type coverings are supplemented with ferromanganese (20-30%). Gas-shielding from the atmosphere is accomplished by the addition of organic compounds (5-9%).

*Specimens for property tests of the weld metal are taken from the 6th to 8th layer of weld metal which makes the sample virtually free of base metal.

The rutile covering base consists of rutile concentrate--pure titanium (about 45%) and ferromanganese (less than 10-15%). Gas shielding is achieved by the addition of carbonates (3-15%) and organic compounds (2-3%).

The base of calcium fluoride covering consists of $CaCO_3$ (about 50%) and fluorspar CaF_2 (about 20%).

Electrode coverings are rather thick and vary from 0.5 to 1.5 mm on each side. The covering weight amounts to 30-45% of the total rod weight*. /165

O, R, T, F coverings provide the weld metal with strength and plasticity conforming to E42 type and higher. Electrodes with F coverings will by and large yield weld metal of higher plasticity. These coverings have been used on most of the electrodes designed for welding heat resistant steels and on all electrodes for high-alloy steels.

E34-type electrodes have a thin chalk covering. The relative weight of such a covering is 3-5%. It offers almost no shielding from the atmosphere and is merely intended to enhance arcing stability (primarily ac current). Due to the low plasticity of the weld metal, inadequate arcing stability (compared to T and R electrodes using heavy coverings) and low welding efficiency, chalk-covered electrodes have not been used in shipbuilding. Electrodes with F, T, and R coverings are most commonly used.

One and the same electrode type may include electrodes with different coverings and different core compositions. Coverings of the same type may have different compositions. The specific compositions of both the covering and cores of a given electrode are shown in the trademark. Trademark designations, as a rule, contain the initial letters of the plant and a sequential number. Electrode markings are not regulated by standard specifications.

Thus, TsM-7-E42, 5, O-R type provides a complete electrode designation. TsM-7 denotes electrodes developed by TsNIITMASH, of version No 7 for low-carbon steel, E42 weld metal, 5mm, core diameter, R-type covering.

Electrodes for welding high-alloy steels with special properties must conform with GOST 10052-62 specifications. This standard covers 27 types of electrodes including 27 chromium-nickel and 5 chromium electrodes.

Electrode classification by type is based on the chemical composition and mechanical properties of the weld metal. Austenitic electrodes are designated by letters EA and numbers 1, 2, 3 and 4. Number 1 indicates

*An exception to the rule are electrodes with O coverings with a respective weight of 10-15%. Electrodes with thin coverings are most often used for weldings vertical and overhead seams and metal up to 2 mm in thickness.

Certain types and grades of electrodes commonly used in shipbuilding TABLE 18

1	2	3	4	5	6	7	8	9	
	Тип электрода	Механические характеристики наплавленного металла			Марка электрода	Вид покрытия	Марка проволоки	Область применения (сварка)	
		σв, МПа	δ5, %	KCV, МДж/м²					
		не менее							
10	Э34	[illegible]	[illegible]	[illegible]	--	Меловое	Ст3	Неответственные конструкции из Ст 3	55
11	Э42	420	18	[illegible]	21 ОМА-2	«О»	Св-08	Конструкции из [illegible] Ст. 3, Ст. 4 и т. п.	56
12	Э46	460	18	0,5	22 ОЗММ-5, ТМ-7, АНО-3*, АНО-4	«Ф»*	Св-08А	То же	57
13	Э42А	420	22	1,3	23 УОНИ 13/45	«Ф»	Св-08А, Св-08АА	» »	58
14	Э50А	500	20	1,0	24 УОНИ 13/55	«Ф»	Св-08А, Св-08АА	Конструкции из сталей Ст 3, Ст. 4, 09Г2, МК 35 и т. п.	59
15	ЭКh5МФ	570	14	[illegible]	25 ЦЛ-17	«Ф»	Св-10Х5М	Конструкционные стали 16ХСНД, 48КС и т. п.	60
16	ЭА1МА	[illegible]	25	[illegible]	27 ЭА-400/10У	«Ф»	Св-01Х19Н10М3	Стали Х5М, 12Х5МА, 15Х5МФА (при температуре эксплуатации сварных соединений до 450°С)	61
17	ЭА1Ф2	600	22	0,6	28 ЭА-606/11	«Ф»	Св-08Х19Н9Ф2С2	Нержавеющие хромоникелевые аустенитные стали 1Х18Н9Т, 1Х18Н12М2Т и т. п.	62
18	ЭА2В	600	21	0,7	29 ЦЛ-9	«Ф»	Св-07Х25Н13	Марганцевистые аустенитные стали 45Г17Ю, 10Г18Х18	63
19	ЭА3М6	600	20	[illegible]	30 ЭА-395/9	«Ф»	Св-10Х16Н25АМ6	Двухслойные котлы со стороны слоя стали 1Х18Н9Т, 0Х18Н10Т, 0Х17Н13М2Т	64
20	ЭFKh11MNFV	750	14	0,[illegible]	40 КТИ 10-62	«Ф»	Св-10ХМНВМФ	Стали 1Х18Н9Т, 1Х17Н13М2Т и т. п. с углеродистыми и низколегированными сталями	65
								Детали турбин из сталей 15Х12ВМФ, 15Х11МФ, 20Х1М1Ф1 (при температуре эксплуатации сварных соединений до 590°С)	

*Electrode covering contains 15% iron powder
**MJ/m^2 obviously means "megajoule per square meter"

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NOTE: Commas in figures mean decimal points

1--electrode types; 2--mechanical characteristics of weld metal; 3--tensile strength, MPa; 4--elongation, %; 5--impact strength, MJ/m^2**; 6--electrode marking; 7--covering type; 8--wire grade; 9--area of application; 10--E34; 11--E42; 12--E46; 13--E42A; 14--E50A; 15--EKh5MF; 16--EA1MA; 17--EA1F2; 18--EA2B; 19--EA3M6; 20--EFKh11MNFV; 21--OMA-2; 22--OMM-5, TsM-7; 23--ANO-3*, ANO4; 24--UONI-13/45; 25--UONI-13/55; 26--TsL-17; 27--EA-400/10U; 28--EA-606/11; 29--TsL-9; 30--EA-395/9; 40--

KTI-10-62; 41--chalk; 42--0; 43--R; 44--T; 45--F; 46--Sv-08; 47--Sv-08A; 48--Sv-08A; Sv-08AA; 49--Sv-10Kh5M; 50--Sv-04Kh19N11M3; 51--Sv-08Kh19N9F2S2; 52--Sv-07Kh25N13; 53--Sv-10Kh16N25AM6; 54--10Kh11NVMF; 55--noncritical structures from St.3 steel; 56--structures from steels St.3, St.4 and so forth; 57--same; 58--structures from steels St.3, St.4, 09G2, MK-35, etc.; 59--constructional steels 10KhSND, 48KG, etc.; 60--steels Kh5M, 12Kh5MA, 15KhMFA (at weld joint service temperatures up to 400°C); 61--stainless Cr-Ni austenitic steels 1Kh18N9T, 1Kh18N12M2T, etc.; 62--manganese austenitic steels 45G17Yu3, 40G17KhN2; 63--bimetal on the side of the layer of 1Kh78N9T, 0Kh13, 0kh12 steels; 64--1Kh18N10T, 1Kh17N13M2T steels, etc. with carbon and low-alloy steels; 65--turbine components from 15Kh12VMF, 15Kh11MFB steels (at weld joint service temperatures up to 580°C).

that the weld metal has the composition of Kh20N9; number 2 identifies the weld metal's composition as Kh25N13; number 3--Kh15N25, and number 4--Kh15N35. The presence of additional elements in the weld metal, is denoted by additional letters and numbers indicating the alloying elements and their contents. Type 1 and 2 are not pure austenitic /166
weld metals. They contain also 2-7% and 5-15% of the ferritic phase. A designation that ends with letter "a" denotes an electrode type with a lower content of the ferritic phase.

For example, TsT-16 electrodes corresponding to EA1V2Ba type yield Kh20N9-type weld metal that is additionally alloyed with about 2% tungsten and about 1% niobium and contains 2-7% of the ferrite phase.

Electrodes for welding ferritic chromium steels are marked with letters EF followed by letters and numbers indicating the composition of the weld metal.

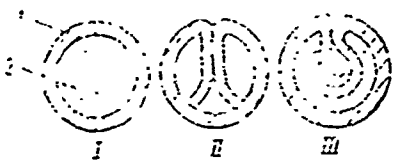

Fig. 78. Typical designs (versions I, II, and III) of powder wire (versions II and III--for high current welding, also provide better metal shielding from open air: 1--Sv-08 steel shell, 2--flux powder

Powder wire is a tubular wire with, sometimes, an intricate inner cross section filled with powder--flux (flux-cored wire) as shown in Fig. 78. The powder's composition conforms to that of F and Г coverings.

In addition to retaining the technological advantages of bare-wire welding, powder wire produces a gas and slag shield to protect the metal from open air, treats the metal with slag (metal refining) and yields a weld metal of high plasticity and ductility.

