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Study of welding of high-alloy austenitic steels and alloys

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ABSTRACT: This article provides a study of the features of welding technology for high-alloy austenitic steels and alloys

KEY WORDS: welding, steel, technology, austenite, structure, heat resistance

I. INTRODUCTION

Existing austenitic high-alloy steels and alloys are distinguished by the content of the main alloying elements - chromium and nickel and by the composition of the alloy base. High-alloy austenitic steels are considered to be iron-based alloys alloyed with various elements in amounts up to 55%, in which the content of the main alloying elements - chromium and nickel - is usually not higher than 15 and 7%, respectively. Austenitic alloys include iron-nickel alloys with an iron and nickel content of more than 65% with a nickel to iron ratio of 1:1.5 and nickel alloys with a nickel content of at least 55%.

Austenitic steels and alloys are classified according to the alloying system, structural class, properties and service purpose. High-alloy steels and alloys are the most important materials, widely used in chemical, petroleum, power engineering and other industries for the manufacture of structures operating in a wide temperature range. Due to their high mechanical properties at subzero temperatures, high-alloy steels and alloys are used in a number of cases as cold-resistant steels. The appropriate selection of alloying elements determines the properties and main service purpose of these steels and alloys.

II. LITERATURE SURVEY

A characteristic feature of corrosion-resistant steels is their low carbon content (no more than 0.12%). With appropriate alloying and heat treatment, steels have high corrosion resistance at 20°C and elevated temperatures both in a gas environment and in aqueous solutions of acids, alkalis and liquid metal media. [1-2]

Heat-resistant steels and alloys have high mechanical properties at elevated temperatures and the ability to withstand heating loads for a long time. To impart these properties, steels and alloys are alloyed with strengthening elements - molybdenum and tungsten (up to 7% each). An important alloying additive introduced into some steels and alloys is boron, which promotes grain refinement. [3]

Heat-resistant steels and alloys are resistant to chemical destruction of the surface in gas environments at temperatures up to 1100-1150°C. They are usually used for lightly loaded parts (heating elements, furnace fittings, gas pipeline systems, etc.). The high scale resistance of these steels and alloys is achieved by alloying with aluminum (up to 2.5%) and silicon,



which contribute to the creation of strong and dense oxides on the surface of parts that protect the metal from contact with the gaseous environment.

According to the alloying system, austenitic steels are divided into two main types: chromium-nickel and chromium-manganese. There are also chromium-nickel-molybdenum and chromium-nickel-manganese steels. [4]

Depending on the basic structure obtained by cooling in air, the following classes of austenitic steels are distinguished: austenitic-martensitic, austenitic-ferritic, austenitic. [5-6].

III. METODOLOGY

Alloys based on iron-nickel (with a nickel content of more than 30%) and nickel bases are stably austenitic in structure and do not have structural transformations when cooled in air.

After appropriate heat treatment, high-alloy steels and alloys have high strength and plastic properties. Unlike carbon steels, these steels acquire increased plastic properties when hardened. The structures of high-alloy steels are varied and depend not only on their composition, but also on heat treatment modes, the degree of plastic deformation and other factors.

Iron-chromium-nickel alloys immediately after solidification have solid solutions of the α and γ types and a heterogeneous region of mixed $\alpha + \gamma$ solid solutions. The stability of austenite is determined by the proximity of the composition to the boundary of the α - and γ -regions. Instability can manifest itself when heated to moderate temperatures and subsequent cooling, when the austenitic structure fixed by rapid cooling partially transforms into martensitic. An increase in the nickel content in these alloys contributes to a decrease in temperature $\gamma \rightarrow \alpha$ (M) - transformation

In addition, the instability of austenitic steels can be caused by the release of carbides from the solid solution when the temperature changes, accompanied by a change in the concentration of carbon and chromium. This causes a disruption of the equilibrium state and the transformation of austenite into ferrite and martensite mainly along the grain boundaries, where the greatest depletion of chromium and carbon in the solid solution is observed. In the ternary system of iron-chromium-manganese alloys, after solidification, a continuous series of solid solutions with a γ -lattice is formed, and during further cooling, various allotropic transformations occur, depending on the composition of the alloy.

Manganese is a γ -band expanding element and in this respect is similar to nickel. With sufficient concentrations of manganese (>15%) and chromium (<15%), steel can have a single-phase austenitic structure.

