ISSN (O): 2320-5407
ISSN (P): 3107-4928
Journal Homepage: - www.journalijar.com
INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)
Article DOI: 10.21474/IJAR01/22608
DOI URL: http://dx.doi.org/10.21474/IJAR01/22608

RESEARCH ARTICLE

MICROSTRUCTURE AND MECHANICAL BEHAVIOR OF 17-7PH STEEL WITH MODIFIED CHEMICAL COMPOSITION AFTER NATURAL AGING

Belma Fakic, Omer Beganovic, Mujagic Dervis and Edib Horoz

1. University of Zenica, Institute "Kemal Kapetanovic" of Zenica.

Manuscript Info

Manuscript History
Received: 08 November 2025
Final Accepted: 10 December 2025
Published: January 2026

Key words:-
microstructure, mechanical properties, stainless steel, precipitation hardening, hardness, heat treatment, natural aging

Abstract

Modification of the contents of alloying elements with a narrower interval of Cr, Ni and Al can be obtained austenitic-martensitic steel 17-7PH which by, a subsequent heat treatment, can have values of mechanical and chemical properties required for components of automotive engine. Studies have confirmed that the rod dimensions ϕ16mm made of steel 17-7PH with modified content of chromium, nickel and aluminum in combination with heat treatment solution annealing and precipitation hardening, gave values of mechanical properties, satisfying the requirements for steel with standard chemical composition.After aging was obtained martensitic austenitic microstru-cture, with a high percentage of martensite with a slight presence of delta ferrite.

Introduction:-

The complex chemical composition achieved by very low carbon content and alloying with aluminum, chromium and nickel allow with different heat treatment that PH steels are materials with a great challenge for researchers. Research into different combinations of the chemical composition of the material and varying the temperatures of heat treatments provides the possibility of creating high-performance materials with a lower production cost and a wider range of applications. Heat treatment of PH stainless steels is carried out in order to achieve microstructural components that will enable different levels of mechanical property values [1,2]. The mechanical properties were determined at room and high temperature after solution annealing at three different temperature, natural aging and after precipitation hardening in state TH1050.

Information of testing material:-

In this paper is described PH steel 17-7PH with modified chemical composition. That means that content of Cr, Ni and Al is changed in regard to values given in standard. The melts were produced in semi-industrial facilities at Institute "Kemal Kapetanović" in Zenica, in a vacuum induction furnace of the "Leybold Heraeus" type, with a capacity of 20 kg. ARMCO iron was used as the charge for the production of the melts with the addition of appropriate amounts of alloying elements, as well as silicon and manganese. The working lining of the ladle was made of 86% MgO and 14% Al_2O_3. The mold format was KV 6. The metal pad is melted in a protective atmosphere, which is achieved by introducing argon into the previously vacuumed working space of the furnace. The goal of melting under a protective atmosphere is to minimize the possibility of oxidation, and thus the loss of alloying elements. The temperature of the liquid metal before casting is between 1520 and 1550 ºC.The standardized

Corresponding Author:- Belma Fakic
Address:-University of Zenica, Institute Kemal Kapetanovic of Zenica.

chemical composition of stainless steel 17-7PH and the modified chemical composition ϕ 16mm bars of two experimental batches are given in Table 1.

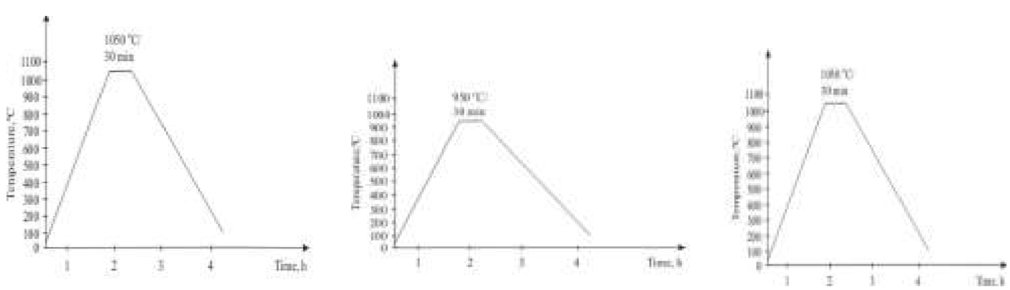
Table 1. Chemical composition [1].

