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ALLOYS FOR CRYOGENIC EQUIPMENT PARTS

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Abstract

Modern mechanical engineering widely uses steels and alloys which possess special properties, such as set conductivity, abnormally low resistivity at near absolute zero temperatures (superconductivity), semiconductor and magnetic properties, capacity to restore the form of an object, etc. Unusual properties of such materials are

conditioned by a certain ratio of alloy components, peculiarities of their chemical structure and structural condition of phases entering their composition, their production and processing technology.

Keywords: Constructional alloys; low-temperature steel brands; molybdenum alloying; phosphorus, sulphur; metastable austenite steels; austenite steels; high-alloy invars.

1. Introduction

Improvement of machines, mechanisms and devices necessitates development of materials with unique properties.

For example, advances in computer technologies, lasers, magneto hydrodynamic generators (MHD generators) initiated development of superconducting materials of a new type which have relatively high temperatures of normal-superconducting transition, sufficient raw materials sources, affordable production and processing technology.

Materials traditionally used in engineering such as semiconductor, high-resistance and magnetic materials as well as materials with specified thermal linear expansion coefficient are constantly improving. Non-traditional approach to metal and alloy processing enabled the development of high-speed crystallization methods.

2. Methods

Many technical appliances and constructions such as gas and oil pipelines, bridges, rails, motor vehicles, aircrafts, etc are subject to the impact of negative temperatures in the process of operation. In the Extreme North regions the temperature can reach −60°C. Hulls of planes and spacecrafts are cooled to the temperature of liquid oxygen (-183°C). Some units of refrigerating and cryogenic equipment operate at the liquid-helium temperature (-269°C).

At the negative temperatures metals lose plasticity and viscosity, show heightened liability to brittle fracture that is they become cold-brittle (cold brittleness is the increase of brittleness with the decrease of temperature). At low temperatures interatomic distances in lattices of metals reduce and the value $\sigma_{0.2}$ increases (up to the temperature 77K). Then the increase of $\sigma_{0,2}$ parameter slows down at the temperature close to the absolute zero, in many metals it becomes temperature-independent (Picture 1).

Metals are divided into four main groups according to cold resistance criterion:

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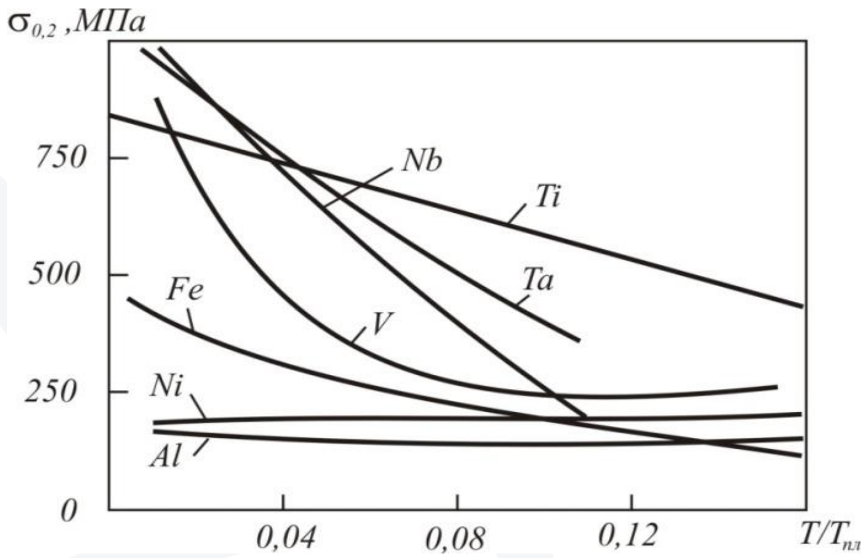
1. Metals and alloys used at the temperatures up to 210K. These materials are employed for production of so called "north" versions of goods. This group includes ferrite and pearlitic fine low-alloyed carbon steels with bcc lattice.
2. Materials preserving preset values of viscosity and plasticity at the temperatures up to 170K. These are the steels additionally alloyed with Ni, Cr, Ni, Mo as well as low-carbon ferrite steels with 2 – 5% Ni content.
3. Constructional alloys that can operate at the temperatures up to 77K (boiling temperature of liquid nitrogen). Here belong the steels 12X18H10T, 0H9A, alloys based on Al, Ti, Cu. The alloys Cr–Mn and Cr–Ni–Mn as well as steels of the brands 10X14Г14Н4Т (ЭИ711), 03Х13АГ19 (ЧС36), 07Х21Г7АН5 (ЭП222) are used for unstressed structures. Strength properties of such steels are given in the Table 1.