Wire grades cored with flux of composition T: PP-DSK-1, PVS-1 are designed for metal-arc welding without additional shielding from open air. They yield a weld metal corresponding to type E46-E50 (see Table 18).

The same category includes PP-AN2*, PP-AN3, EPS-15 grades of wire cored with F-type flux.

Wire grades designed for CO_2-shielded arc welding include: PP-AN5 (yielding E42-type weld metal) for low-carbon steels; PP-AN4, PP-AN9. etc. (yielding E50A-type weld metal) for low-carbon and low-alloy steels.

There are also powder wire grades designed for welding high-alloy steels and hard facing layers with special properties.

Fluxes for automatic metal-arc welding. Flux classification is based on purpose, chemical composition and production methods. The latter plays a major role in varying the composition of the flux. /167

Fluxes are produced in two forms: agglomerated (ceramic) and prefused. The production technology of ceramic fluxes is similar to that of electrode coverings. The constituents are mixed with liquid glass, pulverized, granulated, dried and fired. The composition of ceramic fluxes is close to that of F- or T-type coverings. Alloying these fluxes with metal is accomplished by the addition of ferroalloys.

Ceramic fluxes are not usable for welding of hull steels due to their low mechanical strength, strong dependence of weld metal composition on the welding cycle, and high costs. The major area of application is in welding special high-alloy steels and hard facing operations.

Prefused fluxes are alloys of metal salts and oxides. The production process consists of three stages: calculation and preparation of the mixture, melting and processing of the finished flux (granulation, drying, and screening).

The preground and weighed constituents are mixed and molten in arc or flame-contact (open-hearth-type) furnaces. The melt is held for the duration necessary to complete the reactions and then tapped at about 1400°C.

Granulation is done by either dry or wet methods. For the dry method the flux is poured into metal molds. On cooling the casting is crushed in roll mills to a coarseness of 0.1-3 mm and then sieved. Dry granulation is used for hygroscopic fluxes (with high contents of fluoride and chloride salts). These fluxes are intended primarily for welding aluminum and titanium alloys and high-alloy steels.

In the wet granulation method the molten flux is tapped from the furnace in a thin stream and channeled into a tank with running water. There the flux solidifies in the form of disconnected glass-like grains. The mass is dried at 250-350°C, crushed and passed through two sieves with 16 and 400 holes per cm^2. The residue on the second sieve is the

*PP-AN2--powder wire developed by the Electric Welding Institute Academy of Sciences USSR, version No 2.

finished flux. Ordinarily it appears as irregular grains varying from light-gray to red-brown or brown (according to composition).

Fluxes are stored and transported in steel drums, polyethylene bags or any other vacuum-tight containers.

The basic difference between a prefused and agglomerated flux is in that a prefused flux does not contain alloying component in pure form: they always oxidize in the process of melting. Alloying with prefused flux occurs through the reduction of elements from their oxides contained in the flux.

In practice prefused fluxes are used for alloying only with silicon and manganese (see Russian p. 182) and only for welding carbon and low-alloy steels. In all other cases alloying is performed through wire. /168

Classification of fluxes by chemical composition is based on the content of metal salts and oxides. There are 1) oxidizer-type manganese and silicon fluxes containing unstable oxides MnO and SiO_2, 2) nonoxidizer-type fluxes that contain almost none of these oxides, and 3) oxygen-free fluxes consisting of metal salts throughout.

The greater the amount of MnO and SiO_2 in the flux the greater its capacity of alloying with silicon and manganese and the higher its oxidation capacity for metals. The higher the alloying complexity of the steel the lower the requirements for MnO and SiO_2 contents in the flux. Should it occur otherwise, then the oxidation of alloying elements will exceed the acceptable limits. Additional alloying of metal with silicon and manganese may sometimes be undesirable.

The chemical activity of fluxes is closely related to the chemical composition of the metal and primarily of the wire. The selection of welding materials for submerged welding of one steel or another, therefore, includes concurrent selection of fluxes and wire. In this connection it is customary to use the term "flux-wire system."

Table 19 cites typical flux-wire systems and their uses in shipbuilding. Of the total number of flux grades listed only some are made to conform with GOST-9087-69 specifications (OSTs-45, FTs-9, AN-8, AN-348A).

45-OF-6, ANF-5 and ANF-8 must conform with technical specifications.

Shielding gases fall into two groups: chemically passive and active. Gases of the first group show no interaction with metals. Those of the second group either dissolve in the metal or chemically interact with it.

Chemically passive gases include argon, helium as well as nitrogen (when used for welding copper; nitrogen will neither dissolve in it nor react with it).

Certain flux grades commonly used in shipbuilding* TABLE 19

1 Тип флюса	2 Марка флюса	3 Состав флюса, % по массе										4 Марка проволоки	5 Область применения
		SiO_2	MnO	Al_2O_3	CaO	MgO	CaF_2	NaF	FeO	S	P		
									18 не более				
6 Высококремнистый высокомарганцовистый (сильнооксидительный)	11 ОСЦ-45	40	40	<5	<5,5	<2,5	8	—	2	0,15	0,15	19 Св-08А; 20 Св-08АА	Электродуговая сварка углеродистых и низколегированных сталей Ст. 3; Ст. 4; 09Г2; 10ХСНД и т. п.
	12 АН-348А	42	35	4,5	<6,5	6	5	—	2	0,15	0,12	20 То же	
	12a ФЦ-9	39	39	11	<6,5	<2,5	3	—	2	0,10	0,10	»	
7 Кремне-марганцовистый (окислительный)	13 АН-8	34	21	12	5	6	16	—	3,5	0,15	0,15	21 Св-08ГА; 22 Св-10Г2; 23 Св 10ГСМТ	Электрошлаковая сварка углеродистых и низколегированных сталей Ст. 3; Ст. 4; 09Г2; 10ХСНД и т. п.
5 Кремнистый безмарганцовистый (слабоокислительный)	14 АН-26	30	3	20	5	17	24	—	1,5	—	—	24 Св-04Х19Н9	Дуговая сварка сталей 1Х18Н9Т при умеренных требованиях к коррозионной стойкости сварных швов
9 Безмарганцовистый безкремнистый (неокислительный)	15 48-ОФ-6	<4	<0,3	24	18	3	52	—	1,5	0,05	0,04	25 Аустенитные хромоникелевые различных составов	Дуговая и электрошлаковая сварка хромоникелевых сталей различных составов (сварные конструкции работают в агрессивной жидкой среде или в газовой среде при высокой температуре)
	16 АНФ-6	<2	—	30	16	—	50	—	—	—	—		
10 Безкислородный	17 АНФ-5	<2	—	—	—	—	77	21	—	—	—	25 То же	То же

*Table cites mean values for constituent contents

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NOTE: Commas in figures mean decimal points

1--flux type; 2--flux grade; 3--flux composition, % by mass; 4--wire grade; 5--area of application; 6--high-silicon high-manganese (strong oxidizer-type): 7--silicon-manganese (oxidizer type); 9--manganese-free, silicon-free (nonoxidizer-type); 10--oxygen-free; 11--OSTs-45; 12--AN-348A; 12a--FTs-9; 13--AN-8; 14--AN-26; 15--48-OF-6; 16--ANF-8; 17--ANF-5; 18--no more than; 19--Sv-08A; 20--Sv-08AA; 21--Sv-08GA; 22--Sv-10G2; 23--Sv-10GSMT; 24--Sv-04Kh19N9; 25--austenitic Cr-Ni of various compositions; 26--electric metal-arc welding of carbon and low-alloy steels St.3; St.4; 09G2; 10KhSND, etc.; 27--electroslag welding of carbon and low-alloy steels St.3; St.4; 09G2; 10KhSND, etc.; 28--arc welding of 1Kh18N9T steel at moderate

requirements for corrosion resistance of weld joints; 29--arc and electroslag welding of Cr-Ni steels of various compositions (welded structures operated in a highly corrosive liquid or gas medium at high temperatures.
(end of legend)

CO_2 is a chemically active shielding gas and is used in shipbuilding.

Argon (gas, pure) is made to conform with GOST 10157-62 and comes in three grades: A, B, V. Their argon content is 99.99, 99.96, 99.90%, respectively; their impurities are oxygen, nitrogen, and moisture.

Argon is stored and transported in steel cylinders under a 15-MPa pressure.

Carbon dioxide is made to conform with GOST 8050-64. For welding purposes, "welding carbon dioxide" grades I and II are used. The grades differ merely in water vapor contents (0.178 and 0.515 H_2O per 1 cm^3 of CO_2)*.

Carbon dioxide is stored and transported in steel cylinders or high-capacity tanks in the liquid state. A 40-liter cylinder takes 25 kg CO_2 and yields, on evaporation, about 12m^3 of gas at 102 kPa pressure. /170

*An exception is sometimes made for food-type CO_2 containing free water in the cylinder.

