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INCOLOY 800HT IRON-BASED SUPERALLOY – PRELIMINARY CHARACTERISATION

NADSTOP NA BAZIE ŻELAZA INCOLOY 800HT – WSTĘPNA CHARAKTERYSTYKA

The article presents and characterises Incoloy 800HT iron-based superalloy in terms of: chemical composition, heat treatment, microstructure and properties, in its delivery condition. This material is commonly used in process lines in the petrochemical industry, e.g. into components called 'pigtails'.

Keywords: *Incoloy 800HT, superalloy, pigtails*

W pracy przedstawiono i scharakteryzowano pod względem: składu chemicznego, obróbki cieplnej, mikrostruktury i właściwości w stanie dostawy nadstop na bazie żelaza Incoloy 800HT. Materiał ten jest powszechnie stosowany w liniach technologicznych w przemyśle petrochemicznym m.in. na elementy zwane pigtails.

Słowa kluczowe: *Incoloy 800HT, nadstop, pigtails*

1. INTRODUCTION

Superalloys are materials with a good combination of creep resistance and heat resistance intended for high temperature operation, even up to $0.8T_H$. They are mainly used where high resistance to creep and to the impact of a corrosive environment is required at the same time, i.e. in the aviation, chemical, petrochemical, nuclear and energy industries. Superalloys with a matrix of iron, cobalt and nickel are distinguished here [1, 2].

Iron matrix superalloys are derived from 18-8 corrosion-resistant austenitic steels. The development of this group of materials was particularly visible after World War II, which was related to the search for metallic materials cheaper than nickel (super)alloys that could work in difficult operating conditions of the chemical or petrochemical industry. As a result of modification of the chemical composition of austenitic steels (increase in the content of chromium, nickel, introduction of additives: aluminium, cobalt, silicon), alloys that can work up to 1100°C were obtained [1, 3]. One of the materials developed was the Incoloy 800 series alloy, which is the subject of this article.

2. CHEMICAL COMPOSITION

The Incoloy 800HT alloy belongs to the group of heat-resistant 800 series iron-based superalloys. These alloys were introduced to use in the 1950s as materials characterised by high creep resistance and heat resistance with a relatively low nickel content [2]. The development of these materials was related to the optimisation of their chemical composition. In the case of the 800HT material, it consisted in narrowing the allowable carbon content and the total concentration of titanium and aluminium (Tab. 1). The chemical composition of the tested alloy was selected so as to, on the one hand, enable solution strengthening of the austenite, and on the other hand, ensure the possibility of precipitation strengthening of the matrix and alloy grain boundaries through secondary phase particles during operation [2–4].

The basic alloying element in the analysed alloy is nickel, which was introduced to form and stabilise the austenitic matrix. Nickel also increases the adhesion of the chromium oxide layer to the surface. Chromium is also an important alloy addition in this group of materials. This element, dissolved in the matrix, provides good/very good resistance to

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Table 1. Required chemical composition of 800 series alloys, mass fraction % [5]

Tabela 1. Wymagany skład chemiczny stopów serii 800, % masy [5]

	Incoloy alloy		
Element	**800**	**800H**	**800HT**
Fe	min. 39.5	min. 39.5	min. 39.5
Ni	30.0 – 35.0	30.0 – 35.0	30.0 – 35.0
Cr	19.0 – 23.0	19.0 – 23.0	19.0 – 23.0
C	max 0.10	0.05 – 0.10	0.06 – 0.10
Al	0.15 – 0.60	0.15 – 0.60	0.25 – 0.60
Ti	0.15 – 0.60	0.15 – 0.60	0.25 – 0.60
Al+Ti	0.30 – 1.20	0.30 – 1.20	0.85 – 1.20

high-temperature corrosion and oxidation. In addition, it strengthens with solution, but also with precipitation through $M_{23}C_6$ carbides. Particles of these carbides precipitate inside and on grain boundaries. The addition of titanium ensures the precipitation of primary titanium carbides/nitrides TiX (X = C, N) during crystallisation. These precipitates, binding carbon/nitrogen atoms, limit the precipitation of chromium-rich particles along grain boundaries, which reduces the possibility of intergranular corrosion [1, 5, 6]. TiX particles can also reduce the excessive growth of austenite grain during heat (thermomechanical) treatment, but their effect depends on the solutionising temperature [1, 3, 4]. MC precipitates rich in titanium, according to [1], are characterised by high stability, providing the alloy with high resistance to creep. In addition, titanium, in combination with aluminium, can form A3B g' particles. In turn, the addition of aluminium increases heat resistance by creating Al_2O_3 oxides and stabilising the scale layer [1, 3, 6].