Standard Batch	Chemical composition, [mas %]							
	C, max	Mn, max	Si, max	P, max	S, max	Cr	Ni	Al
BAS EN 10088-5 [6]	0,09	1,0	0,7	0,040	0,015	16,0-18,0	6,5-7,8	0,7-1,5
V1755	0,02	0,59	0,65	0,015	0,016	15,1	8,2	0,80
V1783	0,05	0,55	0,51	0,011	0,029	15,6	7,4	1,18

The ingots were forged and rolled at the semi-industrial facilities of the Institute "Kemal Kapetanović" in Zenica. Forging was carried out on a hydraulic press Pitzman und Pffeeifer with a capacity of 200 t, with light pressures, in order to break the transcrystalline zone. The temperature at the beginning of forging was 1150°C. Forging was carried out up to a temperature of 950°C, after which the forgings were reheated to 1150°C. After reaching the dimensions of the forging below 30x30 mm, reheating and forging were carried out on a B250 pneumatic hammer, with a capacity of 250 kg by free forging. With higher dynamic pressures, uniform deformation was achieved across the entire cross-section. Forging on the hammer was completed after reaching the dimension ϕ18 mm. Hot rolling to the final dimension ϕ 16 mm was performed on a semi-industrial SKET rolling mill, with a diameter of rollers ϕ 350 mm, in the temperature range from 1150°C to 950 °C [1].Rods ϕ 16mm were heat treated in a semi-industrial two-chamber “CER” furnace and laboratory automatic “KOHLER AG” furnace in Institute "Kemal Kapetanović" in Zenica.

The heat treatment of the bars consisted of solution annealing and precipitation hardening as follows:

- solution annealing at 950°C, 1050°C and 1150°C, figure 1 (a, b and c) respectively,
- precipitation hardening by regime TH1050, figure 2.



a) b) c)

Figure 1. Diagrams of solution annealing.

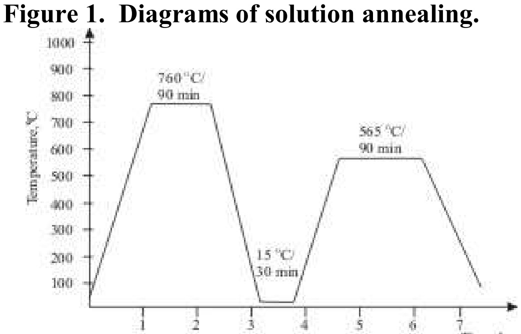


Figure 2. Diagram of precipitation hardening – condition TH1050.

Results:-

The mechanical properties test was carried out on standard test samples taken from ϕ 16 mm bar. The material was tested in the solution-annealed state at room temperature, and in the precipitation hardening state TH1050 at room and elevated temperature (425°C). The testing of mechanical properties at room and elevated temperature was carried out on the Universal hydraulic machine for static tests - AMSLER, in the measuring range from 0 to 200 kN in the Mechanical Laboratory of the Institute. Testing and production of test samples for tensile properties at room temperature was carried out in accordance with the standard EN ISO 6892-1, and at elevated temperature EN ISO 6892-2 [1,3,4]. The appearance of test samples for tensile testing at room and elevated temperatures is given in Figure 3.

Figure 3. Test samples for tensile testing [5].

Table 2. provides an overview of the mechanical properties tested in the TH1050 condition in 2015., after 10 years of natural aging, and after heat treatment of TH1050 in 2025.

Table 2. Mechanical properties [1, 5, 6, 7, 8].

