Research of Properties of Cast Austenitic Steels for Low-temperature Equipment

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\textbf{Abstract.} This paper considers the possibility of using Cr-Ni, Cr-Ni-Mn and Cr-Mn cast metastable austenitic steels with alloying systems of the grades 12Cr18Ni10TiL, 10Cr14Mn14Ni4TiL and 10Cr14NMn20L for the manufacture of complex-shaped parts for use in equipment operated at low temperatures. The results of tests to assess the characteristics of strength, ductility and toughness of austenitic steels in the cast state in the temperature range from plus 20 to minus 196 °C are presented. The obtained data allow us to estimate the change in the values of the mechanical properties of cast austenite steels with decreasing test temperature. Based on the analysis of the results obtained, recommendations were given on the use of austenitic steels in a cast state for low-temperature equipment at various operating temperatures. It is shown that metastable austenitic steel 10Cr14NMn20, in comparison with other studied steels, despite relatively low values of plasticity, has higher values of strength and toughness at minus 196 °C and can be recommended for the manufacture of cast parts of low-temperature equipment.

1. \textbf{Introduction}

Materials used for the manufacture of low-temperature equipment in the manufacture and operation must ensure their reliable operation during the design life, taking into account the specified operating conditions (design pressure, minimum negative and maximum design temperature), the composition and nature of the environment (corrosion activity, explosion hazard, toxicity, etc.), the influence of ambient temperature [1-4].

Given the unique properties of austenitic steels in a wide temperature range [5-10], it is possible to use them, for example, for shut-off valves in equipment for the transportation of liquefied natural gases. During operation, the valve body works in difficult conditions. Continuous passage of cryogenic liquids under pressure creates static loading. At the same time, short-term dynamic loading is possible under transient conditions or hydraulic shock. Therefore, the materials that are used for the manufacture of reinforcement should be required both for technological properties and for the values of the characteristics of strength, ductility, toughness, especially at low temperatures [11-15].

2. \textbf{The Purpose of the Work}

Evaluation of the possibility of using austenitic steels of various alloying systems for the manufacture of cast parts of low-temperature equipment.
3. The Method of the Experiment

The work carried out tests to assess the mechanical properties of austenitic steels in the cast state under static loading in a wide temperature range. Austenitic steels of various alloying systems traditionally used in low-temperature engineering are investigated. From the group of Cr-Ni – steel 12Cr18Ni10Ti, from Cr-Ni-Mn – steel 10Cr14Mn14Ni4Ti and from Cr-Mn – steel 10Cr14NMn20, additionally alloyed with nitrogen. The chemical composition of the studied materials is shown in Table 1.

Table 1. Chemical composition of the investigated steels.

| Grade of steel   | Content of elements, [%] |
|------------------|--------------------------|
|                  | C  | Mn  | Si  | P  | S  | Cr | Ni | Cu | Ti | N  |
| 12Cr18Ni10TiL   | 0.11 | 1.3 | 0.65 | 0.035 | 0.020 | 18.9 | 10.2 | 0.21 | 0.30 | -  |
| 10Cr14Mn14Ni4TiL| 0.10 | 14.9 | 0.76 | 0.020 | 0.019 | 14.6 | 4.6  | -   | 0.23 | -  |
| 10Cr14NMn20L    | 0.10 | 20.3 | 0.50 | 0.012 | 0.011 | 14.8 | -   | -   | -   | 0.30|

All steels were smelted by open method in an induction steel furnace with the main magnesite crucible with a capacity of 150 kg. When smelting chromium-manganese steel for the introduction of nitrogen as an alloying additive, nitrided ferrochrome containing about 6% nitrogen was used. The estimated number of nitrided ferrochromium were given to the melt for 20 minutes before casting. Steel poured into a cast iron ingot moulds and casting threefourthree samples in accordance with [16, 17].

Ingots after Stripping and Stripping were forged into square and round billets. The forging temperature of Cr-Ni steel was 1050-1250 °C, Cr-Ni-Mn and Cr-Mn – 1000-1250 °C.

The obtained billets for the austenitic structure were subjected to heat treatment consisting of austenitization with 1050-1100 °C cooling in water for steel 12Cr18Ni10TiL and 10Cr14Mn14Ni4TiL and austenitization with 900-950 °C for steel 10Cr14NMn20L. Tensile tests were carried out in accordance with [18], impact bending – taking into account [19]. Samples for testing were made in accordance with [20-22].