3. HEAT TREATMENT

The heat treatment of the 800HT alloy consists in its solution heat treatment from a temperature enabling the dissolution of most of the precipitates in the matrix. The solution heat treatment temperature for the tested alloy according to [5] is in the range of 1150–1200 °C, while according to [7] the solution heat treatment is carried out from the temperature of 950–1200 °C. The solution heat treatment temperature higher than 950 °C enables complete dissolution of $M_{23}C_6$ carbides in the matrix and is the beginning of the dissolution of titanium-rich MC precipitates in the matrix (Fig. 1) [7].

At 950 °C, the volume fraction of TiX particles in the matrix is about 0.33 %, while at 1200 °C it decreases to 0.18 %. The dissolution of precipitates in the matrix allows for its saturation with interstitial elements – carbon and nitrogen, as well as with substitutive elements – chromium and titanium. Cooling from

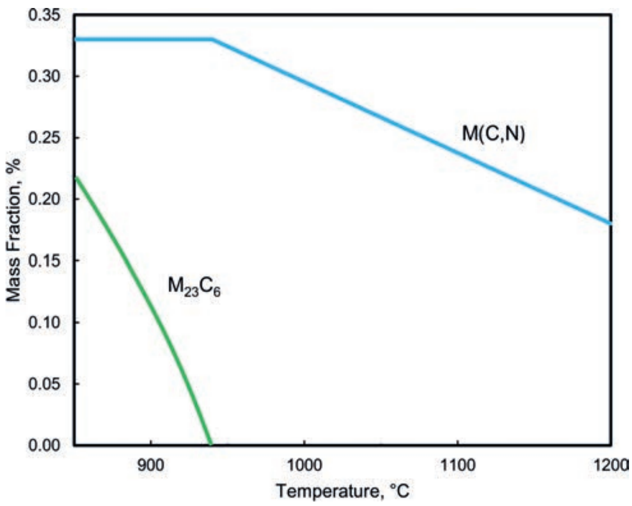

Fig. 1. Change of mass fraction of precipitates in 800H alloy as a function of temperature [7]

Rys. 1. Zmiana ułamka masowego wydzieleń w stopie 800H w funkcji temperatury [7]

the solution heat treatment temperature is usually done in air. In [8], it was shown that the cooling rate of superalloys is of great importance for their subsequent properties. The increase in the cooling rate translates into higher strength properties and lower plastic properties (elongation).

The influence of the solution heat treatment temperature on the mechanical properties of the 800 group alloys is shown in Fig. 2.

An increase in the solution heat treatment temperature (Fig. 2) directly affects the increase in the size of austenite grain in the tested alloy, which results in a decrease in strength properties (conventional yield strength, tensile strength). In turn, the decrease in the hardness value after solution heat treatment should be associated not only with an increase in grain size, but also a decrease in the number of MX precipitates with the increase in solution heat treatment temperature (Fig. 1). The plastic properties of metallic alloys significantly depend on the size, distribution and morphology of the precipitates. At the primary precipitate/matrix interface, crack nucleation and propagation may occur, which negatively affects not only plastic properties, but also crack resistance. Hence, an increase in the solution heat treatment temperature – a decrease in the amount of titanium-rich primary precipitates positively affects the plastic properties of the iron superalloy.