Literature/Batch	Mechanical properties					
	Rm, N/mm^2			Rp$_{0,2,}$ N/mm^2		
	Natural aging					
	Room temperature		425ºC	Room temperature		425ºC
V1755	983		893	736		598
V1783	1031		923	711		744
	Precipitation hardening, room temperature					
Standard EN 10088-5	1170 N/mm^2			965 N/mm^2		
Temperature of solution annealing	950°C	1050°C$^{1)}$	1150°C	950°C	1050°C$^{1)}$	1150°C
V1755	1119	1291	1090	1031	1224	975
V1783	1294	1419	1263	1171	1276	1085
	Precipitation hardening, 425°C					
Standard EN 10088-5	979 N/mm^2			895 N/mm^2		
Temperature of solution annealing	950°C	1050°C$^{1)}$	1150°C	950°C	1050°C$^{1)}$	1150°C
V1755	810	810	809	779	776	732
V1783	923	923	876	744	906	761

$^{1)}$ tested in the TH1050 condition in 2015.

Samples for metallographic analysis in longitudinal section are prepared in accordance to standard ASTM E 3 [9]– grinding and polishing using automatic mashine PHOENIX BETA. Grinding of the samples were done from paper gradation 240SiC to 1000SiC. Polishing were done using diamond suspension from 9μ to 1 μ on adequate polish clothes. Metallography analysis of samples was carried out on light optical microscopy OLYMPUS PMG3 using software ANALYSIS 5.0 and software LAS X. Figure 4. and 5. shows microstructures for natural aging after 10 years, TH1050 condition carried out after solution annealing at 950ºC, 1050ºC and 1150°C for batches V1755 and V1783, respectively. Samples are etched in Kalling reagent: 100cm^3 HCl, 5g $CuCl_2$, 100 cm^3 C_2H_5OH. Microstructure of martensite, austenite and some delta ferrite was revealed by etching in the Kalling reagent [10].