During the crystallization of chromium-nickel steels, crystals of chromium-nickel ferrite, which has a δ -iron lattice, first begin to fall out of the melt. As it cools, crystals of chromium-nickel austenite having a γ -iron lattice are formed in the δ -ferrite, and the steel acquires an austenitic structure. Carbon in austenitic-ferritic and austenitic steels at temperatures above the SE line is in solid solution and in the form of interstitial phases.

Slow cooling of steel below the SE line leads to the release of carbon from the solid solution in the form of a chemical compound - chromium carbides of the $Cr_{23}C_6$ type, located mainly along the grain boundaries. Further cooling below the SK line promotes the precipitation of secondary ferrite along the grain boundaries. Thus, when slowly cooled to 20°C, steel has an austenitic structure with secondary carbides and ferrite.

During rapid cooling (quenching), the decomposition of the solid solution does not have time to occur, and austenite is fixed in a supersaturated and unstable state.

The amount of precipitated chromium carbides depends not only on the cooling rate, but also on the amount of carbide in the steel. When its content is less than 0,02—0,03%, i.e. below the limit of its solubility in austenite, all carbon remains in solid solution. In some compositions of austenitic steels, accelerated cooling can lead to the fixation of primary δ -ferrite in the structure, preventing hot cracks.

A change in the content of alloying elements in steel affects the position of the phase regions. Chromium, titanium, niobium, molybdenum, tungsten, silicon, vanadium, being ferritizers, contribute to the appearance of a ferritic component in the steel structure. Nickel, carbon, manganese and nitrogen maintain the austenitic structure. However, the main alloying elements in the steels under consideration are chromium and nickel.

Depending on their ratio, steels are sometimes divided into steels with a small ($\frac{\%Ni}{\%Cr} \leq 1$) and large ($\frac{\%Ni}{\%Cr} > 1$)

austenitic margin.

In austenitic chromium-nickel steels alloyed with titanium and niobium, not only chromium carbides are formed, but also titanium and niobium carbides. When the content of titanium $Ti > [5(\%C - 0,02)]$ or niobium $Nb > (\%C \times 10)$ all free carbon (above the limit of its solubility in austenite) can be released in the form of titanium or niobium carbides, and austenitic steel becomes not prone to intergranular corrosion. The precipitation of carbides increases the strength and reduces the plastic properties of steels.



This property of carbides is used for carbide hardening of heat-resistant steels, carried out in combination with intermetallic hardening with Ni_3Ti particles; $\text{Ni}_3(\text{Al}, \text{Ti})$, Ee_2W , $(\text{N}, \text{Fe})_2\text{Ti}$, etc. Intermetallic compounds also include the σ -phase, which is formed in chromium-nickel steels during prolonged heating or slow cooling at temperatures below 900-950°C. It has limited solubility in α - and γ -solid solutions and, being released mainly along the grain boundaries, strengthens the alloy and at the same time sharply reduces the plastic properties and impact strength of the metal.

Increased concentrations of chromium (16–25%) and ferritizing elements (molybdenum, silicon, etc.) in steel contribute to the formation of the σ phase at 700–850° C.

In chromium-manganese steels with a high content of chromium and manganese, precipitation of the σ phase is also observed during slow cooling. Carbon in chromium-manganese and chromium-manganese-nickel steels leads to dispersion hardening of steels after appropriate heat treatment, especially when combined with carbide-forming elements (vanadium, niobium and tungsten).

The main difficulties in welding the steels and alloys under consideration are due to the multicomponent nature of their alloying and the variety of operating conditions of welded structures. The main and general feature of welding is the tendency to form hot cracks of an intergranular nature in the weld and heat-affected zone. They can be observed both in the form of tiny microtears and visible cracks. Hot cracks can also occur during heat treatment or operation of the structure at elevated temperatures.

The formation of hot cracks is associated with the formation of a coarse-grained macrostructure during welding, especially pronounced in multilayer welds, when the crystals of the subsequent layer continue the crystals of the previous layer, and the presence of shrinkage stresses.