The 800HT alloy belongs to the materials which owe their relatively high mechanical properties to strengthening with the solution mechanism [3–5]. The strengthening by this mechanism is related to the interaction of foreign atoms dissolved in the matrix with dislocations. The increase in strength by solution heat treatment is proportional to the difference in the diameters of the alloy component atoms and the matrix. The greatest solution strengthening is provided by elements forming interstitial solu-

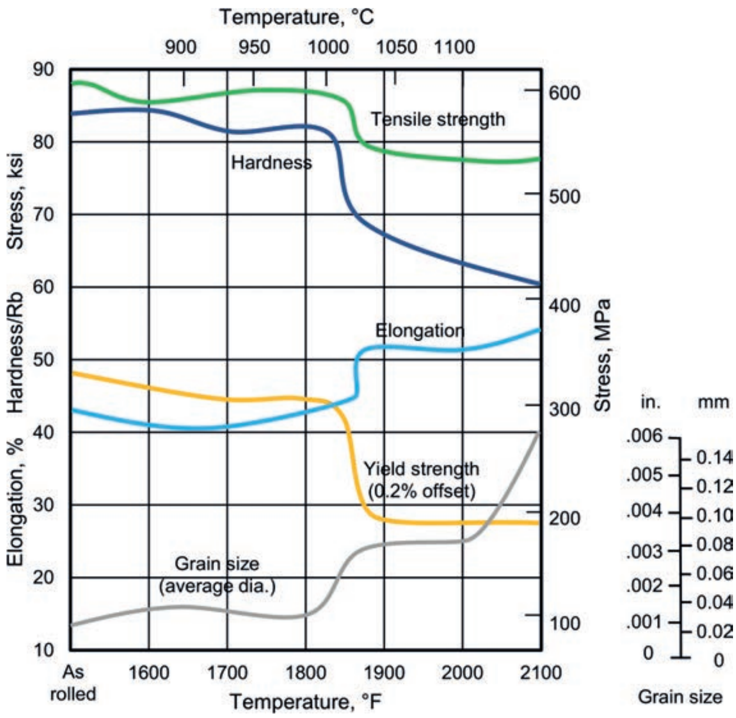

Fig. 2. Influence of solution heat treatment temperature on 800 series alloy properties [5]

Rys. 2. Wpływ temperatury przesycania na właściwości stopu serii 800 [5]

tions, i.e. carbon and nitrogen (Fig. 3). On the other hand, in the case of substitutive elements, tungsten, molybdenum and vanadium have the strongest influence on the strengthening increase.

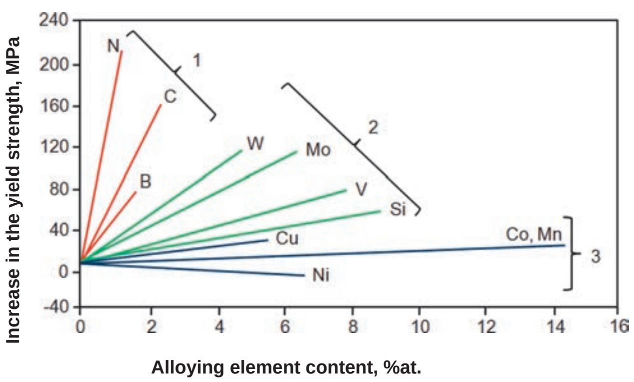

Fig. 3. Influence of interstitial elements (1); ferrite-forming substitutive (2) and substitutive – austenite-forming (3) on the increase in the yield strength of austenite [6]

Rys. 3. Wpływ pierwiastków międzywęzłowych (1); substytucyjnych ferrytotwórczych (2) i substytucyjnych – austenitotwórczych (3) na przyrost granicy plastyczności austenitu [6]

The influence of individual elements on their content in alloy strength S_i^γ can be presented by the following relationship (1) [9]:

$$S_i^\gamma = \beta_i^\gamma (x_i^\gamma)^{2/3} \qquad (1)$$

where:

β_i^γ – solution strengthening coefficient for a given element

x_i^γ – content of a given element in phase γ.

The value of the solution strengthening coefficient for selected elements is shown in Table 2.

Table 2. Solution strengthening coefficient β_i^γ of selected elements in austenite [9]

Tabela 2. Współczynnik umocnienia roztworowego β_i^γ wybranych pierwiastków w austenicie [9]

Element	β_i^γ, MPa/at %
Al	225
Cr	337
Fe	153
Ti	775

It can be seen (Tab. 2) that titanium has the strongest effect among the substitutive elements, however, due to the binding of this element into precipitates, chromium is important from the point of solution strengthening.