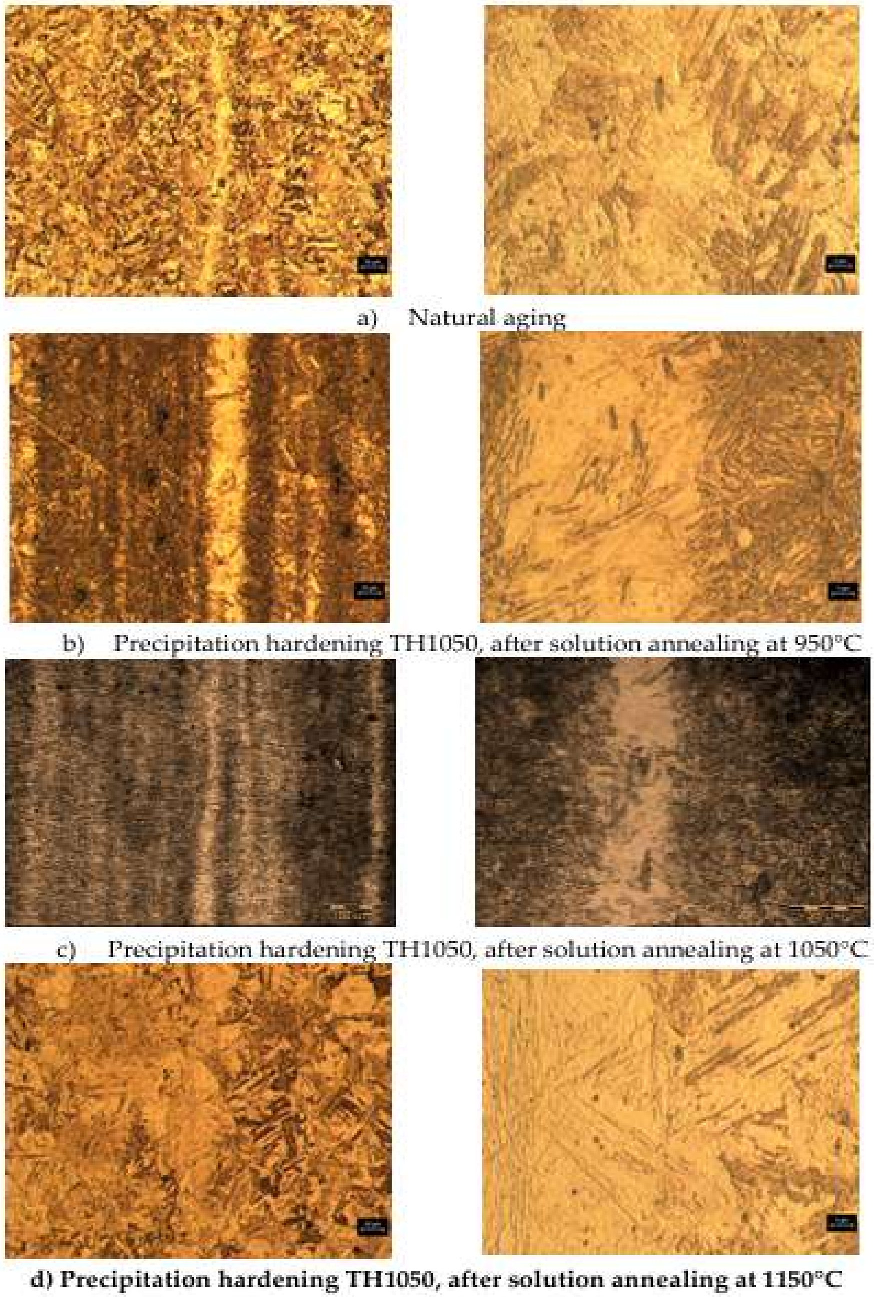


Figure 4. Microstructure, batch V1755, a) natural aging; b) Precipitation hardening TH1050, after solution annealing at 950°C; c) Precipitation hardening TH1050, after solution annealing at 1050°C; Precipitation hardening TH1050, after solution annealing at 1150°C [1,5] .

