NPP STEAM GENERATORS

Materials. Mechanical engineering calculations of SGs

Lecture outline

1. Requirements for materials for NPP SGs.
2. Materials used in SG design.
3. Steels for water-cooled SG.
4. Steels for SGs with liquid metal coolant.
5. Steels for gas-cooled SGs.

Requirements for materials for NPP SGs.

- high mechanical properties (*durability, plasticity*)
- corrosion and erosion resistance
- good thermal physical properties (*thermal expansion, heat conductivity*)
- good manufacturing properties (*machinability, welding properties*)
- radiation stability

Definition of alloy steel

Steel is a alloy of iron and carbon.

Alloy steel is a steel which, apart from typical impurities, contains elements that are intentionally introduced in specified amounts to ensure the required physical and mechanical properties.

These elements are called alloying elements.

Definition of alloy steel

- By the degree of alloying we distinguish: low alloy (less than 3.5%); medium alloy (3.5…10%); high alloy (10-50%) steels.
- Symbols for alloying additives (Russian letters):
  - С- silicon;
  - В- tungsten;
  - Ф- vanadium;
  - Г- manganese;
  - М- molybdenum;
  - Н- nickel;
  - Х- chrome;
  - Ю- aluminium;
  - Т- titan;
  - Б- niobium, etc

General characteristics of alloying additives

Molybdenum (Mo) – increases strength of steel (at high temperatures) and corrosion resistance.

Chrome (Cr) – enhances corrosion and wear resistance of steel.

Nickel (Ni) – increases corrosion resistance of austenitic steels, increases yield strength of perlite steel.

Tungsten (W) – increases heat and wear resistance.

Vanadium (V) – increases durability under long-term usage.

Titanium (Ti) – increases strength, corrosion and heat resistance, enhances machinability.

Grading of alloy steels

2 initial figures – mean content of carbon in basis points (1/100th of 1%); 1 figure – in 1/10th of 1%).

No figures in the beginning of a grade - carbon content is equal to or more than 1%.

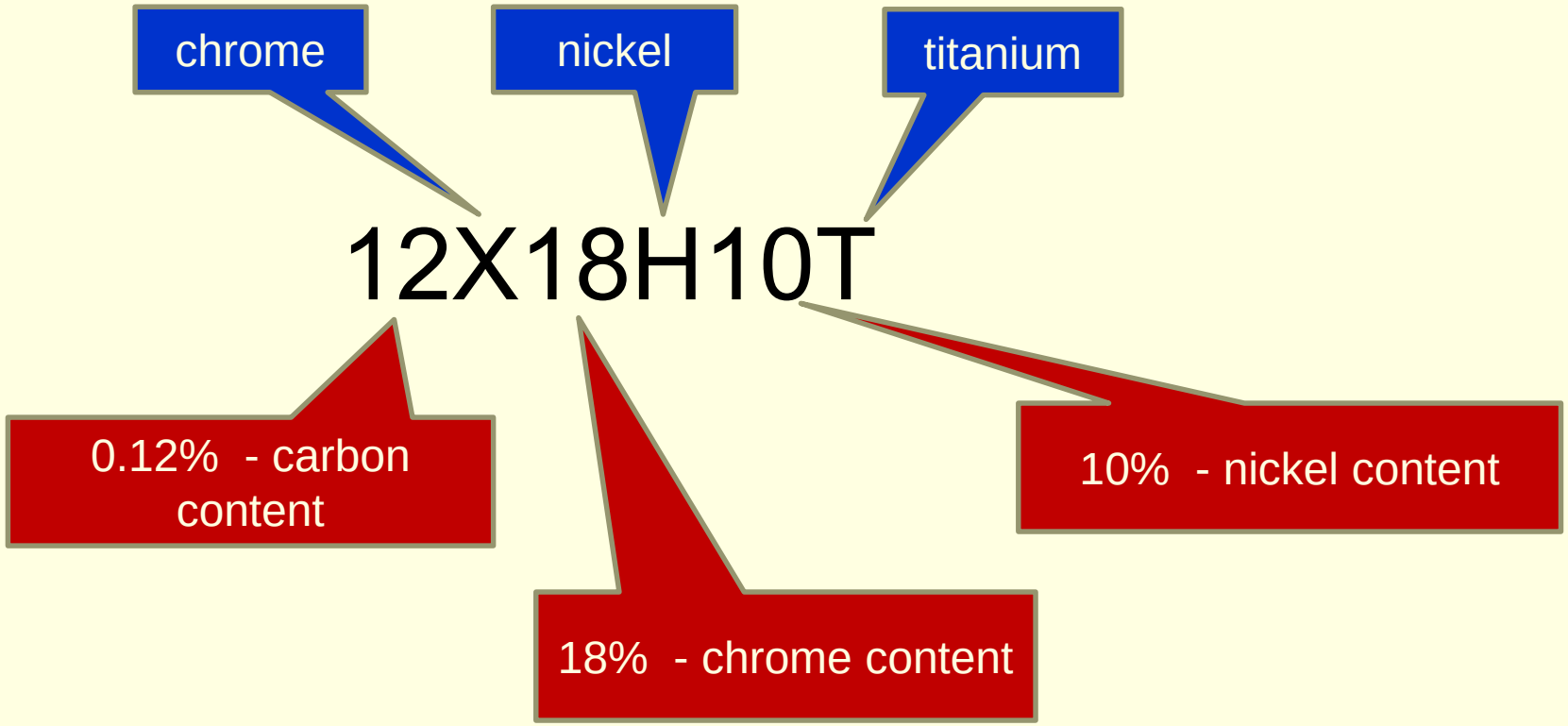
Russian letter – name of an alloying additive