Picture 1. Dependence of metal yield point on testing temperature

Constructional alloys operating at the lowest (below 77K) temperatures. These are the materials used in space engineering, hydrogen production and consumption, in vacuum technology - high-alloy corrosion-resistant steels of the brands 03Х20Н16АГ6, 10Х11Н23Т3МР (ЭП33), some bronzes, magnesium-alloyed nickel and aluminium alloys, and titan alloys.

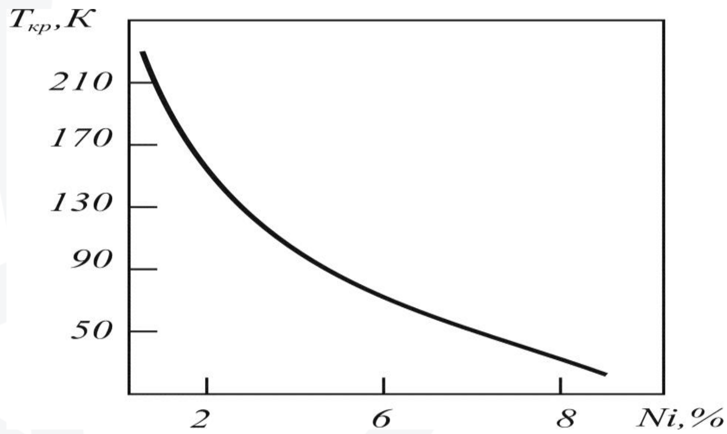
Table 1. Mechanical properties of 03Х13АГ19 steel flats at low temperatures

Specimen cut-off direction	T, K	$\sigma_в$, MPa	$\sigma_{0,2}$, MPa	δ, %	Ψ, %	KCU, J/sm²	KCV,J/sm²
Lengthwise	293	730	370	60	63	320	300
	195	1050	490	70	75	320	310
	77	1330	730	30	20	220	100
Crosswise	293	790	410	60	63	230	150
	195	1020	480	66	68	200	130
	77	1300	730	31	22	140	70

Low-temperature steel brands combine strength and high viscosity with plasticity; they have both low sensitivity to stress concentrators and low liability to brittle fracture. The steel brands 09Г2, 09Г2С, 09Г2СД, 16Г2АФ, 14Г2АФ, 14Г2САФ, etc belong to this group. The steels 14Г2АФ, 16Г2АФ, 14Г2САФ, 16Г2САФ are used for production of 1020 - 1420 mm gas pipes. Steels' viscosity grows when chromium content is up to 1%. Transition temperature rises when chromium concentration is more than 1,5% and lowers when steels are alloyed with nickel. Introduction of 1% nickel into an alloy reduces transition temperature by approximately 20K (Picture 2). Molybdenum alloying of steels up to 0.5% considerably lowers transition temperature too. Favourable influence of nickel on cold brittleness of steels is especially effective in combination with molybdenum.

Phosphorus, sulphur and gases dissolved in metal matrix such as oxygen, nitrogen and hydrogen unfavourably influence on cold brittleness of steels.

The number of sulphide inclusions which function as stress concentrators grows with the increase of sulphur content in an alloy. It reduces impact toughness at low temperatures. The increase of sulphur content by every 0,01% increase transition temperature by approximately 15K.



Picture 2. Nickel content influence on critical brittle temperature of low-carbon steel

Phosphorus causes embrittlement of steels due to heavy liquation and formation of stress concentrators such as phosphide eutectic. Embrittling influence of phosphorus grows with the increase of carbon content. The growth of phosphorus content by 0,01% for cast steel 35 Л increases critical brittle temperature by approximately 20K. Cargo bodies for the Extreme North are made of 03Г4АФ steel. After hardening and tempering it has mechanical properties and cold resistance similar to the properties of more expensive molybdenum steel 14Х2ГМ for north versions of pipe headers. In the USA and Canada high-strength weld steels Mn–Mo–Nb containing 1.6 – 2.2% Mn, 0.25 – 0.4% Mo, 0.04 – 0.10% Nb are used.