PARAGRAPH 41. PROCESSING PROPERTIES OF WELDING MATERIALS

[Excerpt from Ch. 8--Metallurgical Processes in Welding. Welding Materials in "Svarka sudovykh konstruktsiy" (Welding of Ship Structures), a Russian book by G. A. Bel'chuk, K. M. Gatovskiy, V. A. Kokh and V. D. Matskevich, 1972, pp 184-187.]

The processing (technological) properties of welding materials have become a single concept to integrate a combination of properties including welding process stability, deposition and welding efficiency, the capacity of producing a weld joint of proper shape without inner defects (pores, hot and cold cracks), sanitary welding conditions and other related processing aspects. /184*

High processing properties can be achieved by combining specific compositions of welding materials (flux, gas, wire) with a specific type and polarity of welding current, welding cycle and electrodynamic properties of welding sets.

The stability of the arc welding process is governed by the composition of the welding materials, the type of current used and electrode current density. Manual welding electrodes (for low current density) with F-type fluorspar-containing coverings require the use of dc current. To reduce the amounts of hydrogen and nitrogen, reverse-polarity current is used. Electrodes with R-, T- and O-type coverings without fluoride compounds are used with ac current.

Submerged welding (shielded with fluoride flux) with high-density current electrodes requires the use of ac current. However, for cases involving highly basic fluxes, dcrp (direct current, reverse polarity) is used to minimize weld hydrogenation and to promote deeper fusion of the base metal.

As a rule, dcrp is used for gas-shielded consumable-electrode welding as well as for welding without additional shielding from open air. It appears to reduce molten metal sputtering and promotes welding process stability.

Fluxes with high fluorspar contents are conducive to stabilizing the electroslag (arc-free) welding process because they impart high electric conductivity to the molten metal and inhibit arc discharge. /185

The outer weld shape is governed primarily by slags. This shaping capacity of the slags is closely related to the physicochemical properties** of the slag and the metals. Acid (low-basicity) slags, rich in SiO_2 or TiO_2, seem to have the best shaping capacities. This includes slags produced by the fusion of OSTs-45 and AN-348A-grade fluxes and by T-type electrode coverings.

The effect of welding materials on the deposition efficiency is characterized by the deposition rate factor α_d. This value determines the welding efficiency for fillets and butt joints with grooving.

*Numbers in the margin indicate pagination in the foreign text.
**Metal ductility-to-slag ratio; changes in slag viscosity with temperature: interphase tension at the slag-metal boundary.

TABLE 22

Technological characteristics of welding materials for welding hull steels (based on reference data)

Welding method	Welding materials	Kind of current; dc polarity	Electrode diameter, mm	Welding current range, a	Deposition rate factor α_d, g/a·hr
Manual arc welding using heavily covered electrodes	Electrodes OMM-5; TsM-7; ANO-1; ANO-4	ac or dc; reverse polarity	3 - 6	90 - 300	7.5 - 8.5 10 - 11 12 - 14 8 - 8.3
	Electrodes UONI-13/45; UONI-13/55; TsL-9; EA-606/11	dc; reverse polarity	3 - 6	90 - 300	8.5 - 9.5 8.5 - 9.5 11.5 - 12.5 12 - 14
Automatic and semi-automatic submerged welding*	Fluxes AN-348A; OSTs-45	ac	2 3 - 6	200 - 650 300 - 1200	12 - 23 13 - 18
	Wires Sv-08; Sv-08A	dc; reverse polarity	2 - 3 4 - 6	200 - 650 300 - 1200	12 - 15.5 11 - 12
Automatic and semi-automatic CO_2-shielded welding	Wires Sv-08GS Sv-08G2S	dc; reverse polarity	0.8 1.2 1.6 - 2	50 - 130 120 - 380 200 - 500	10 - 12 12 - 16 14 - 20
	Wires PP-AN-4; PP-AN-5	dc; reverse polarity	2 - 2.5	300 - 650	15 - 20
Semiautomatic arc welding without additional shield-from open air	Wires PP-AN1; PP-AN3	dc; reverse polarity	2 - 2.5	200 - 500	12 - 17
	Wires Sv-15GSTYuTs; Sv-20GSTYu	dc; reverse polarity	1 - 2	80 - 300	12 - 16
Electroslag welding	Flux AN-8 Wire Sv-10G2	ac	3	300 - 800	22 - 30

* Effect of Mechanized Welding Conditions on the Deposition Rate Factor. See "Svarnyye soyedineniya v sudovykh konstruktsiyakh" (Weld Joints in Ship Structures), Leningrad, "Sudostroyeniye" Press, 1969, Table 23.

Table 22 cites the deposition rate factors for various welding materials as applied to shipbuilding specifications (current, dc polarity, welding current amperage). Iron powder (for example ANO-3 grade) is added to the electrode coverings in order to upgrade the deposition rate factor and the processing properties of the electrodes.

The efficiency of multipass welds depends much on the separability of the slag crust from the weld joint. Slag separability is related to the physicochemical properties of both the metal and the slag.* In welding steels, the slag separability is greater (and the efficiency higher) if the slag is free from metal oxides--the base of the weldable metal and amphoteric oxides Al_2O_3, Cr_2O_3, V_2O_3, etc.

The tendency of weld joints to pore formation and cold cracking depends largely on the hydrogen content in the weld puddle. This tendency diminishes with decreasing the hydrogen content in the metal. The tendency of weld joints to hot cracking is closely related to the presence of sulfur, phosphorus and carbon in the metal. A decrease in the contents of these elements raises the resistance of weld joints to hot cracking.**

*The most important properties are: the capacity of the solidifying slag to complete the building of the crystal lattice in the metal alloy leading to greater cohesion of the slag with the metal; the ratio of the linear expansion factors of the slag and the metal.

**Formation of pores and both hot and cold cracking are discussed in greater detail in Chs. 9 and 11.

PARAGRAPH 45. MECHANICAL PROPERTIES OF WELD JOINTS. METAL WELDABILITY

[Excerpt from Ch. 9--Structure and Mechanical Properties of Weld Joints in "Svarka sudovykh konstruktsiy" (Welding of Ship Structures), a Russian book by G. A. Bel'chuk, K. M. Gatovskiy, V. A. Kokh and V. D. Matskevich, 1972, pp 201-205]

A weld joint is understood to mean a particular location on a workpiece or an article where individual members have been fastened together by welding. The weld joint is formed from the weld metal, all heat-affected zones and the adjoining base metal on both sides of the joint. /201*

The mechanical properties of a weld joint are complex in nature. They depend not only on the properties of the metal of the individual zones but also on the relationship between the properties and the geometrical dimensions of the contacted section and, in general, are not governed unambiguously only by the properties of the "weak component."

The preceding chapters have demonstrated a variety of factors--determinants of the mechanical characteristics of the individual regions and zones. Below is discussed in brief the role of the relationships between properties and zones in shaping the mechanical properties of a weld joint as a whole.

In elastic-plastic stretching and bending of a weld along the seam, the latter's working capacity depends on the reserve of metal plasticity of each of the zones. The joint may show premature failure (compared to the base metal) if the limit plasticity value of either zone appears to be lower than the deformation of the component under stress at respective types of loading (static, impact). In this case the information on the mechanical properties is adequate to rate the working capacity of the weld joint.

In elastic-plastic stretching or bending across the seam having sections with different yield points, the performance conditions (state of stress) of the metal of the "soft" (with lower yield points) and "hard" (higher yield points) sections will differ from the performance conditions of components from the base (homogeneous) metal. The behavior of the metal under stress will change accordingly. The /202 mechanical properties of the metal will no longer reflect the working capacity of the weld joint.

At the very instant the "soft" zones reach their yield point, the contacting (on both sides) "hard" zones begin to inhibit the development

*Numbers in the margin indicate pagination in the original foreign text

of plastic deformation in the soft zone (lateral compression). This results in three-dimensional (triaxial) expansion at the zone boundary (in the "soft" zone), and produces two-dimensional compression and linear expansion in the metal on the side of the "hard" zone. Either type of stress may cover the entire interlayer if it is reasonably narrow. In consequence--the yield point of the "soft" zone metal will increase while that of the "hard" zone will decrease which will result in what is known as "contact hardening."* Owing to this effect, the tensile strength of the weld across the seam will appear greater than that of the "soft" interlayer metal; at the same time the risk of brittle failure along the "soft" interlayer metal will increase since such conditions are conducive to raising the transition temperature of the metal. This will not occur if the "soft" interlayer metal will have higher ductility.

In welding hull steels the objective is to produce welds with increased technological strength which requires the use of welding materials that will produce a built-up metal of higher ductility (in some cases permitting lower strength). In welding steels of higher tensile strength the uniformity of strength of both the joint and base metal is attained by virtue of contact hardening (Table 24).