Figure following the letter – mean content an alloying additive in percent.

No figure following the letter – content of alloying additive is less than 1…1.5 %.

Letter A (or AA) in the end of a grade – high-grade steel (without S and P)

Example of steel grade decoding



Material used for SG design

- Carbon steels (10; 20; 15К; 22К)
- Perlite low alloy steels (12Х2М; 2,25Cr1Mo; 16ГНМА; 12Х1МФ; 10ГН2МФА)
- Chromium steels (05Х12Н2М; 15Х11МФ)
- Austenitic stainless steels (08Х18Н10Т; Х18Н9Т; 316; 321).
- High-nickel alloys (inconel; incoloy)

Material used for SG design

10ГН2МФА

07Х25Н13

04Х20Н10Г2Б

08Х19Н10Г2Б

Chemical composition (%) of steels used for NPP SGs in Russia

	C	Si	Mn	Cr	Ni	Ti	S	P
08Х18Н10Т	<0.08	0.8	2	17-19	9-11	5C<0.7	<0.025	<0.035

	C	Si	Mn	Cr	Mo	V	Ni	P
12Х1МФ	0.08-0.15	0.17-0.37	0.4-0.7	0.9-0.12	0.25-0.35	0.15-0.35	<0.3	<0.025

	C	Cr	Cu	Mn	Mo	Ni	S	P
10ГН2МФА	<0.12	<0.3	<0.3	0.8-1.1	0.4-0.7	1.8-2.3	<0.02	<0.02

Chemical composition (%) of steels used for NPP SGs abroad

- Inconel (J-600): *Ni-72%; Cr-14..17%; Fe-6..10%.*
- Incoloy (J-800): *Ni- 32..35%; Cr- 21..23%; C- 0.3%; Mn- 1%; Ti- 0.35%.*
- 316, 321 – analogs of Russian austenitic stainless steels of X18H9 type

Application area of constructional materials in NPP SGs

Steel grade	Application area	Max operating temperature, ^{0}C
Carbon steels (10, 20, 15К, 22К)	Pipelines, vessels, headers, tubesheets	350
Perlite low alloy steels (2,25Cr1Mo, 16ГНМА, 12Х2М, 12Х1МФ, 10ГН2МФА)	Pipelines, vessels, headers, tubes	500
Chromium steels (15Х11МФ, 05Х12Н2М)	Pipelines, fittings	550
Austenitic stainless steels (08Х18Н10Т, Х18Н9Т)	Headers, tubes, separate nodes	700
High-nickel steels (inconel, incoloy)	Tubes	800

Mechanical characteristics of steels

Yield strength		**Предел текучести**
proof strength, proof stress		условный предел текучести при остаточной деформации 0,2%
Tensile strength		**Предел прочности**
long-term strength		предел длительной прочности
rupture strength		предел прочности на растяжение
eensile strength brake		временное сопротивление разрушению/ предел прочности