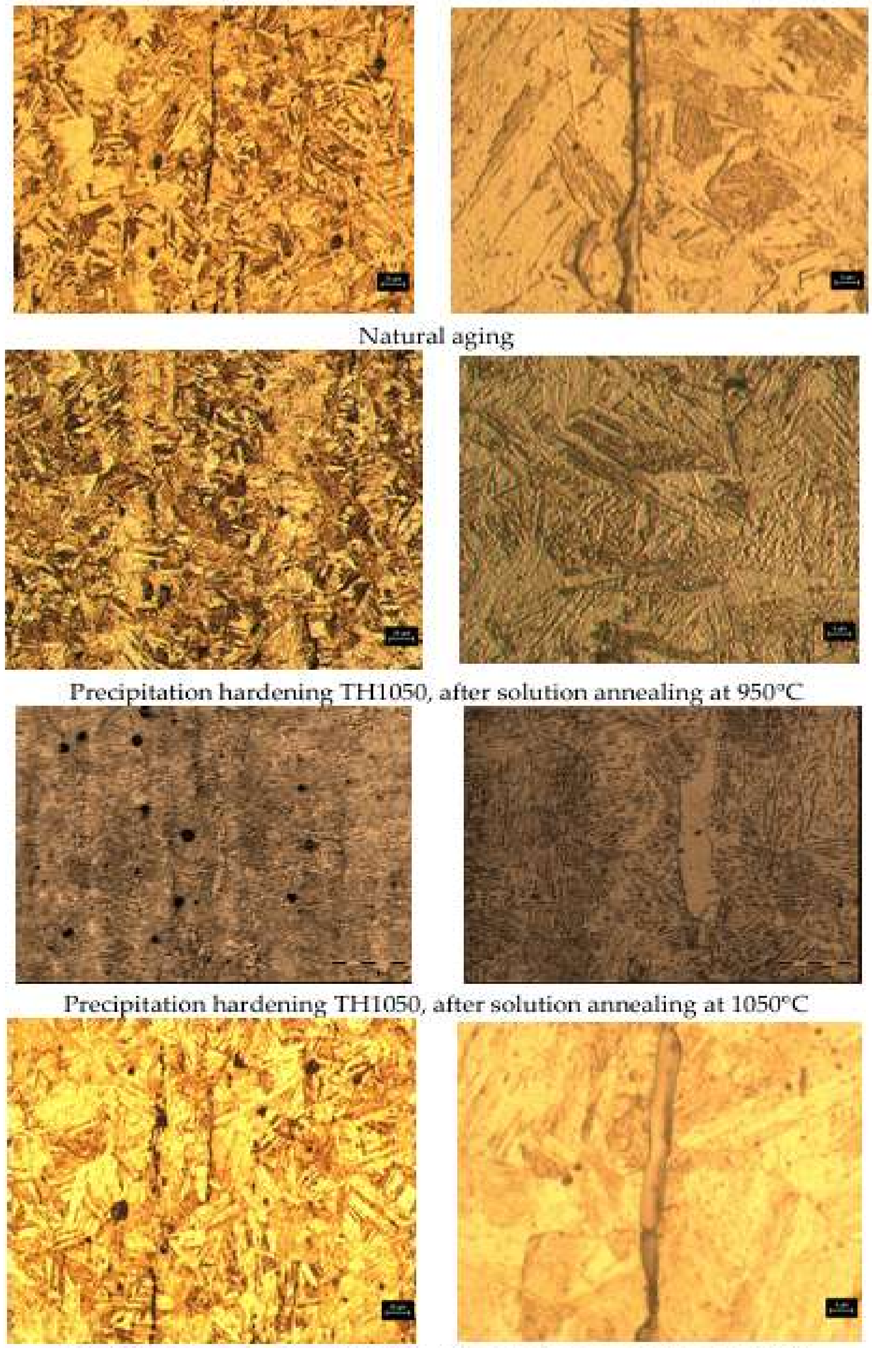
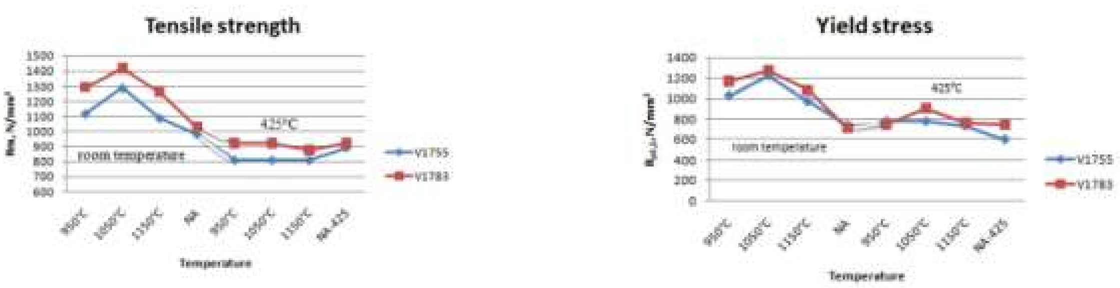


Figure 5. Microstructure, batch V1783, a) natural aging; b) Precipitation hardening TH1050, after solution annealing at 950°C; c) Precipitation hardening TH1050, after solution annealing at 1050°C; Precipitation hardening TH1050, after solution annealing at 1150°C [1,5].

On figure 6. show diagram of tensile strength and yield stress for samples which are solution annealing at three different temperatures (950°C, 1050°C and 1150°) and precipitation hardening with standard TH1050 treatment.



a) b)

Figure 6. Diagram : (a) Tensile strength; (b) Yield stress.

