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REVIEW OF THE DEVELOPMENT OF RESEARCH IN THE DESIGN OF SEMI AUSTENITIC STAINLESS STEEL 17-7PH

Belma Fakić
Metallurgical Institute
“Kemal Kapetanović” Zenica
Travnička cesta 7, Zenica
Bosnia and Herzegovina

Diana Ćubela
Faculty for metallurgy and materials
Travnička cesta 1, Zenica
Bosnia and Herzegovina

ABSTRACT
This paper provides an overview of the development of research in the design of semi austenitic stainless steel 17-7PH, with a focus on research mechanism of precipitation hardening, assessment of the current situation in the field of development of the steel and new possibilities for research in this area.
Keywords: PH steels, 17-7PH steel, mechanism of precipitation hardening, mechanical properties, microstructure

1. INTRODUCTION
“Starting from rust, men have produced something which look like platinum and resists chemical attack like gold, and yet a square inch can support a quarter of a million pounds… this is the crowning achievement of metallurgy.”- Carl Zapffe Stainless steel – The Miracle Metal [1]. Stainless steel are defined as iron based alloys containing at least 10,5% chromium and a maximum of 1,2 % carbon. Stainless steels may contain nickel as another major alloying element, with a content of up to 38%, plus other alloying elements and stabilisers. The chromium content renders stainless steels corrosion resistant [2,3].

2. PRECIPITATION HARDENING STAINLESS STEEL
There are more than hundred grades of stainless steel. Stainless steel are classified into five groups: austenitic, martensitic, ferritic, austenitic-ferritic (duplex), and precipitation hardening [2]. The first four of these classes are defined based on the metallurgical crystalline microstructure of the material. Precipitation hardening stainless steel, as the fifth class, is based on the material's ability to be hardened by convential heat treatment. Precipitation hardening stainless steels (PHSS) are alloys of iron – chromium – nickel with the addidion of one or more precipitation hardening elements such as aluminium, titanium, copper, niobium and molibdenum. These steels are designed to be formable in the solution annealed condition and can subsequently be hardened by treating to strength levels.

2.1 Classification of precipitation hardening stainless steel
Precipitation hardening stainless steels may be devided into three groups: martensitic, austenitic, and semi-austenitic (metastable austenitic) [4,5,6].
Martensitic PHSS– 17-4 PH (AISI 630), 15-5 PH, PH 13-8Mo; **Austenitic** PHSS – 286 (AISI 600), 17-10 P, HNM; **Semiaustenitic** PHSS – 17-7 PH (AISI 631), PH 15-7Mo, PH 14-8.
The location of PHSS in the Schaeffler-Delong's diagram is given at figure 1 [5].

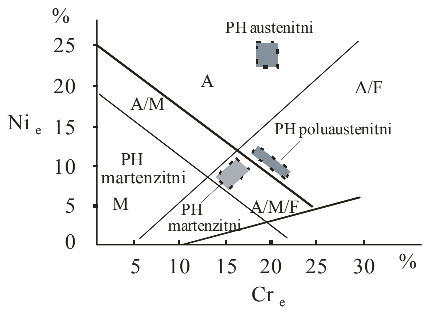

Figure 1. The location of PH steels in the Schaeffler-Delong's diagram

2.2 Application of precipitation hardening stainless steel

Precipitation hardening stainless steels are developed as material for avio and space industry. Today, these steels are available in a wide range of products - bars, wires, plates, sheets [7].

Precipitation hardening stainless steels usually used for:

- mechanical components,
- turbine blades
- nuclear waste casks.

3. SEMIAUSTENITIC STAINLESS STEEL 17-7PH

Semiaustenitc stainless steel 17-7PH, contains both a martensitic and austenitic microstructure as its chromium-nickel ratio prevents the formation of the fully austenitic phase. This 17-7PH stainless steel was developed to have corrosion resistance as well as significant mechanical strength but principally better stress corrosion resistance.

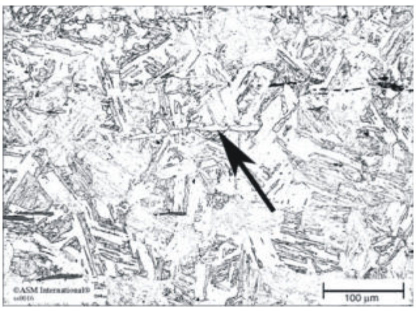

Figure 2. Microstructure of 17-7 PH steels Villela reagent, x1000 [8].

Figure 2. represents the microstructure of semiaustenitic stainless steel which is:
- solution annealed at 1065 ºC,
- 955 ºC hold 10 minutes, air cold,
- -75 ºC hold 8 hours, air heat to room temperature,
- 510 ºC hold 60 minutes, air cold.

Arrow shows stringer of delta ferrite in austenitic matrix [8].

3.1. Chemical composition of stainless steel 17-7 PH

Semiaustenitic stainless steel 17-7PH is alloy with 0.07% C, 7% Ni, 17% Cr and 1.1% Al, which is balanced so that austenite has a low thermodynamic stability. Prescribed chemical composition in accordance to standards, and manufacturers specification High Temp Metals is given in table 1.