In the overwhelming majority of cases the required properties of weld joints are reflected immediately after welding. Only in some cases recourse is made to heat treating following welding. The treatment is intended for refining the structure of the weld metal in the weld-affected zone, raising its ductility (normalizing), removing weld stresses, eliminating quench structures (tempering). Heat treating is conducted on certain electroslag-welded structures (normalizing) and weld joints of heat resistant and rapidly hardenable steels (tempering). /203

The working capacity of weld joints depends to a very large measure on the presence of defects, pores, and particularly cracks of any type. Weld joints with cracks are not acceptable.

The foregoing account in this chapter indicates the great number of various factors that have to be taken into consideration to obtain a high-quality weld joint.

The significance of the effect of the chemical composition and structure of the weldable metal on the resistance of the joints and heat-affected zones to both hot and cold cracking, softening, and

---

* This follows from Hoober-Meeses yield condition: σ_{eq} (equiv. tens. strength) $= \sqrt{1/2[(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2]}$ if the condition of linear expansion $\sigma_2 = \sigma_3 = 0$ is substituted with $\sigma_2 = \sigma_3 > 0$; $\sigma_1 > 0$ for the soft interlayer and with $\sigma_2 = \sigma_3 < 0$; $\sigma_1 > 0$ for the hard interlayer.

TABLE 24

Resistance to rupture of the weld metal and the joints (in MPa***) for 09G2, 10KhSND and 10GSND steels

1 Объем испытания	2 Способ сварки и сварочный материал					
	3 полуавтоматическая сварка в CO_2 проволокой Св-08Г2С		4 ручная сварка электродами УОНИ 13/45		5 автоматическая сварка под флюсом ОСЦ-45 проволокой Св-08А	
	09G2*	10KhSND	10GSND	10KhSND	10GSND	10khSND
6 Шов стыкового соединения	550	563	522	514	547	539
7 Стыковое соединение**	528	598	589	567	586	569

* Контактного упрочнения не наблюдается из-за невысокой прочности стали (разрушение соединений по основному металлу).
** Образцы со снятым валиком.

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*No contact hardening occurred due to the low strength of the steel (the joints failed along the base metal)
**Specimens with beads removed

***TRANSLATOR'S NOTE: "MPa" is obviously "meganewton per square meter"

1--scope of test; 2--welding method and material; 3--semiautomatic CO_2-shielded welding with Sv-08G2 wire; 4--manual welding with UONI 13/45 electrodes; 5--automatic submerged welding using OSTs-45 flux and Sv-08A wire; 6--weld metal strength; 7--butt weld strength

other undesirable phenomena that are bound to reduce the technological and service strength of weld joints requires evaluation of the so-called operative weldability.

Operative weldability is the capacity of producing a weld joint of a specific quality from a given material with the use of existing technical facilities at lowest cost.*

It has been firmly established that welding will produce high-quality joints using any metals and alloys and that attaining such welds is merely a matter of costs and technical problems.

*Aside from operative weldability, there is physical weldability--the capacity of materials to produce unseparable joints with an interatomic bond, i.e. by welding or brazing. Almost all metals and alloys, including many metal-nonmetal pairs, have this capacity.

Materials that can make high-quality welds without specialized equipment, additional expenditures for materials and labor (using conventional methods and existing equipment) are presumed to have good weldability. Materials that require specialized welding equipment, special techniques and subsequent heat treatments are considered to have limited weldability.

Weldability, however, is not an isolated property of a metal. The concept of weldability varies with changes in requirements on weld joints in the process of development of new welding methods. It /204 depends on advances in the science and technology of welding. Hence the evaluation of the weldability of one material or another is meaningful only when linked with the methods and conditions of welding equipment and technical specifications for the properties of the weld joint. Developments in the science of welding entail continuous changes in weldability ratings--poorly weldable materials are being reclassed as materials with good weldability, while some that had been rated earlier for good weldability are given unsatisfactory weldability ratings and are to be replaced with new materials on account of higher quality requirements on structures.

The weldability ratings are based on a variety of testing systems. Their form and content depends on the designation and service conditions of the weld joints in the structure.

The susceptibility of the weld metal to hot cracking is determined by special methods (including one developed by N. N. Prokhorov, another at the Leningrad Polytechnic Institute, another again at the Institute of Metallurgy, Academy of Sciences USSR, etc.)--through the deformation of the weld metal during overlaying or from changes in the specimen dimensions (i.e., from changes in specimen rigidity); in both cases, the tendency to hot cracking leads to changes in the deformations acting in the weld metal at the instant of crystallization.

The arbitrary measure of the weld metal resistance to hot cracking is either the maximum deformation at a given temperature cycle $T = f(t)$, or the specimen rigidity preceding the formation of hot cracks.

The methods for testing the tendency of a weld joint to cold cracking are equally numerous and are based on the simulation of the welding process under various cooling conditions in the heat-affected zone and on changes in the specimen dimensions (rigidity). For example, the bead-on-plate test developed by the Moscow Higher Technical School permits the study of changes in both the structure and mechanical properties of the metal during welding.

Noteworthy here is a complex test (adopted in shipbuilding) involving butt welding (along the long edges) of plates measuring 2000 x 500 x 20-25 mm. The samples are stiffened by the use of longitudinal and transverse ribs. The cooling conditions are varied by changing the

welding cycle and pre-cooling the plate down to 20-40°C below zero. The positive outcome of such rigid tests on the weld metal (i.e., the absence of any type of cracks in the the weld) is indicative that neither hot nor cold cracks would occur in welds on real structures. It should be noted, however, that such tests are cumbersome and rather costly which limits the use of these "large rigid samples."

All tests are fairly arbitrary and the number of test version may run very high; however, the use of even arbitrary test methods provides comparative characteristics enabling the rating of the /205 tendency of the weld metal and weld-affected zones to cracking for various types of electrodes, wire, flux, and various welding conditions and specifications.

PARAGRAPH 55. PRINCIPAL FACTORS HINDERING THE WELDABILITY OF AUSTENITIC AND FERRITIC STEELS

[Excerpt from Ch. 11--Technological Features of Welding Steels With Higher Ammounts of Alloying Components in "Svarka sudovykh konstruktsiy" (Welding of Ship Structures), a Russian book by G. A. Bel'chuk, K. M. Gatovskiy, V. A. Kokh and V. D. Matskevich, 1972, pp 247-250]

This group includes stainless, acid-resistant, heat-resistant, and refractory steels. Their chief alloying components are chromium, chromium in combination with nickel, as well as manganese. /247*

Aside from the principal alloying components, the steels are, in some cases, supplemented with relatively small amounts of other alloying additions. /248

According to their carbon contents, chromium steels may be classed as martensitic (e.g., 2Kh13; 1Kh12N2VMF, etc.), martensitic-ferritic (1Kh17, 1Kh13, etc.), and ferritic (0Kh13; 0Kh17 and others).

Chromium-nickel and manganese high-alloy steels are identified as austenitic steels (e.g., 1Kh18N9T; 0Kh23N18; 45G17Yu3 and others).

Martensitic and martensitic-ferritic chromium steels tend to harden at an extremely high rate; because of this, the procedures for welding and subsequent heat treatment follow the same specifications as for low-alloy hardenable steels discussed in paragraph 54.

Austenitic and, to a lesser extent, ferritic steels find applications in ship machinery (steam lines, turbine components, etc.). 1Kh18N9T chromium-nickel stainless steel is widely used as a cladding layer on ordinary hull steels (double-layer steels) to provide high resistance against the action of corrosive media (for example, sea water). In recent years, austenitic steels made with manganese and nitorgen (45G17Yu3, YuG17KhN2--as nonmagnetic materials and 30Kh10G10, 20Kh10G10AT--as cavitation resistant steels are finding ever increasing application.

Both ferritic and austenitic steels are single-phase materials. Because of this, grain enlargement of the base metal of these steels in the weld-affected zones cannot be remedied (unlike the pearlitic steels) by subsequent heat treating; the tendency of these steels to grain growth which is greater than in ferritic steels plays a major role in their weldability: the tendency to grain growth reduces the plasticity of the weld joints. This particular feature has contributed to the widespread use of austenitic chromium-nickel steels as a constructional corrosion-resistant material (despite the scarcity of nickel). In cases

*Numbers in the margin indicate pagination in the original text

where the corrosion-resistance requirements are less rigid, Cr-Ni austenitic steels are replaced to advantage by Cr-Mn and Cr-Mn-N steels. Discussed below are primarily the problems of welding Cr-Ni austenitic steels.

The most typical complication in welding austenitic stainless steels as well as ferritic steels is the risk of the loss of corrosion resistance in the weld-affected zone. A similar situation has been observed in some areas of these zones heated within 600-750°C (Fig. 113 a).