In turn, the total increase in strength, resulting from the austenite solution strengthening σ_{SSS}^γ, can be presented by the following formula (2):

$$\sigma_{SSS}^\gamma = (1 - f_{\gamma'})\left(\sum_i (S_i^\gamma)^{2/3}\right)^{2/3} \qquad (2)$$

where:

$f_{\gamma'}$ – volume fraction of phase γ'.

An additional strengthening mechanism used to increase the properties of this group of alloys is precipitation strengthening through $M_{23}C_6$ carbides and TiX particles. The precipitation of these particles occurs during the use of the alloy. The morphology of the particles precipitated during operation depends mainly on the temperature [4, 10].

4. MICROSTRUCTURE AND PROPERTIES IN DELIVERY CONDITION

In its delivery condition, the microstructure of the Incoloy 800HT alloy is similar to the structure of creep-resistant austenitic steels and is characterised by an austenitic matrix with visible twins (Fig. 4) and TiX precipitates (Fig. 5). Primary particles are precipitated during the solidification process, therefore they are often observed near or at the boundaries of austenite grains (Fig. 4).

The content of these precipitates in the delivery condition of the analysed alloy depends on the solution heat treatment temperature (Fig. 1). Higher solution heat treatment temperature reduces the amount of TiX particles in the matrix, which in turn affects the size of austenite grain and the mechanical properties of the material (Fig. 2).

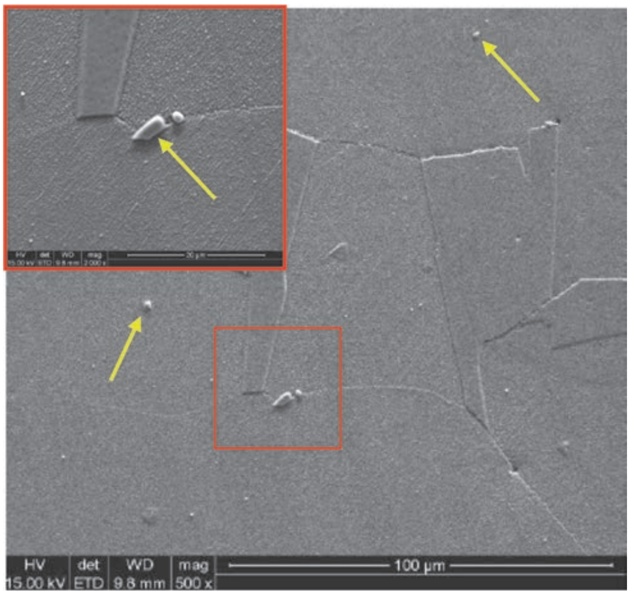

Fig. 4. Microstructure of 800HT alloy in its delivery condition; arrows indicate TiX primary precipitates, SEM

Rys. 4 Mikrostruktura stopu 800HT w stanie dostawy, strzałkami wskazano wydzielenia pierwotne TiX, SEM