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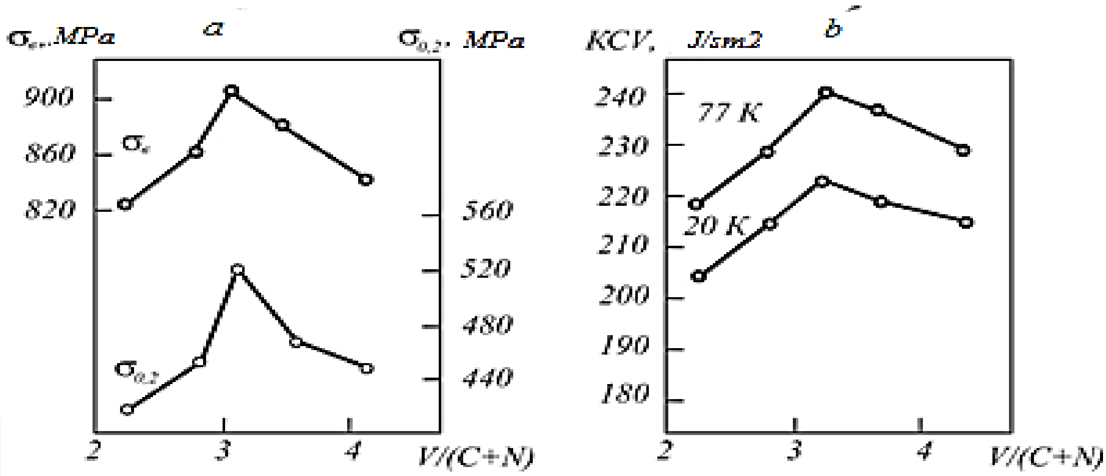
Metastable austenite steels containing not more than 0.06% C, 13-17% Cr, 8 – 10% Ni, 6 – 10% Mn have the optimal combination of plastic and tough properties at low temperatures. Fortification of these steels is achieved by the introduction of nitrogen which generates solid interstitial solutions. Alloying of steels with both nitrogen and vanadium with subsequent dispersion hardening increases yield point at room temperature (Picture 3).



Picture 3. Dependence of strength indicators (a) and impact toughness (b) of metastable austenite steels alloyed with nitrogen (N) and vanadium (V) on alloying elements ratio

3. Results and Discussion

Austenite steels alloyed with Cr, Ni and Mn are quite promising for application in cryogenics. Such steels include corrosion-resistant steel 10Х14Г14Н4Т economically alloyed with nickel which is satisfactorily processed with pressure and cutting, and have good welding characteristics. It can replace the steel 12Х18Н10Т at low temperatures by its mechanical properties and corrosion resistance in atmospheric conditions. The steel 10Х14Г14Н4Т is used for production of welded elements of vessels (rings, bottoms, flanges, branch pipes) and pipelines operating at the temperature range 77 – 773 К (-196 – 500°C).

Properties of steels used for production of pressure vessels are given in the Tables 2 and 3. High-strength maraging steels 03Х9К14Н6М3Д and 03Х14К14Н4М3Т combine high strength and hardness with sufficient plasticity and viscosity at low temperatures. They are used in cryogenics and space engineering as well as for production of thin-sheet structures operating up to 77K.

Table 2. Properties of materials used for production of pressurized cylinders in cryogenics

Material	$\sigma_в$, MPa	$\sigma_{0,2}$, MPa	δ,%		KCV, J/sm²		E, 10⁴ MPa	$\sigma_{0,2}$ / (γg), km
	Temperature, K							
	293	293	77	20	77	20		
AMn5	280	127	23	15			6,9	47
BT1-окт	470	400	48	24			10,7	89
12Х18Н10Т	529	23560	37	34	280	250	18,6	30
06Х15Н9Г8	650	260	50	42	247	224	20	33
06Х15Н9Г8АФ	900	500	46	36	240	221	20	64

Table 3. Properties of high-strength steels for pressurized cylinders

Steel grade	$\sigma_в$, MPa	$\sigma_{0,2}$, MPa	δ, %	KCV, J/sm²	Cylinder destruction pressure, MPa	Stress in a wall at destruction point, MPa
	Temperature, K					
	293	23	77	20		
12Х18Н10Т	660	260	37	32	300	280
06Х15Н9Г8АФ	900	500	46	46	242	220

4. Conclusion

High-alloy invars are used to produce units of cryogenics with stable sizes. They are used in rocket engine pipelines, some fittings of cryogenic devices operating at temperatures up to 20K.

Aluminium, titan and copper alloys are used in low-temperature equipment along with steels.

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