Characteristics of mechanical strength

- Yield strength - $\sigma^{t}_{0,2}$

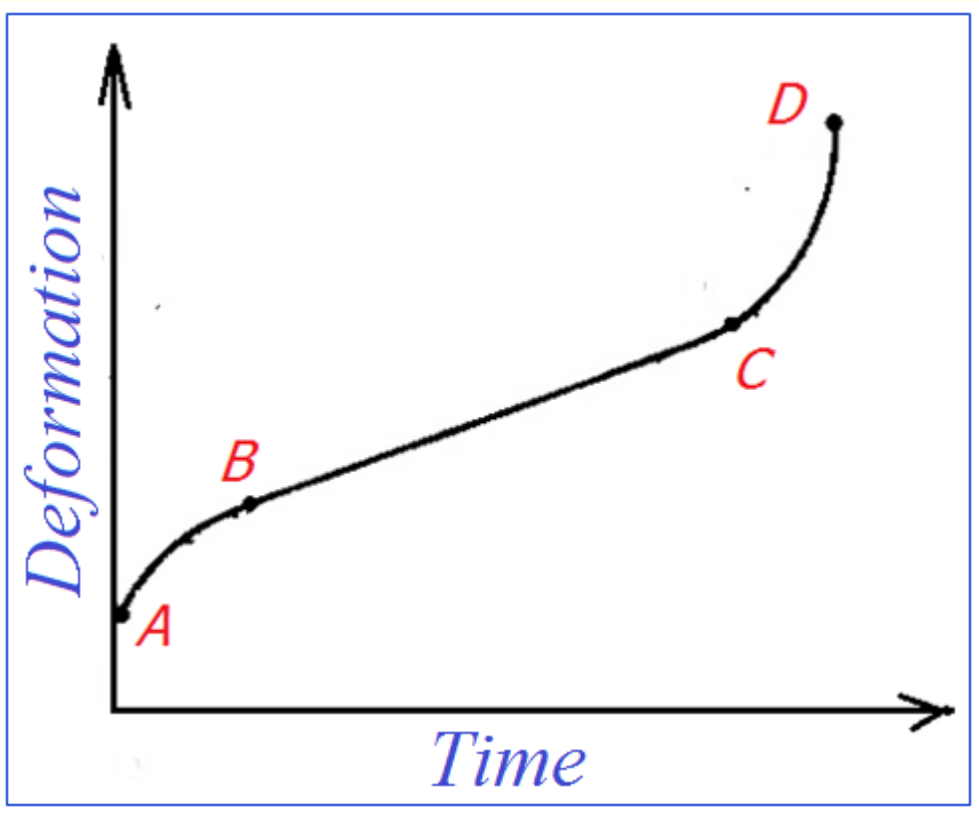
  Stress at which plastic deformation starts developing

  Conventional yield strength is a stress at which the residual (plastic) deformation is 0.2%.

- Tensile strength- σ^{t}_{B}

  - max stress that a material can undergo before it fails.

Creep curve and mechanical strength characteristics



AB – creep transition stage;

BC – settled creep stage (plastic deformation);

CD – failure stage

Mechanical characteristics of steels used in SG design

Grade	$\sigma_в^t$, MPa	$\sigma_{0,2}^t$, MPa
22К t=20…350 ºС	430…392	215…177
12Х1МФ t=20…500 ºС	390…323	195…137
05Х12Н2М t=20…550 ºС	539…352	372…245
08Х18Н10Т t=20…500 ºС	510…353	195…137
10ГН2МФА t=20 ºС	539	345

Physical characteristics of steels used in SG design

Grade	λ, W/(m·K)	ρ, kg/m³	α, 10^{-6}·1/ºC
22К t=20…350 ºC	51.7…42.7	7859…7736	11.5…14.4
12Х1МФ t=20…500 ºC	12.4…14.4	7800…7640	11.5…14.4
08Х18Н10Т t=20…500 ºC	16…19	7900	16.1…18.2
10ГН2МФА t=20 ºC	36…40	7850	11.2…11.6

Advantages and disadvantages of various steels

Perlite steels (12Х1МФ, 10ГН2МФА и др.) are cheap, with good manufacturing properties. Can be used up to 520 °C.

