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Research Article

Microstructure and Some Mechanical Properties of AISI 630 Stainless Steel Hardened by Precipitation Hardening

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Abstract

AISI 630 stainless steel hardened by precipitation hardening (PH) is increasingly being used as a maraging steel. In this study, the microstructure and some tensile properties of these steels were examined at room temperature. Additionally, the impact absorption energies of the materials were calculated by conducting the Charpy impact tests on PH steels. This value, calculated as 138.9 J, is very close to the value obtained by other researchers.

Keywords: EN 1.4542 steel, Precipitation hardening, tensile failure, Charpy impact energy

Çökelme Sertleşmesi ile Sertleştirilmiş AISI 630 Paslanmaz Çeliğin Mikro Yapısı ve Bazı Mekanik Özellikleri

Öz

Çökeltme sertleştirmesi (PH) ile sertleştirilmiş AISI 630 paslanmaz çelik, maraging çeliği olarak giderek daha fazla kullanılmaktadır. Bu çalışmada, bu çeliklerin oda sıcaklığındaki mikro yapıları ve bazı çekme özellikleri incelenmiştir. Ayrıca PH çelikleri üzerinde Charpy darbe testleri yapılarak malzemelerin darbe yutma enerjileri hesaplanmıştır. 138.9 J olarak hesaplanan bu değer diğer araştırmacıların elde ettiği değere oldukça yakındır.

Anahtar Kelimeler: EN 1.4542 çeliği, çökeltme sertleşmesi, çekme kopması, Charpy darbe enerjisi

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1. Introduction

AISI 630 (17-4 PH) – EN 1.4542 is one of the most widely employed PH stainless steels [1]. PH stainless steels belong to the Fe-Cr-Ni stainless steels family and contain alloying elements such as copper, molybdenum, niobium, titanium and aluminum [2]. These stainless steels are widely used in high-speed aircraft exteriors, missile hulls, watercraft, fuel tanks, aircraft landing gear, pumps, shafts, nuts, bolts, cutting tools, and couplings, because of their high strength, good ductility, nice fabrication characteristics and superior corrosion resistance [3]. For this reason, intensive studies have been carried out on these steels [1,2,4,5]. Most of the previous studies on 17-4 PH stainless steels have focused on further development of these features especially microstructure, tribological and fatigue properties at room temperature. Corresponding to this, Mohd et al. [6] showed that 17-4 PH stainless steels exhibit the bi-modal failure mechanics. The scatter of the fatigue strength is very small and almost equal to that of tensile strength.

Nowadays, structural materials require knowledge of tensile and impact properties for severe service environments of machine components. Although there are many studies on the structure and plastic deformation behaviour of 17-4 PH stainless steels [7-10], different and interesting results have been obtained in many studies. Corresponding to this, Zhaoet al. [11] showed that there is a lack of hardening ability in the initial stage of plastic deformation due to the fine microstructure of 17-4 PH steel due to formed complex Lüders band. In addition, it has been shown that severe plastic deformation of PH steels influences diffusion kinetics significantly during phase transformation as well as during precipitation [12]. On the other hand, Bhambroo et al. [13] obtained that the Cu-rich precipitates in the martensitic matrix mainly determine the mechanical properties of 17-4 PH steels rather than the reverted austenite from the mechanical testing results. In this work, an attempt is made to understand the microstructure and some mechanical properties (tensile and impact properties) of 17-4 PH stainless steel used in the industrial practice.

2. Materials and Methods

The chemical composition of the commercial 17-4 PH stainless steels was determined using an optical emission spectrometer and is given in Table 1. Microstructural characterization was done with optical metallography. For microstructure analysis, the surfaces of the samples were initially sanded with 120, 320, 600, and 1000 mesh SiC abrasive-containing sandpapers placed on the rotating disc. Then, the 17-4 PH stainless steels were polished using a standard metallographic process and chemically etched by 5 g $FeCl_3$ +15 mL HCl + 85 mL H_2O to reveal the microstructure.

Table 1 Chemical composition of 17-4 PH stainless steels

Element	C	Si	Mn	Cr	Ni	Mo	Cu	P	Nb
wt.%	0.03	0.47	0.29	16.91	4.32	0.18	3.02	0.012	0.22

Tensile tests on 17-4 PH stainless steels were carried out at room temperature at a speed of 0.032 mm/s with the Zwick 250 kN tensile device. Standard Charpy V-notch samples (55 mm x10 mm x10 mm) were used for the determination of the fracture using a Galdabini - Impact 450 machine**.** Yield strength (σ_y), ultimate tensile strength (σ_{UTS}), elongation, and Charpy impact energy were determined on tensile and Charpy samples and were given in Table 2.

3. Results and Discussion

PH stainless steels are low-carbon (≤ 0.1%) grades and depending on the amount of Cr and Ni, the structure becomes austenitic, semi-austenitic, or martensitic. Fig 1 shows the microstructure of PH stainless steels obtained from optical microscopy. As seen in this figure, the microstructure consists of acicular martensite and massive martensite. In literature, it has been obtained that the microstructure of 17-4 PH stainless steel is a mix of various phases, primarily martensite and, depending on the annealing conditions, retained austenite and δ ferrite with additional small precipitates of Cr and Ni carbides and nano-Cu precipitates [14].