Table 1: Chemical composition of stainless steel 17-7 PH [3,9,10].

	Chemical composition, %							
	C, max	Si, max	Mn, max	P, max	S, max	Cr	Ni	Al
BAS EN 10088-5	0,09	0,7	1,0	0,040	0,015	16-18	6,5-7,8	0,7-1,5
ASTM A564/A564M	0,09	1,0	1,0	0,040	0,030	16-18	6,5-7,75	0,75-1,5
High Temp Metals	0,09	1,0	1,0	0,04	0,030	16-18	6,5-7,75	0,7-1,5

3.2. Mechanical properties of stainless steel 17-7 PH

Values of mechanical properties of stainless steel 17-7PH, WNo: 1.4568, for bars are given in table 2.

Table 2: Mechanical properties of stainless steel 17-7 PH [2,3,10,11].

Literature		Mechanical properties at room temperature				
		Rm, MPa	$Rp_{0,2}$, MPa	A, %	HRB	HRC
BAS EN 10088-3:2010	condition +AT 1)	≤1030	-	>19	-	-
	condition +P 1)	≥1450	>1310	>2		
Hitemp 17-7PH	A	896	276	35	85	-
	TH 1050	1379	1276	9	-	43
	RH 950	1620	1517	6	-	48
	CH 900	1828	1793	2	-	49
Metals Handbook	TH 1050 2)	1170	965	6	-	25-38
	RH 950 2)	1275	1030	6	-	41

1) AT – solution annealed, +P – precipitation hardened, 2) Values obtained in the longitudinal direction

4. MECHANISM OF PRECIPITATION HARDENING

The first stage of strengthening steel 17-7PH is transformation austenite to martensite. At temperatures solution steel is in the austenitic γ area. The solubility of carbon in γ-Fe is significantly higher than in α -Fe. Because of the great cooling rate the carbon is not able to leave the bcc lattice of α -Fe, that is why bcc lattice deforms into volume centered tetragonal (VCT) lattice. This volume centered tetragonal phase is martensite – supersaturated solid solution carbon in α- Fe, which has more hardness and strength than austenite. Stainless steel 17-7PH has low content of carbon, and the martensite created quenching is soft.

4.1. Condition TH 1050

Conditioning austenite is carried out at temperature 760 ºC fir 90 minutes. During this treatment, chromium carbides precipitate at grain boundaries or at slip planes. Precipitation, reducing the effective carbon content and chromium in austenite, leading to a transformation during cooling. **Transformation** – after conditioning, cooling from 760 ºC starts transformation austenite into martensite at temperatures about 95 ºC. Transformation continue lowering temperature. Transformation finishes holding for 30 minutes at 15 ºC. It is important to note that the cooling from 760 º C to 15 º C should be carried out within one hour, in order to transform completely finished.
Aging - further increasing the strength and hardness is achieved by aging transformed material, that is precipitation of secondary phases and additional precipitation of carbides. Strengthening during aging reaches a maximum at 510 º C, but it is accompanied by a minimum ductility [12].

4.2. Condition RH 950

Conditioning austenite is carried out at temperature 955 ºC for 10 minutes. The effect of this treatment is increasing M_s temperature near the room temperature. The material which is conditioned at 955 ºC, hold austenitic microstructure cooling to room temperature.
Transformation – after conditioning, at 955 ºC, and cooling at -75 ºC, transformation from austenite to martensite takes place holding 8 hours at this temperature. Transformation is mostly achieved during cooling at -75 ºC and during first hour at this temperature.
Aging - temperature aging is 510 ºC for one hour. In the case of higher or lower temperature aging, the result is a lower strength, but at higher temperatures aging obtained better ductility [12].

4.3. Secondary phases in steel 17-7PH

Transformation of austenite occurs low carbon martensite which has got hardness (34-49HRC) which is lower than martensitic stainless steels [13]. In martensitic matrix, there are intermetallic phase Ni_3Al and precipitated carbides $M_{23}C_6$ at the grain boundaries.
Further hardening steel 17-7PH is achieved thanks to the precipitation of intermetallic phase Ni_3Al and NiAl. The secondary phase is Ni_3Al known as γ' phase, has ordered cubic, and phase NiAl has a cubic crystal lattice. Intermetallic γ' phase precipitate as coherent precipitate [15]. Coherence shows high stability of precipitates, that means very low surface energy per unit area of the precipitate/matrix.

Researchers Kear and Wilsdorf were the first to describe the unique behavior of intermetallic γ' phase, which shows increasing strength at elevated temperature [14].

Factors that contribute hardening due to the presence γ' phase are fault energy, coherently strain caused by the elastic reaction, volume participation and size of the precipitated particles. Coherently of γ' phase is important because it reduces the surface energy and results in reduced tendency to coarsened over the exposure time increased temperatures. γ' precipitates increase the resistance movement of dislocations. The amount of stress that is required to cut dislocation particle or the bypass depends on the coherent elastic strain around the precipitated particles, energy of anti-phase boundary, surface energy and fault energy in sequence precipitates and matrix [16].

5. CONCLUSIONS

Precipitation hardened stainless steel, as class, offer the designer a unique combination of fabricability, stength, easy of heat treatment, and corrosion resistance not found in any class of materials.

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