The loss of anticorrosion properties as a result of heating and adequate holding within the said temperature interval is caused by the precipitation of chromium carbides $(CrFe)_4C$, $Cr_{23}C_6$ (Fig. 113 b) along the grain boundaries. This may reduce the chromium content in the zones adjoining the grain boundary of the metal below 12%, i.e. the limit that ensures the metal's corrosion resistance. The predominant separation of chromium carbides along the grain boundaries is attributed to the low diffusion mobility of chromium; because of this, when moderately heated, its diffusion mobility is localized at the near- /249

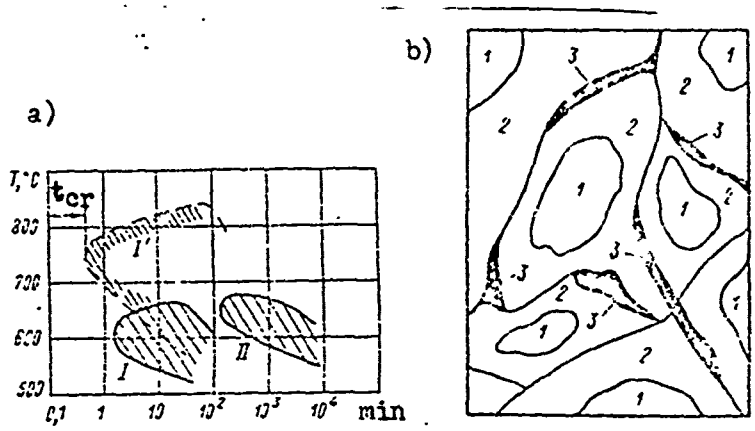

Fig. 113. Conditions for the loss of intergranular corrosion by the Cr-Ni austenitic steel: a--temperature-time curves; I and II--loss of resistance by 1Kh18N9 and 1Kh18N9T steels on heating in furnace; I'--the same for 1Kh18N9 steel on welding (according to data by N. Yu. Pal'chuk); b--nature of changes in grain composition. 1--central section with no changes in chemical composition; 2--boundary zone (lost chromium); 3--grain boundaries with carbide precipitations along them

boundary zones where the atomic packing density is at its lowest. It is not until heated above 850°C, that the diffusion rate increases to a point to bring chromium from the central areas to the boundaries. This takes place without losses of chromium in the zones adjoining the boundaries and without loss of anticorrosion properties (Fig. 113 a).

The contact of the metal with the liquid corrosive medium destroys the boundaries (what is known as intergranular corrosion) since the carbides and austenite have different electrochemical potentials. Due to its electrochemical nature, corrosion forms microgalvanic pairs (sections 1-3 being the cathode, section 2--the anode).

To increase the resistance of weld joints against the effect of heating within the critical temperature interval, the steel can be stabilized by alloying with strong carbide-forming elements (generally titanium or niobium). Heating the stabilized steel causes precipitation of titanium (or niobium) carbides which protects the solution /250 from chromium depletion. Stabilized steels are still subjected to some loss of corrosion resistance but to a lesser extent since the duration of their incubation period-- t_{cr} (see Fig. 113 a) is greater. These steels readily make high-quality welded structures and enjoy the highest number of uses.

Austenitic steel that has lost its resistance to intergranular corrosion during welding but had not been exposed to a corrosive medium can be remedied by the following heat treating procedures:

heating to 1000°C, holding to dissolve chromium carbides and followed by quenching of the metal in water; the procedure is difficult to apply to welded structures and is, therefore, rarely employed;

annealing at 850°C for two hours; this procedures is much simpler and is, therefore, most frequently used.

PARAGRAPH 60. WELDING TECHNOLOGY OF TITANIUM AND ITS ALLOYS

/Excerpt from Ch. 12--Characteristics of Welding on Nonferrous Metals and Their Alloys in "Svarka sudovykh konstruktsiy" (Welding of Ship Structures), a Russian book, by G. A. Bel'chuk, K. M. Gatovskiy, V. A. Xokh and V. D. Matskevich, 1972, pp 263-267/

Light, high-tensile and corrosion-resistant titanium alloys begin to find expanding applications in hull structures. With increasing production and decreasing costs, titanium will find a growing number of uses in shipbuilding. /263*

In terms of welding, titanium is characteristic for its very high chemical activity; to cite an example, when heated from 400°C and more rapidly from 600°C, the metal interacts actively with all gases, except for the inert ones; at melting temperatures titanium actively dissolves a number of gases including nitrogen, hydrogen, water vapors, carbon mono and dioxides, etc. and interacts with them. Yet, the presence of even small inclusions of these gases adversely affects the mechanical properties of the metal and, in particular, the plastic properties, a situation well observed in Fig. 118 which reflects changes in the properties of titanium as a function of O and N in it (in percent of initial properties).

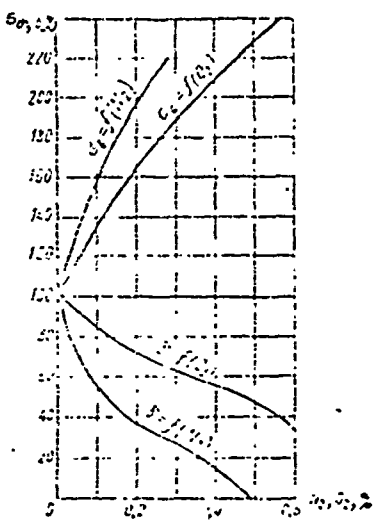

Fig. 118. Changes in the mechanical properties of titanium as a function of N and O contents

Quality titanium welds can be obtained only by limiting the content of detrimental impurities (N, O, C) that reduce metal plasticity and by providing reliable shielding of the weldpool, weld metal and heat-affected area (of all metal sections heated above 600°C) with inert gases (Ar, He) that will not interact with titanium. The maximum allowable contents of gases in titanium are generally set at the following values: 0.15% for O, 0.04% for N, and 0.01% for H.

In a number of cases, the suitability of titanium for welding can be prerated by the calculated HB hardness determined from the empirical formula

$$HB = 40 + 310\sqrt{O_e} \qquad 12.5$$

where O_e is the equivalent oxygen content.

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*Numbers in the margin indicate pagination in the original foreign text

This, in turn, is determined from the formula /264

$$O_e = O_2 + 2N_2 + \frac{2}{3} \cdot C, \%, \qquad 12.6$$

where O_2, N_2, C is the percentage of O, N, and C in titanium, respectively.

Titanium shows good weldability with an H content no greater than 0.01% and an HB hardness < 200.

Inert-gas arc welding of Ti and its alloys may be done with either nonconsumable or consumable tungsten electrodes. In welding titanium plates of medium thickness (up to 3-4 mm), ordinary nonconsumable argon-arc welders are used. Filler material is used only for thicknesses above 1.5 mm. The tentative welding specifications are given in Table 35.

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TABLE 35

Specifications for argon-arc welding recommended for titanium of medium thickness (based on reference data)

1 Толщина листов, мм	2 Диаметр, мм		5 Режим сварки		8 Подача аргона, л/мин	
	3 присадочного прутка	4 вольфрамового электрода	6 $I_{св}$, А	7 $v_{св}$, м/ч	9 через горелку	10 с обратной стороны шва
0,3—0,7	—	1,6	40	55	13—18	2,0—2,5
0,8—1,2	—	1,6	60—80	40—50	13—18	2,0—2,5
1,5—2,0	2,0—2,5	2,0	80—120	35—40	13—18	2,0—2,5
2,5—3,5	2,0—2,5	3,0	130—200	—	13—18	2,0—2,5

1--plate thickness, mm; 2--diameter, mm; 3--filler rod; 4--tungsten electrode; 5--welding specification; 6--I_w, a; 7--V_w, m/hr; 8--argon feed; 9--through burner; 10--through the back of the weld.

NOTE: Commas in the figures mean decimal points.

Straight polarity d-c current is used to promote deeper metal fusion penetration and to minimize contamination of the weld metal by the tungsten electrode waste.

Welding without filler material produces a weld joint with a strength equal to that of the base metal. Addition of filler material facilitates adsorption of the atmosphere's gas by the heated metal and reduces the plasticity of the weld metal by 40-50%.

Quality welds using either consumable or nonconsumable electrodes may be obtained by providing adequate shielding for both the weld metal and the weld-affected zone (heated above 600°C) on both the face and the back of the weld. In practice, this is accomplished by burners

equipped with special extensions for additional supply of the shielding gas to the back of the weld (Fig. 119). The extensions are 400-500 mm long. Argon and helium serve as the shielding gases.

/265

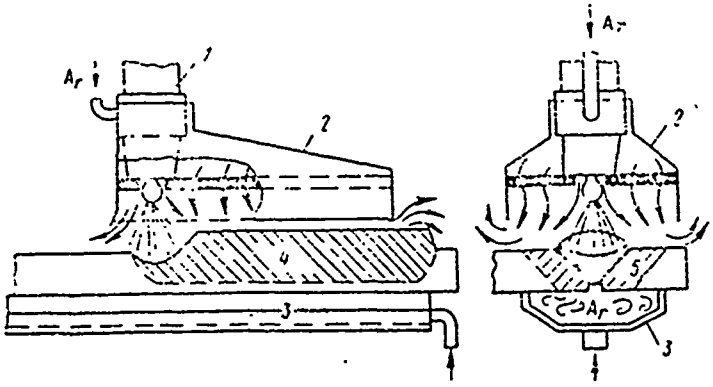

Fig. 119. Flow chart for welding titanium using an additional feed of argon: 1--burner; 2--extension for feeding additional argon; 3--tubular backing for feeding argon to the back of the weld; 4--weld joint; 5--heat-affected zone (above 350-600°C)

Table 36 cites welding specifications (recommended by V. S. Golovchenko) for consumable-electrode welding of Ti metal plate 4-36-mm thick. Under these conditions the metal is butt-welded with two passes; argon welding appears to produce much "narrower" seams, while helium forms "wider" seams, a phenomenon related to the physical properties of the shielding gases. Welding with helium requires a higher voltage which widens the seam while reducing somewhat the depth of fusion penetration (Fig. 120). The welder uses a-c current of reverse polarity.