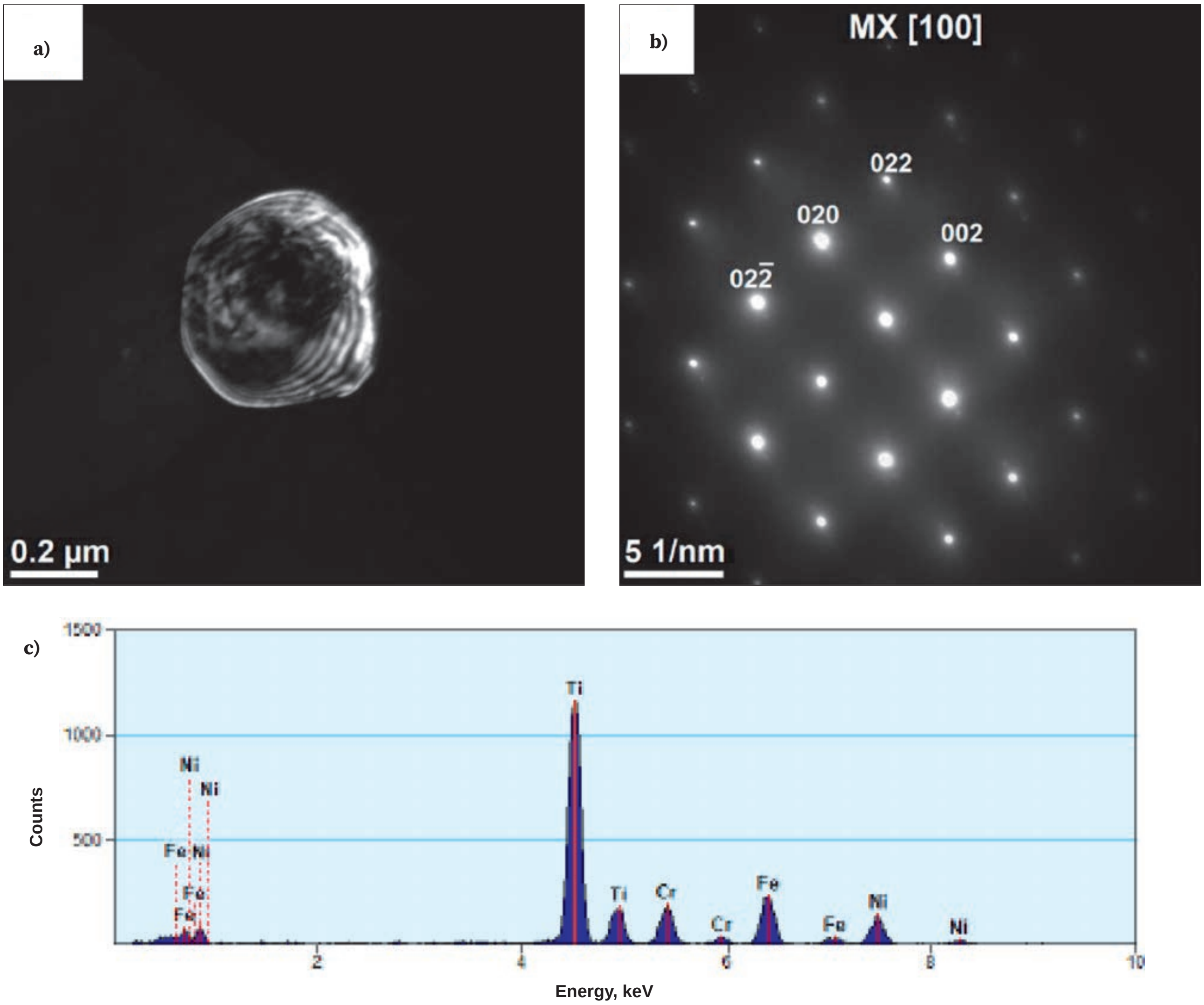

Fig. 5. TiX precipitate in 800HT alloy in its delivery condition: a) dark field; b) resolved diffraction; c) EDS spectrum

Rys. 5. Wydzielenie TiX w stopie 800HT w stanie dostawy: a) ciemne pole; b) rozwiązana dyfrakcja; c) widmo EDS

800HT alloys are supplied as coarse-grained materials with a grain size of no more than 5 according to the scale [5]. The coarse-grained structure is to ensure high creep resistance, because in the case of alloys with the A1 lattice structure, there is a strong dependence of the decreasing creep rate established with the increase in grain size [11].

5. SUMMARY

The initial analysis was performed on the iron-based 800HT superalloy, used e.g. in the petrochemical industry. This material was created on the basis of optimisation and modification of the chemical composition of 18/8 austenitic steel. High chromium content, coarse-grained austenitic structure and strengthening with the solution mechanism and, additionally, the precipitation mechanism (TiX, $M_{23}C_6$) ensure adequate heat resistance and creep resistance of this material at operating temperatures above 700°C. The high functional properties of the analysed alloy allow for its potential use in the power industry for responsible parts of the boiler. In order to confirm the above assumption, metallurgical tests of this alloy are carried out, including, among others, creep tests.

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