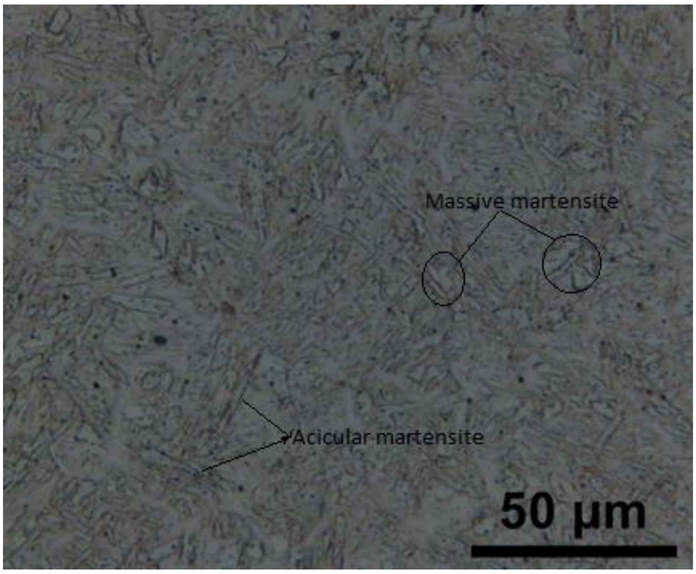

Fig.1 Microstructure of the 17-4 PH stainless steel.

The most widely used test to reveal the mechanical properties of the material is the tensile test. Fig. 2 shows a typical tensile stress–strain curve of PH stainless steel studied in the present study. The σ_y , σ_{UTS} and elongation values were determined from these tensile stress–strain curves as displayed in Table 2

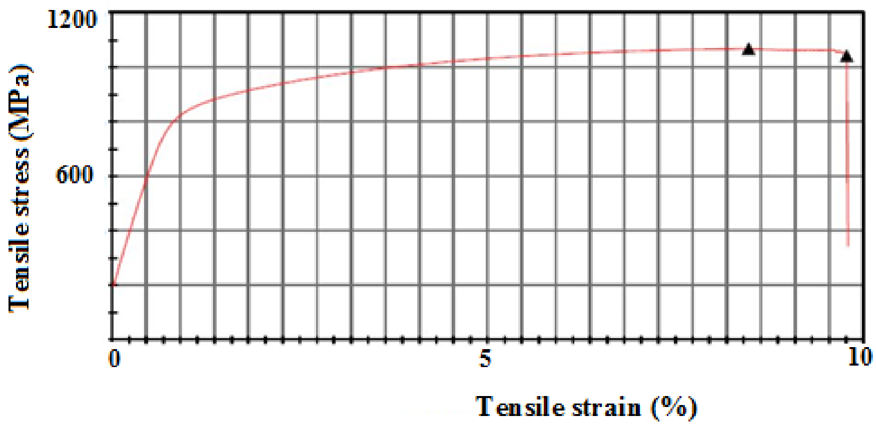

Fig. 2 Tensile stress-strain curve of the 17-4 PH stainless steel

To compare room temperature tensile properties for PH stainless steels, the obtained results were given together with some of the more common grades including 17-4 PH (17% Cr 4% Ni), 13-8 PH (13% Cr 8% Ni), 17-7 PH (17% Cr 7% Ni) and 15-5 PH (15% Cr 5% Ni) in Table 2. These steels are generally known as PH stainless steel and are widely used in areas requiring high strength and corrosion [15].

Table 2 Tensile properties of PH stainless steels

Steels	σ_y (MPa)	σ_{UTS} (MPa)	Elongation (%)	References
17-4 PH	1098	1159	9.3	Present study
17-4 PH	1173	1381	16	7
	1170	1310	10	16
	1002	1103	5	8
17-7 PH	1030	1280	10	16
	962	1170	6	17
	793	1206	9	8
15-5 PH	1260	1370	9.2	18
	1170	1310	10	16
	1275	1379	14	8
13-8 PH	1415	1515	10	16
	1480	1530	9.7	19
	1241	1310	5	8

From Table 2, we observed that the tensile values (σ_y, σ_{UTS} and elongation) obtained for 17-4 PH stainless steels in the present study seem to be quite close to the values obtained for sample 17-4 PH stainless steels by other researchers. However, when compared to σ_y and σ_{UTS} values obtained for 13-8 PH and 17-5 PH stainless steels, the values obtained in our study appear to be smaller. It is possible to say that this difference is due to the difference in porosity and especially in alloy element concentrations. On the other hand, in the literature, it is stated that these values can be increased much higher values with surface improvement and heat treatments [20, 21].

Impact behavior is a very important parameter for design. Performing numerical impact analyses in the light of experimental data to be applied in obtaining these data will provide a lot of convenience for designers. With the Charpy impact test, also known as the Charpy V-notch test, the amount of energy absorbed by the sample during fracture is measured. This process is carried out by hitting the sample placed in the testing device with a weight attached to the pendulum arm. The energy transfer between the weight and the sample is used to determine the fracture mechanics of the material. Figure 3 is the image of the destroyed sample at the end of the impact test.

Fig. 3 Photograph of the sample after impact testing

The impact energy value obtained in our study is approximately 138.9 J. This value was obtained by Bressan et al. [22] and Isogawa et al. [23] as 137.6 J and 140 J for the 17-4 precipitation hardening steels at the room temperature, respectively, which is quite close to the value obtained in our study.

4. Conclusion

In this study, the microstructure and some mechanical properties of 17-4 PH stainless steels were determined. The values obtained seem to be quite close to the values given for steels with similar structures in the literature. Thus, these materials will be able to work under long and demanding working conditions in the industry without deformation.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

Author Contributions

Adnan Çalık: Designing the study, performing the calculations, evaluating the results,
Nazım Uçar: Evaluating the results, writing the article.

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