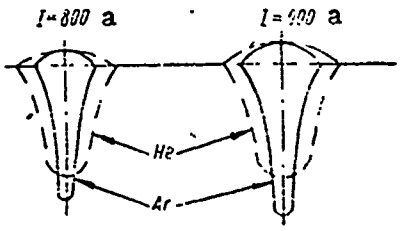

Fig. 120. Changes in the configuration of the cross sectional weld area in Ti welding as a function of adsorbed shielded gas (d_e = 4 mm; U = 30-34 v; V_w = 14-18 m/hr)

In this type of welding both the strength and other mechanical properties of the weld joint as a whole depend on the grades of titanium and filler wire and may be brought to match the respective characteristics of the parent metal. The automatic welding flow chart specifies modernized self-powered welding heads ADS-500M and ADS-100024; ASU-4M is specified for fillet welding. Semiautomatic (hand) welding is done with PGT-2*-type semiautomatic equipment. In modernizing the equipment, primary consideration is given to increasing /266

*V. S. Golovchenko. Semiautomatic Consumable-Electrode Gas-Shielded Welding. Avtomaticheskaya svarka, No 10, 1965.

TABLE 36

Specifications for consumable-electrode welding of Titanium and its alloys (according to data by V. S. Golovchenko)*

(1) Диаметр электрода, мм	(2) Сварочный ток, А	(3) Сварка аргоном					(4) Сварка в гелии				
		(5) Диапазон толщин свариваемых встык листов (без разделки кромок), мм	(6) Напряжение $U_д$, в	(7) Скорость сварки $V_{св}$, м/ч	(8) Вылет электрода, мм	(9) Расход аргона, л/мин	(5) Диапазон толщин свариваемых встык листов (без разделки кромок), мм	(6) Напряжение, $U_д$, в	(7) Скорость сварки $V_{св}$, м/ч	(8) Вылет электрода, мм	(9) Расход гелия, л/мин
0,6—0,8	150—250	4—8	22—24	30—40	10—14	20—30	4—6	28—32	30—40	10—14	30—40
1,0—1,2	250—320	5—10	24—26	30—40	17—20	25—35	4—8	32—36	30—40	17—20	35—45
1,6—2,0	310—420	8—12	30—34	20—25	20—25	35—45	5—10	38—40	20—25	20—25	70—90
3,0	480—750	14—34	32—34	18—22	30—35	40—50	10—28	42—48	18—22	30—35	80—100
4,0	680—980	16—36	32—36	16—18	35—40	50—60	12—32	46—50	16—18	40—50	100—120
5,0	780—1200	16—36	34—38	14—16	40—45	50—60	12—32	46—52	14—16	45—55	100—120

*Avtomaticheskaya svarka, No 8, 1967

NOTE: Commas in the figures mean decimal points

1--electrode diameter, mm; 2--welding current, a; 3--argon welding; 4--helium welding; 5--thickness range for plates to be butt welded (without grooving), mm; 6--voltage U_d, v; 7--welding speed V_w, m/hr; 8--extension, mm; 9--argon consumption, 1/min; 10--helium consumption, 1/min.

the feed rate of the filler wire (to 2500-3000 m/hr instead of the present rate of 500-600 m/hr) as well as to creating conditions for the adequate shielding of the metal during welding.

The welding heads are powered from PSG-500 and PSM-1000 welding sets with rigid performance curves cited in Ch. 5.

The Electric Welding Institute has developed procedures for automatic submerged welding and electroslag welding of titanium. The specifications include AN-T1 and AN-T2 oxygen-free fluxes with fluorides (CaF_2, NaF) and chlorides (KCl, NaCl) as the principal components. To preclude the entry of hydrogen into the metal, it is required that the moisture content of the flux is not to exceed 0.05%.

The submerged welding of titanium is performed with conventional equipment using direct current of reverse polarity. The process is economically effective for joining plates above 6-8 mm in thickness but may also be used for thinner plates. The back of the weld is shielded by gas or by an AN-T1 flux pad. The strength and plasticity of such weld joints are equal to that of the base metal.

Good results were also obtained by pressure contact welding of /267
titanium with the use of pulse machines (see Ch. 4) under specifications similar to those for welding stainless steels.

PARAGRAPH 62. WELDING TECHNOLOGY OF DISSIMILAR METALS

[Excerpt from Ch. 12--Characteristics of Welding of Nonferrous Metals and Their Alloys in "Svarka sudovykh konstruktsiy" (Welding of Ship Structures), a Russian book by G. A. Bel'chuk, K. M. Gatovskiy, V. A. Kokh and V. D. Matskevich, 1972, pp 268-274]

The problems of welding dissimilar metals, as a rule, stem from the marked differences in their physical, mechanical and physicochemical properties. These properties govern the interaction between one metal and another as well as between the metals and the newly formed phases. For example, the Fe-Al pair forms the compounds $FeAl_3$ and Fe_2Al_5 having a microhardness of the order of 8-9 GPa**; in welding 18-8 grade steels and aluminum the Al-Ni pair forms highly brittle intermetallides NiAl and Ni_3Al; the Al-Ti pair forms brittle phases of TiAl and $TiAl_3$ while the Fe-Ti pair forms brittle phases of FeTi and Fe_2Ti. The newly formed brittle phases are chemical compounds and differ markedly from the component-metals in all characteristics. /268*

In consideration of these aspects and other problems involved in welding dissimilar metals and their alloys, various investigators have stated that individual pairs can most successfully be welded by methods and techniques that will insure:

minimum contacting time of the weldable metals in the liquid state to reduce the dimensions of the brittle intermetallide layers as well as preclude their occurrence. This may be attained by preheating separately the electrode and the base metal;

reliable shielding of the metal during fuse welding against contaminants from the ambient air;

prevention of formation of brittle intermetallides by matching similar or combined (from various metals) fuse elements that will readily weld with each element of the weldable pair (for example, vanadium, beryllium bronze);

inhibition of the growth of intermetallide brittle phases by alloying the weld metal with certain components (Si, Ni, Zn, Ca).

The techniques most extensively used are fusion welding (argon metal-arc, compressed-arc, electron-beam) and pressure welding (diffusion, explosion, friction, cold and pressure contact welding).

*Numbers in the margin indicate pagination in the foreign text
**Translator's note: "GPa" obviously identifies "giganewton per square meter"

considerable grain growth on heating (inevitable with welding) and formation of brittle interlayers along the grain boundaries.

For zirconium alloys argon-arc welding appears to yield optimum results only when done in special helium-filled chambers. /268

TABLE 37

Specifications for argon-arc welding of niobium, tantalum and molybdenum (accord. to reference data)

1 Свариваемый металл	2 Толщина свариваемого металла, мм	3 Диаметр вольфрамового электрода, мм	4 Сварочный ток, А	5 Скорость сварки, м/ч	6 Расход газа, л/мин *
		9 Сварка в аргоне			
7 Ниобий	0,3	1,6	40	30,5	6/2
	0,5	1,6	60	30,5	7/2
8 Тантал	0,76	1,6	80	30,5	7/2
	0,3	1,6	45	30,5	6,2
	0,5	1,6	80	38,0	7,2
	0,76	1,6	100	38,0	7/2
	1,0	2,4	125	30,5	7/2
	1,3	2,4	150	30,5	7/2
	1,5	3,2	160	30,5	7/2
	2,0	3,2	180	30,5	7/2
		10 Сварка в гелии			
11 Молибден (сварка вольфрамовым электродом)	3,0	3,0	425	18	20/5
12 Молибден (сварка плавящимся электродом $d_э$ = 1,2 мм; $U_д$ = 32В; $v_{под}$ = 600 ÷ 900 м/ч)	13 свыше 3 (число проходов по толщине металла)	—	400—500	30—40	140/20

14 * Числитель — через горелку и приставку; в знаменателе — через подкладку с обратной стороны шва.

1--metal to be welded; 2--metal thickness, mm; 3--tungsten electrode diameter, mm; 4--welding current, amp; 5--welding speed, m/hr; 6--gas consumption, l/min; 7--Nb; 8--Ta; 9--welding in argon; 10--welding in helium; 11--Mo (tungsten electrode welding); 12--Mo (consumable electrode welding d_e = 1-2 mm; U_{arc} = 32 v; v_{feed} = 600-900 m/hr; 13--above 3 (number of passes over the metal thickness); 14--gas consumption: in the numerator--through the torch and extension; in the denominator--through the weld backing.