Low alloy perlite steels are characterized by 2…3 times higher heat conductivity as compared to chrome-nickel stainless steels.

Disadvantage of these steels is low corrosion resistance (general, pitting).

Perlite steels are prone to decarbonization in sodium and, as a result, to degradation of mechanical properties and durability at temperatures higher than 500…520 °C.

Advantages and disadvantages of various steels

Chromium steels (05X12H2M) possess all the advantages of perlite steels.

Their additional plus is high corrosion resistance. Although, their welding properties are low.

Advantages and disadvantages of various steels

Austenitic steels (X18H9 and X18H10T) are easily manufactured, have high general corrosion resistance, are not susceptible to corrosive cracking under stress.

To prevent intercrystallite corrosion, stabilizing additives are introduced (for example, Ti).

Disadvantages of austenitic steels are low heat conductivity and thermal expansion coefficient, which results in increased temperature stresses.

Advantages and disadvantages of austenitic stainless steels (e.g. X18H10T)

Advantages

1. Good mechanical properties
2. High corrosion resistance (with regard to general corrosion).
3. Quite good erosion resistance.
4. Relatively good welding properties

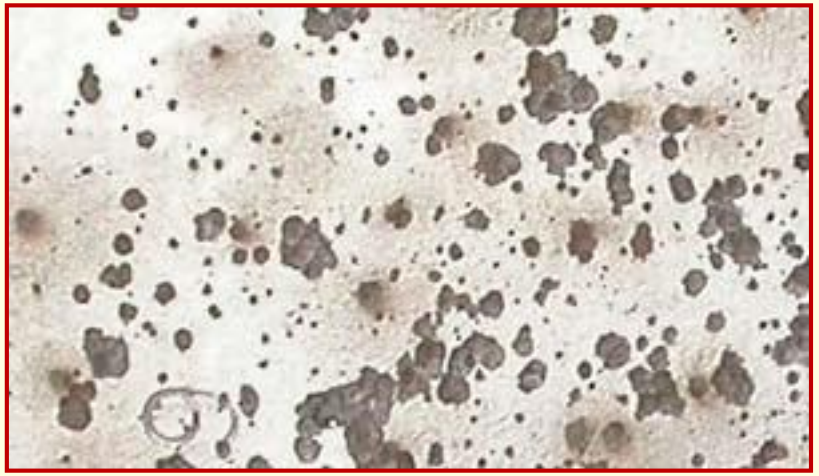
Disadvantages

1. Cost
2. Low heat conductivity
3. Susceptibility to specific corrosion

Specific corrosion of austenitic stainless steels

SG part with corrosive cracking

SG part with pit corrosion



Technical and engineering aspects of material selection

The cost of steels of various grades differs greatly. The cost ratio of carbon, perlite alloy, and austenitic steels is about 1:2.5:10 respectively.

Materials for water-cooled SGs

Significant requirement is general corrosion resistance in water.

Materials for water-cooled SGs

Corrosion products in coolant flow can be the reason of:

- impaired heat transfer of heating elements under the conditions of corrosion products deposits;
- worsened radioactivity conditions of the whole circuit;
- obstructions in channels decreasing the coolant flowrate;
- corrosion initiation when contacting with some materials

Materials for water-cooled SGs

The speed of general uniform surface corrosion of a primary circuit material must not be more than 0.01 mm/year.

Low alloy perlite steels can provide for the specified corrosion resistance in primary circuit water at reactor's power operation (pH is about 10).

It is difficult to ensure these conditions in standby mode.