4. Results

The results of static tensile tests of cylindrical specimens are shown in Table 2.

Table 2. Influence of low temperatures on the strength characteristics of the investigated steels.

| Grade of steel   | The values of strength, [MPa], at the temperature of test, [°C] |
|------------------|---------------------------------------------------------------|
|                  | Г₀     | Г₀₂     | Г₀₅     | Г₀₁₂    | Г₀₅₂    | Г₀₁₀    | Г₀₃₂    | Г₀₆₀    | Г₀₁₀₂     |
|                  | 20     | -50     | -100    | -196    |
| 12Cr18Ni10TiL   | 360    | 160     | 590     | 180     | 710     | 205     | 820     | 295     |
| 10Cr14Mn14Ni4TiL| 580    | 220     | 760     | 230     | 840     | 240     | 910     | 320     |
| 10Cr14NMn20L    | 620    | 420     | 910     | 505     | 980     | 600     | 1180    | 820     |

As follows from the results, the decrease in temperature leads to an increase in the values of both the time resistance and the yield strength of the steels studied. The values of the strength characteristics chromomagnetic steel with nitrogen 10Cr14NMn20 exceed the same values for 10Cr14Mn14Ni4TiL and 12Cr18Ni10Ti steels at all temperatures tests.

The plasticity of steels was evaluated by the characteristic of the relative contraction in the fracture zone, since it is considered that this characteristic provides more complete information about the behavior of the material, especially when the temperature decreases. The results of evaluation of plasticity of the studied steels are given in Table 3.
Table 3. Influence of low temperatures on the values of the relative narrowing of the studied steels.

| Grade of steel   | Steel grade values of relative narrowing $\psi$, [%] at test temperature, [°C] |
|------------------|--------------------------------------------------|
|                  | 20  | -50 | -100 | -196 |
| 12Cr18Ni10TiL    | 49  | 39  | 33   | 16   |
| 10Cr14Mn14Ni4TiL | 45  | 42  | 28   | 19   |
| 10Cr14NMn20L     | 31  | 28  | 21   | 12   |

When the test temperature decreases, the values of the relative contraction of steels in the cast state are significantly reduced. The values of plasticity for steel 12Cr18Ni10Ti and 10Cr14Mn14Ni4TiL are at a higher level than for steel 10Cr14NMn20. For all tested steels in the cast state, a decrease in the test temperature below -100 °C leads to a sharp drop in ductility.

Taking into account the possible dynamic effects during the operation of low-temperature equipment fittings, impact bending tests were carried out for all the steels studied. The results of tests of samples with a sharp incision are shown in Table 4.

Table 4. Influence of low temperatures on the impact strength of the steels studied.

| Grade of steel   | Steel grade Impact strength KCV, [J/cm²] at test temperature, [°C] |
|------------------|--------------------------------------------------|
|                  | 20   | -50  | -100 | -196 |
| 12Cr18Ni10TiL    | 195  | 134  | 96   | 56   |
| 10Cr14Mn14Ni4TiL | 240  | 152  | 142  | 57   |
| 10Cr14NMn20L     | 260  | 224  | 210  | 72   |

The analysis of the obtained results shows that all investigated steels are characterized by a drop in toughness with a decrease in the test temperature. Comparison of the results with the data for steels in the deformed state [1, 2] shows a significant decrease in the values of toughness for the cast state. At the same time, for all the materials studied, the impact viscosity value is at the level of the required value of 50 J/cm², which ensures the operation of the equipment at low temperatures.

The results of the studies have shown that under shock loading at low temperatures all investigated steels have sufficient viscosity reserve, despite the low values of plasticity. It is likely that the high rate of deformation prevents or completely suppresses phase transformations in steels. In addition, the nature of the dynamic destruction of austenitic steels is significantly influenced by the local heating of the material in the plastically deformed zone.

It is shown that, despite the lower values of plasticity (see table. 3), 10Cr14NMn20L steel provides higher values of strength characteristics (see table. 2) and impact strength (see table. 4).

5. Conclusion

Thus, the results allowed us to conclude that for the manufacture of cast parts of low-temperature equipment operating to temperatures -196 °C, 10Cr14NMn20L steel can be recommended. The possibility of using steels at lower temperatures requires additional testing.

6. References

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