The metal of welds is characterized by cellular-dendritic forms of crystallization, which leads to the formation of large columnar crystals and the enrichment of interdendritic areas with impurities that form low-melting phases. In austenitic welds, the columnar structure is most clearly expressed. The use of methods that help to refine the crystals and eliminate the columnar structure increases the resistance of the seams against the formation of hot cracks.

One of these methods is to obtain welds with a certain amount of primary δ -ferrite in the structure. The positive effect of ferrite in austenitic-ferritic welds on preventing the formation of hot cracks in them is associated with a change in the crystallization pattern and the greater solubility of liquidating impurities in it. The simultaneous precipitation of austenite crystals and primary δ -ferrite from the liquid phase leads to refinement and disorientation of the structure, i.e., to a decrease in the cross-section of columnar crystals separated by areas of primary δ -ferrite.

As a result, the likelihood of hot cracks forming at the locations of liquid layers is reduced. The production of austenitic-ferritic welds is achieved by their additional alloying with ferrite-forming elements, such as chromium, silicon, aluminum, molybdenum, etc. In products that operate as corrosion-resistant at temperatures up to 400° C, a ferrite content of up to 20-25% is allowed. In products made of heat-resistant and heat-resistant steels operating at higher temperatures, in order to prevent stigmatization, the amount of δ -ferrite in the welds is limited to 4-5%.

In steels with a large reserve of austeniticity, it is difficult to obtain welds with an austenitic-ferritic structure. The ability to prevent hot cracks in them is achieved by limiting the content of impurities in the welds that form low-melting eutectics (phosphorus, sulfur). For this purpose, welding consumables made from steels of vacuum smelting or electroslag remelting are used, and the penetration of the base metal is limited.

In some cases, it is possible to improve the resistance of welds against hot cracks by increasing the content of liquidating impurities to concentrations that ensure the production of abundant eutectic on the surface of crystallites at the final stages of crystallization, for example, when alloying steel with boron (0,3—1,5%). At the same time, the deformations accumulated in the weld metal towards the end of crystallization are reduced due to a decrease in the upper temperature of the effective crystallization interval. Reducing the effect of the force factor (by limiting the current, filling the groove with rollers of small cross-section, rational design of the connection, etc.) is also a factor in preventing hot cracks. In addition to the difficulty of obtaining welds without hot cracks on austenitic high-alloy steels and alloys, there are other welding features due to the peculiarities of their use. Welded joints of heat-resistant steels are required to maintain high mechanical properties for a long time at elevated temperatures. High cooling rates during welding lead to the fixation of nonequilibrium structures in the weld metal. During operation at temperatures above 350°C, as a result of diffusion processes, new structural components appear in the steel, leading to a decrease in the plastic properties of the weld metal. Thermal aging at 350-500°C causes the appearance of “475-degree brittleness”, and at 500-650°C it leads to the precipitation of carbides and at the same time to the formation of the σ -phase. Exposure at 700-850°C intensifies the formation of the σ -phase with a corresponding strong embrittlement of the metal at lower temperatures and a decrease in strength at high temperatures. At the same time, the role of intermetallic hardening also increases.

In the processes of thermal aging of austenitic steels, the leading place is occupied by the processes of carbide and intermetallic hardening, therefore, in order to reduce the tendency of welded joints of heat-resistant and heat-resistant



steels to embrittlement as a result of carbide precipitation, it is effective to reduce the carbon content in the base metal and weld metal.

In the heat-affected zone of some heat-resistant austenitic steels, under the influence of the thermal cycle of welding, the plastic and strength properties are reduced, which can lead to the formation of cracks in this zone. Such changes in the properties of the base metal are caused by the development of diffusion processes, leading to an increased concentration in the metal of the heat-affected zone of surface-active elements (carbon, oxygen, etc.), which, together with other impurities, can form low-melting eutectics and, ultimately, cause the appearance of hot cracks. In addition, during long-term operation, finely dispersed carbides and intermetallic compounds may be released in this zone. The formation of a continuous layer of carbides and intermetallic compounds along the grain boundaries leads to weld embrittlement. When welding these steels to prevent hot cracks in the weld, a deposited metal is often obtained that differs in composition from the base metal and has a two-phase structure. However, during high-temperature operation, carbide and intermetallic hardening of such a deposited metal occurs and a corresponding decrease in its plastic properties occurs, which leads to the localization of deformations in the heat-affected zone and the formation of cracks in it.