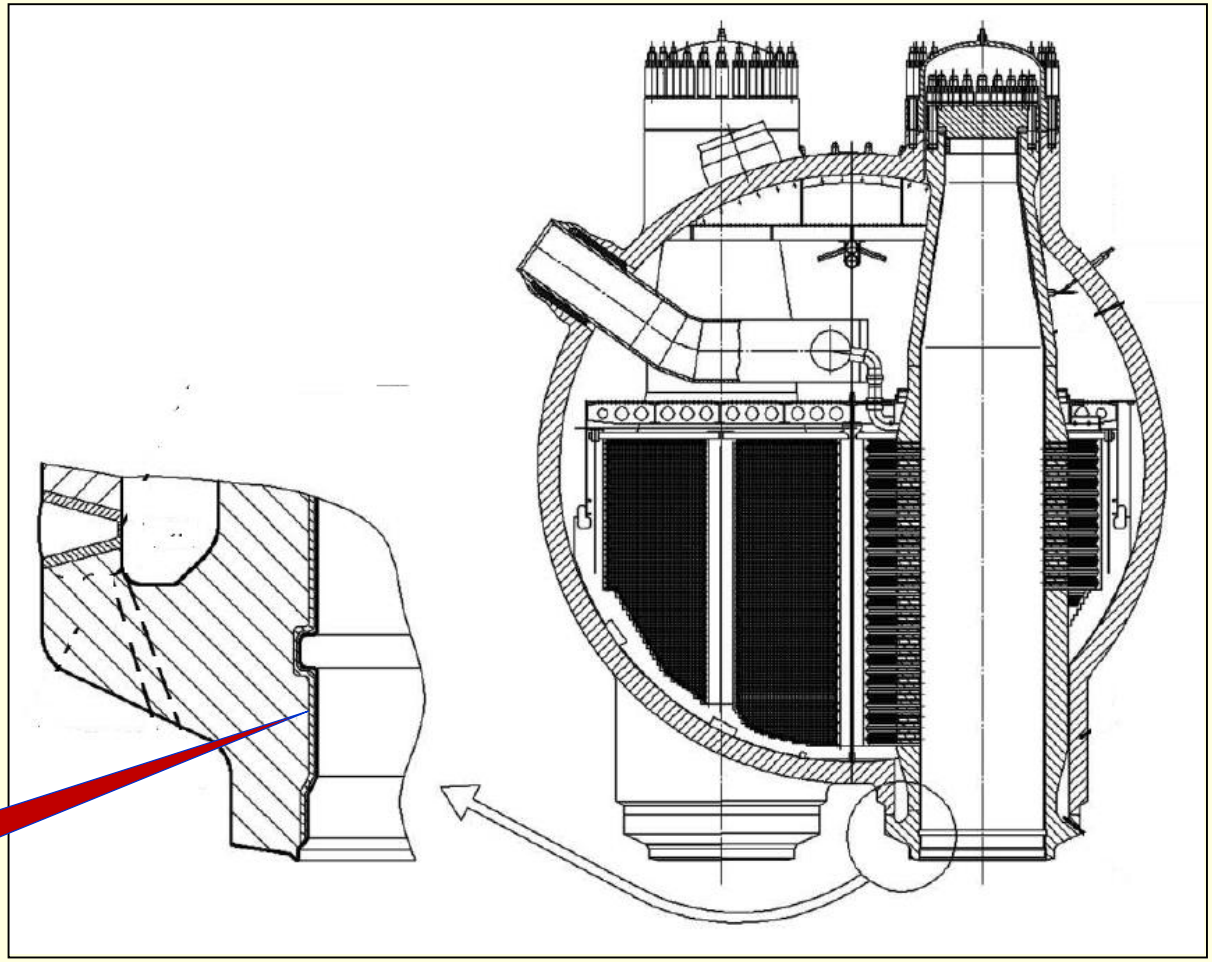
Materials for water-cooled SGs

Decreased corrosion resistance as well as some other parameters require application of corrosion resistant steels.

Currently, high-strength heat-resistant perlite steel 10ГН2МФА is used for outer shell and collectors of WWER SGs.

The inner surface of headers is coated with anticorrosion cladding (07Х25Н13 – first layer; 04Х20Н10Г2Б or 08Х19Н10Г2Б – second layer)

SG of WWER-1000 NPP



Cladding

Materials for water-cooled SGs

Among all the NPP components that are not in the reactor, the tube system of a SG functions in the most strict operating conditions.

Tubes are exposed to two-side corrosive impact of aggressive mediums of various composition in the conditions of heat flux and thermal stresses.

Materials for water-cooled SGs

Austenitic stainless steel 08X18H10T is used for the production of heat-exchange tubes.

Long-term operation of NPPs in Russia proves the possibility of using such tubes in PGV-440 and PGV-1000M SGs provided the secondary water purity is maintained according to the specified standards.

Materials for SGs with liquid metal coolants

Vessel components (including tubesheets): 10Х2М (in future high-chromium steels 07Х12НМФБ);

Tubes 1Х2М, Х18Н9

Thank you for attention