Discusion:-

Chemical composition of two analyzed batches have different amount of nickel, chromium and aluminum. The amount of chromium is lower than is prescribed in standard EN 10088-5 in both batches. The amount of nickel is lower in batch V1783 than is prescribed in standard EN 10088-5, and higher in batch V1755. The amount of aluminum lower in both batches is in accordance to standard EN 10088-5. The tensile strength Rm of the V1755 batch with lower chromium and a higher nickel content compared to the values given in the EN 10088-5 standard is lower in the naturally aged and TH1050 conditions tested at room temperature and 425ºC. Values of yield stress tested at room temperature are higher for batch V1783 for all three different temperature of solution annealing, but only for temperature of solution annealing of 1050ºC the value of $Rp_{0,2}$ is higher for batch V1783 tested at 425ºC.The microstructure of the V1755 batch samples shows a larger amount of austenite, which is observed in the form of white bands. The presence of delta ferrite in the V1783 batch is within the limits allowed for steel 17-7PH.

Conclusion:-

The heat treatment of precipitation hardening, which includes the austenite conditioning step, and the cooling of samples from temperature of 760 °C enabled the transformation of austenite into martensite, which represents the first step of hardening. By subsequent heating at temperature of 565 °C, aging treatment is carried out, which additionally strengthens the material, by precipitation of the intermetallic phase and excretion of carbides. According to the chemical analysis of the produced batches, the carbon content is from 0.02 to 0.05%, and for a period of 90 minutes and at a precipitation hardening (aging) temperature for the TH1050 condition of 565 °C for a period of 90 minutes, the precipitation of $Cr_{23}C_6$ carbide is possible. The achieved values of mechanical properties, even above the upper limit for steel 17-7PH of the prescribed chemical composition, indicate that during the precipitation hardening, the strengthening intermetallic phase was precipitated, which by its existence contributed to high values of tensile strength and yield stress.Heat treatment at different temperatures of solution annealing of 17-7PH steel with modified chemical composition (low chromium content) gives very good tensile and yield strength after precipitation hardening with standard TH1050 treatment with satisfied microstructure.

Literature:-

1. Metals handbook: Properties and Selection: Iron, Steels and High-Performance, 10th Edition, Vol.1, Belma Fakić: A Modification of Chromium, Nickel, and Aluminum Content in Precipitation Hardening Steel 17-7PH Intended for the Production of Automotive Engine Components, Ph.D., University of Zenica, December 2015.
2. Belma Fakić, Diana Ćubela: Martensitic transformation in semiaustenitic stainless steel 17-7PH with modified chemical composition, . 11th International conference New Technologies, development and application" NT 2025, June 2025, B&H.
3. Standard EN ISO 6892-1: Metallic materials –Tensile testing – Part 1: Method of test at room temperature
4. Standard EN ISO 6892-2: Metallic materials –Tensile testing – Part 2: Method of test at elevated temperature
5. Edib Horoz: Influence of solution annealing temperature on the precipitation hardening of steel 17-7PH modified chemical composition, University of Zenica, December 2025.
6. Standard EN 10088-5: Stainless steels -- Part 5: Technical delivery conditions for bars, rods, wire, sections and bright products of corrosion resisting steels for construction purposes
7. Metals handbook Properties and Selection: Iron, Steels and High-Performance, 10th Edition, Vol.1, ASM American Society for Metals, 1990.

8. B. Fakić, Adisa Burić, Diana Ćubela: Microstructural and mechanical properties of modificated precipitation hardening steel 17-7ph after modification heat treatment, International Journal of Advanced Research (IJAR), ISSN No:2320 5407;Article DOI:10.21474/IJAR01/xxx; DOI URL: https://dx.doi.org/10.21474/IJAR01/10375
9. Standard ASTM E 3: Standard Practice for Preparation of Metallographic Specimens
10. Standard ASTM E 407: Standard Practice for Microetching Metals and Alloys