This is facilitated by significant residual welding stresses, as well as operating stresses. The prevention of such local destruction is achieved by heat treatment: austenitization at 1050-1100°C to remove residual welding stresses, self-hardening and imparting more uniform properties to the welded joint. In some cases, austenitization is accompanied by subsequent stabilizing annealing at 750–800°C to obtain relatively stable structures as a result of the precipitation of carbide and intermetallic phases.

When welding high-strength steels, cold cracks may form in the heat-affected zone. Therefore, before welding, it is recommended to austenitize them to obtain high plastic properties of the metal, and to carry out strengthening heat treatment after welding. Preliminary and concomitant heating to 350-450°C also reduces the risk of cold cracking.

When welding heat-resistant steels under the influence of heat, the same structural changes can be observed in the weld metal as when welding heat-resistant steels. Most heat-resistant steels and alloys have a large reserve of austeniticity and therefore do not undergo phase transformations during welding, except for carbide and intermetallic dispersion hardening. On these steels, the formation of cold cracks in the weld and heat-affected zone is also possible, the prevention of which in some cases can be achieved by preheating to 250-550°C.

High-alloy austenitic steels and alloys are most often used as corrosion-resistant. The main requirement for welded joints is resistance to various types of corrosion. Intergranular corrosion can develop both in the weld metal and in the base metal near the fusion lines (knife corrosion) or at some distance from the weld. The mechanism of development of these types of corrosion is the same, but the reasons for the occurrence of these types of intergranular corrosion are different. Intergranular corrosion in the weld metal occurs as a result of the precipitation of chromium carbides from austenite under the influence of the thermal cycle of welding, leading to the depletion of border grain volumes in chromium.

The main reasons for this are the increased content of carbon in the weld metal and the absence or insufficient content of titanium or niobium. The resistance of the weld against intergranular corrosion decreases as a result of prolonged exposure to heat during an unfavorable thermal cycle of welding or operation of the product. Austenitic-ferritic welds with a continuous structure and tortuous outlines of grain boundaries have increased resistance to intergranular corrosion compared to austenitic ones. An increase in the extent of grain boundaries due to grain refinement increases the surface area on which carbides are precipitated. The released carbides are more dispersed, and local depletion of the grain volume in chromium occurs to a shallower depth. In addition, diffusion processes in ferrite occur much faster, which accelerates the equalization of chromium concentration in the depleted border and central areas of grains. Intergranular corrosion (ICC) of the base metal at some distance from the weld is also caused by the action of the thermal cycle of welding on that part of the base metal that was heated to critical temperatures.

The tendency of steel and seams to intergranular corrosion is prevented:

- 1) reducing the carbon content to the limits of its solubility in austenite (up to 0,02—0,03%);
- 2) alloying with more energetic carbide-forming elements than chromium (stabilization with titanium, niobium, tantalum, vanadium, etc.);
- 3) stabilizing annealing at 850-900°C for 2-3 hours or austenitization - hardening from 1050-1100°C;
- 4) creation of an austenitic-ferritic structure with a ferrite content of up to 20-25% by additional alloying with chromium, silicon, molybdenum, aluminum, etc.

However, such a high content of ferrite in the structure can reduce the resistance of the metal to general corrosion. These same measures also help prevent knife corrosion.

Knife corrosion attacks the base metal. This type of corrosion develops in steels stabilized with titanium and niobium in areas heated during welding to temperatures above 1250°C, where titanium and niobium carbides dissolve in austenite. Repeated thermal exposure of this metal to critical temperatures of 500-800°C (for example, during multilayer welding) will lead to the retention of titanium and niobium in solid solution and the release of chromium carbides.



General corrosion, i.e. the dissolution of metal in a corrosive environment, can develop in the weld metal, in various areas or in the heat-affected zone as a whole and in the base metal. In some cases, uniform general corrosion of the base metal and welded joint is observed.

There is another type of corrosion destruction - corrosion cracking, which occurs under the combined action of tensile stresses and an aggressive environment. Fracture develops both intergranular and transgranular. Reducing residual welding stresses is one of the main measures to combat this type of corrosion damage.

IV.CONCLUSION

The results of the research performed provided the necessary basis for the development and implementation of welding technology for high-alloy austenitic steels and alloys.

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