NOTE: Commas in the figures mean decimal points.

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PARAGRAPH 61. WELDING TECHNOLOGY OF ZIRCONIUM, NIOBIUM, TANTALUM AND MOLYBDENUM

[Excerpt from Ch. 12--Characteristics of Welding of Nonferrous Metals and Their Alloys in "Svarka sudovykh konstruktsiy" (Welding of Ship Structures), a Russian book by G. A. Bel'chuk, K. M. Gatovskiy, V. A. Kokh and V. D. Matskevich, 1972, pp 267-268]

Zirconium alloys meet the requirements for high corrosion resistance and service strength in the water compartments of nuclear reactors. Tantalum and niobium are materials that are especially resistant on exposure to most corrosive agents. /267*

Molybdenum which features a high melting point, high mechanical properties, and an equally high elastic modulus, is used in the form of plates of medium thickness for the individual components of combustion chambers in turbocompressors of jet engines.

In terms of welding, all these metals have a common feature--when heated, they react actively with all gases except for inert ones. Even small admixtures of these gases have a marked deteriorating effect on the plasticity of these metals (Fig. 121).

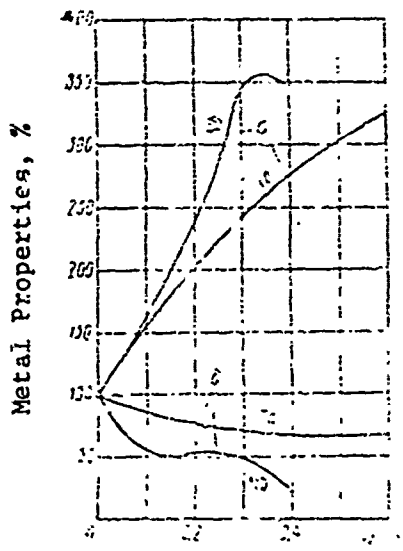

Fig. 121. Changes in the mechanical properties of Ta and Nb as a function of O content

The principal welding methods for these metals are, therefore, electron-beam, vacuum diffusion, and argon-arc welding in inert-gas atmosphere controlled chambers.

For plates up to 3-mm thick, the metals can also be tungsten-arc welded under conditions specified in Table 37.

Yet, with the strength of the weld metal being equal to that of the base metal, its plastic properties are usually somewhat lower due to possible weldpool contaminations with gases from the base metal as well as from impurities (O_2, N_2, H_2) contained in the inert gases. This is particularly pronounced in molybdenum because of the metal's tendency to

*Numbers in the margin indicate pagination in the original foreign text

Completion of a welding operation without the formation of a brittle phase sometimes presents problems since in real welded structures the contact areas are large and the contact per se does not occur simultaneously over the entire surface. Hence, based merely on the period of metal interaction and the objective to produce a brittle phase-free joint, it is possible under real conditions to obtain a joint with a "disruptive" contact, i.e., a contact in which bonds have formed only in isolated areas. The strength of such a joint is totally unsatisfactory and in some cases, involving the welding of large parts, the duration of contacting is such as to deliberately form a dense and uniform intermetallide layer and produce a reliable bond between the weldable metals though at much lower strength levels. All foregoing has been demonstrated in practical applications at the Leningrad Shipbuilding Institute (LKI). Proposed here, as a result, is a new method for welding aluminum and its alloys with steel; according to this method, the steel is pre-coated with a thin (30-40 microns) layer of aluminum, zinc or nickel.*

The following details the argon metal-arc welding technology developed by the Department of Welding LKI** for AMg5V, AMg6, and AMg61 aluminum alloys with steel. The alloys are widely used for superstructure sections including light partitions, bulkheads and some conduits. /269

The new procedure is applicable to all principal types of weld joints. The specifications for preparing the steel for welding includes double bevelling at 70° to the vertical to give the weld its maximum strength. The edges are thoroughly machined, sandblasted or chemically etched and coated. Shot blasting is ruled out on account of oxide inclusions that remain on the metal's surface.

For carbon- and low-alloy steels the procedure specifies zinc plating which costs much less and can be applied after machining either by electrodeposition or by the hot method. Austenitic steels (18-8 grades) are pre-coated with aluminum (aluminizing). The optimum (in terms of weld strength) aluminizing specifications are as follows: aluminum bath temperature, 750-800° C; holding time for aluminizing--1.5 min, according to the size of the part. Steel parts may be aluminized by the use of high-frequency current (as proposed by LKI).***

LKI studies have ruled out application of zinc or aluminum coats by spraying on account of the coat particles which may oxidize and hinder the execution of a satisfactory weld between the aluminum and the steel.

*See papers by G. A. Bel'chuk--Trudy LKI, No XIX, 1959.
**See papers by G. A. Bel'chuk in Trudy LKI, No XXXIV, 1961; "Svarochnoye proizvodstvo," No 5, 1961; "Svarochnoye proisvodstvo," No 11, 1963; "Avtomaticheskaya svarka," No 7, 1962.
***Trudy LKI, No XXXVI, 1962.

The specifications for equipment and materials include UDAR-300 and UDAR-500 or UDG-301 and UDG-501 welding sets; lanthanized tungsten electrodes of 2-5 mm in diameter; argon grades A and B to meet GOST 10157-62.

The specific feature of welding aluminum with steel (as compared with conventional procedures of argon metal-arc welding of aluminum alloys) is the positioning of the arc. At the beginning of the first seam the arc must be kept at the filler rod and then later--in the process of welding--at the filler rod and the bead (Fig. 122); otherwise a prolonged exposure to the arc heat will destroy the coating of the steel and hinder the welding process. After the initial portion of the bead has been made the arc must be restarted at the aluminum bead. The other version calls for guiding the arc along the edge of the aluminum part and guide the filler rod -- along the edge of the steel part in such a manner that the molten aluminum will flow onto the surface of the zinc-plated or aluminized steel.

The welding current is selected according to the thickness of the parts to be welded. /271

Thickness, mm	Welding Current, a
up to 3	110-130
6 to 8	130-160
9 to 10	180-200

Adherence to these specifications will ensure adequate preheating of the parts as well as the formation of an appropriate bonding interlayer.

AD-1 grade wire (consisting of pure aluminum with a small addition of silicon which is conducive to the formation of a stable diffusion interlayer) is specified as the filler material.

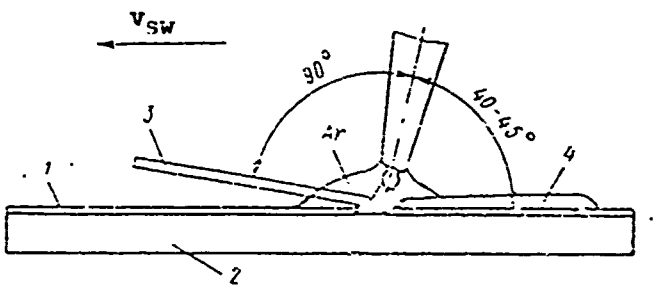

Fig. 122. Diagram for guiding the arc in welding aluminum with steel: 1--coating (aluminum; zinc); 2--steel; 3--filler rod; 4--bead

AMg6 filler material is not recommended since it impairs the weld strength. This is attributed to the magnesium constituent which participates in the formation of the intermetallide layer and impairs both the stability and strength of the interlayer.

The sequence of applying the beads is maintained according to the specific type of the weld joint, as shown in Fig. 123.

Strong emphasis is placed on the proper welding travel speed since it determines the interaction time of the liquid aluminum with the steel and governs both the thickness and stability of the bonding diffusion layer (Fig. 124). The initial layers are to be made at a welding rate (V_w) of 7 to 10 m/hr, while the subsequent layers (after the steel has been thoroughly heated)--at a V_w of 12 to 15 m/hr. Under those welding conditions the static tensile strength will conform to that of aluminum 100MPa*).

The weld strength is 30-40% higher (tensile strength = 130-180 MPa) if the steel has been aluminized (or coated with aluminum by high-frequency current instead of zinc plated). By and large the weld strength may be raised by increasing the effective cross section of the weld joint.

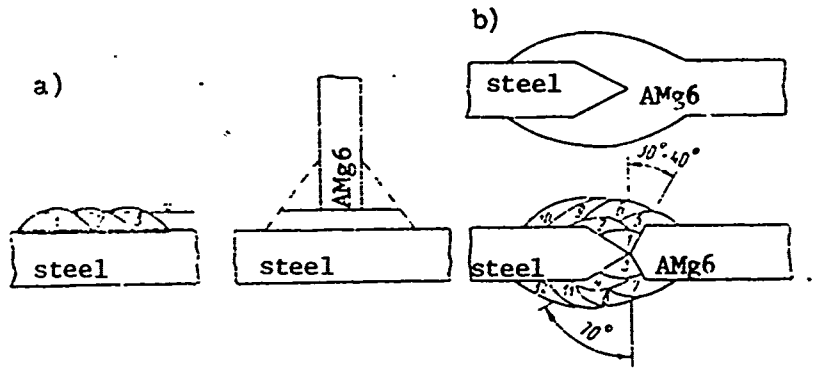

Fig. 123. Sequence of passing: a--on T joints; b--on butt welds

The welds produced in this manner are not only suitable for absorbing static loads but also have a high fatigue strength under alternating bending loads which is well evidenced by test data cited in Fig. 125.

Prolonged corrosion tests of weld joint specimens in synthetic sea water as well as in open air have failed to detect corrosion failures on weld joints coated with ALG, FL-03 and similar paints commonly used

*Translator's note: "MPa" obviously identifies "meganewton per square meter"

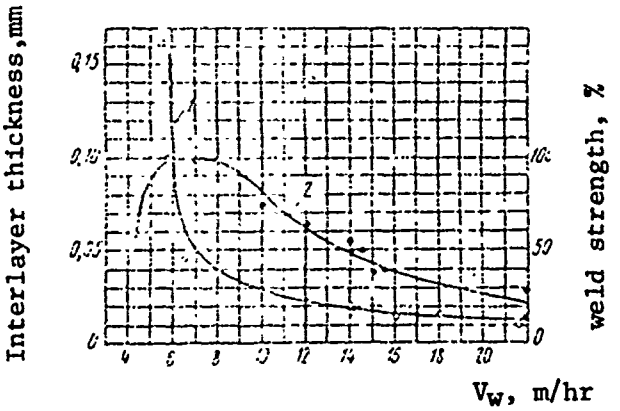

Fig. 124. The strength of the weld joint of aluminum with steel as a function of interlayer thickness. 1--interlayer thickness curve; 2--weld joint strength curve.

for aluminum alloys; on specimens of unpainted weld joints the corrosive effects were observed in the form of brown (on steel) and of white deposits (on aluminum). There were no corrosion failures in the weld specimens.

The favorable test results relative to corrosion resistance may be attributed to two factors:

zinc plating or aluminizing of steel that is required for the welding process appears to alter the steel's potential in a favorable manner so as to block the development of corrosion in the weld; /273

the protective paints produce an additional shield for the weld. The initial state of the weld surface is fully preserved under the prime coat.

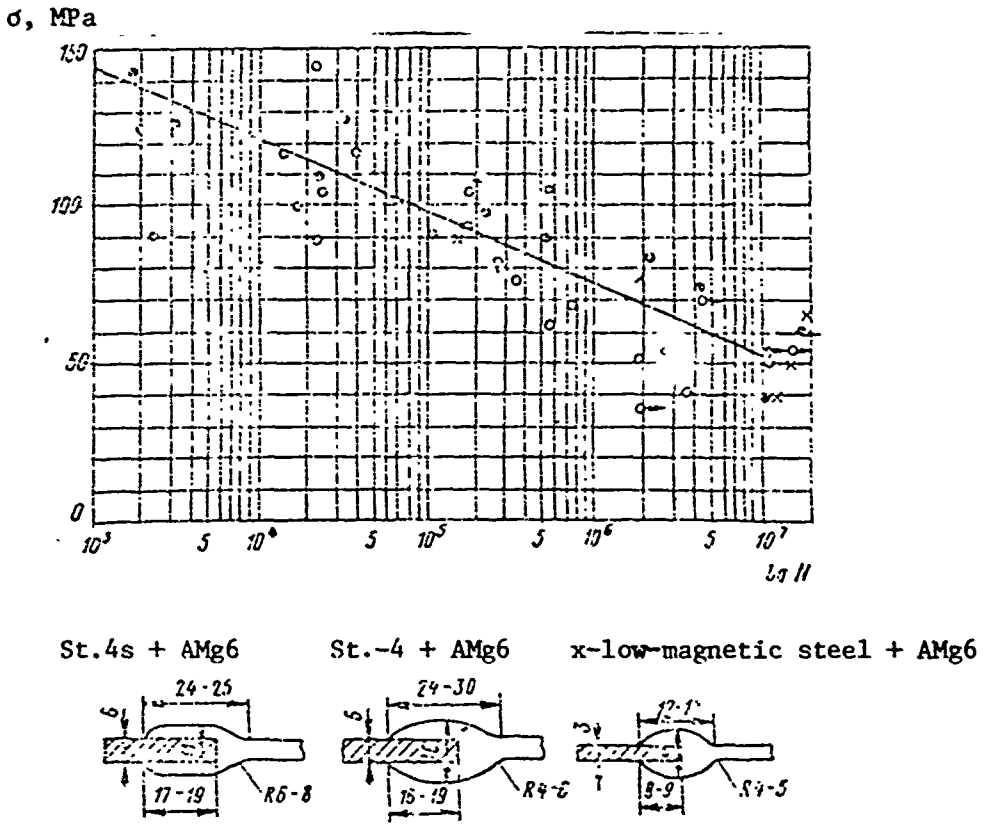

Fig. 125. Fatigue strength of weld joints of steel and AMg6 aluminum under alternating bending (r = -1)

Fig. 126 shows diagrams of aluminum alloy parts welded according to procedures developed at IKI.

Hard facing of steel with copper. The manufacture of sliding doors shutters, and other similar articles sometimes involves hard facing the steel with copper and its alloys. In the state of equilibrium at room temperature copper dissolves in α-Fe up to 0.3%, while iron dissolves in copper up to 0.2%. The interaction does not produce any brittle intermetallides.

The problems that arise in hard facing steel with copper are related /274
to the much lower melting temperature of copper than that of the steel, excessive absorption of gases by molten copper, linear expansion, etc. A major possible defect in hard facing is the formation of cracks (in the steel under the copper surface layer) which are filled with copper or its alloys; this is attributed to the wedge effect of liquid copper penetrating the microtears in the steel along the grain boundaries

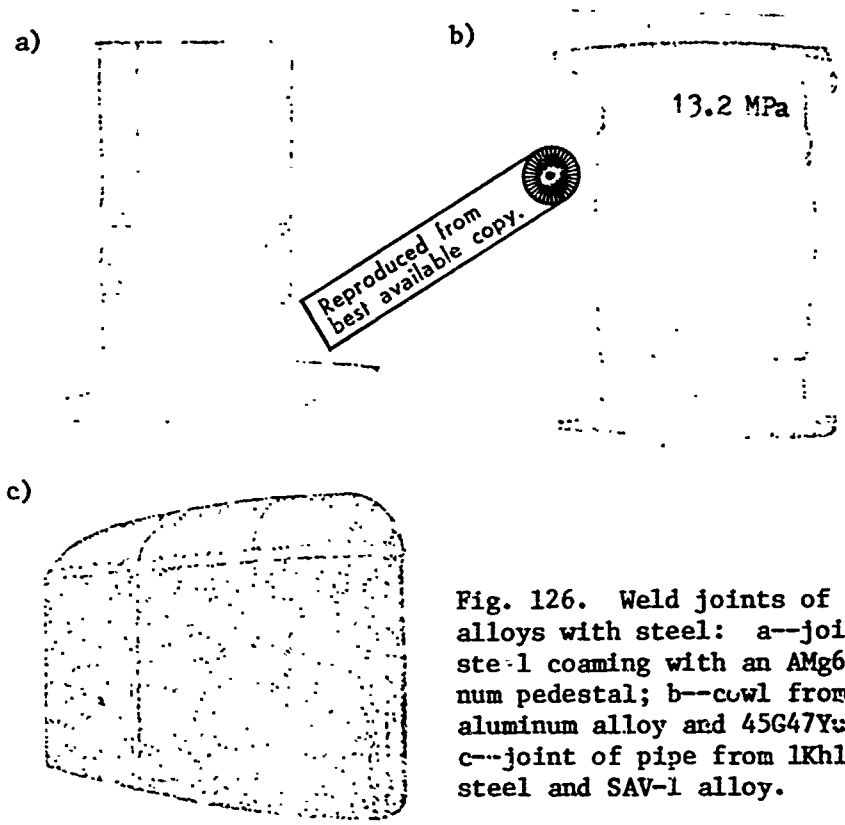

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Fig. 126. Weld joints of aluminum alloys with steel: a--joint of a steel coaming with an AMg6 aluminum pedestal; b--cowl from AMg6 aluminum alloy and 45G47Yu3 steel; c--joint of pipe from 1Kh18N9T steel and SAV-1 alloy.

as well as to the simultaneous effect of thermal tension stresses. Such cracks were observed primarily on austenitic steels and to a lesser extent on pearlistic steels.

The procedure for hard facing and welding copper, Br.AMts9-2 and Br.KMts3-1 bronzes, L90 brass with St.3, St.4, St.10 and 09G steels specifies the use of "Komsomolets"-type electrodes for manual welding,

Br.KMts3-1 grade filler wire for OS-Ts-45 flux-shielded welding,

and Br.KMts3-1, Br. AMts9-2, and MNZhKT5-1-02-02 grade filler wire for argon welding.