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Araştırma Makalesi

The Effect of Cr and Ni Addition on Mechanical Properties of Plain Carbon Steel

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ABSTRACT

In this study, the effect of Cr-Ni addition on the mechanical properties of plain carbon steel was investigated. For this purpose, Cr-Ni (wt. % 0.5-3) was added to the matrix containing 0.5 C with powder metallurgy method. The tensile test, micro hardness measurement and microstructure analysis were performed to investigate the effect of the additions on the mechanical properties. As a result, it was determined that the added alloying elements increased the mechanical properties, but the mechanical properties decreased with the amount of alloying elements increasing after 1% wt. due to the powder metallurgy process.

Keywords: *Powder metallurgy, Alloyed steel, Mechanical properties*

Cr ve Ni İlavesinin Sade Karbonlu Çeliğin Mekanik Özelliklerine Etkisi

ÖZET

Bu çalışmada, Cr-Ni ilavesinin sade karbon çeliğinin mekanik özellikleri üzerindeki etkisi araştırılmıştır. Bu amaçla, toz metalürji metoduyla 0.5 C içeren matrise Cr-Ni (ağırlıkça %0,5-3) ilave edilmiştir. Alaşım elementlerinin mekanik özelliklere etkisini araştırmak için çekme testi, mikro sertlik ölçümü ve mikro yapı analizi yapılmıştır. Sonuç olarak, ilave edilen alaşım elementlerinin mekanik özellikleri arttırdığı, ancak toz metalürjisi işleminden dolayı ağ. %1'den sonra artan alaşım elementi miktarı ile mekanik özelliklerin azaldığı tespit edilmiştir.

Anahtar Kelimeler: *Toz metalürjisi, Alaşımlı çelik, Mekanik özellikler*

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I. INTRODUCTION

The increase in the use of powder metallurgy (PM) for iron alloys over the last years is due to its proven advantage over similar metalworking processes. PM is efficient because it economically produces medium or high-volume net or near net forms without loss of almost any raw material. The parts markets produced by powder metallurgy vary [1,2]. Automotive applications have dominated the growth of the industry. However, non-automotive applications are also becoming increasingly attractive. [1].

Generally, Cu and Ni are used as alloying elements because of low oxidation problems during sintering in iron alloys. Elements such as Cr and Mo are also used in wrought steels. However, these elements tend to be oxidized and it is difficult to remove these oxides afterward. Careful atmosphere control is required during sintering of Cr, which has a higher oxygen affinity than conventional alloying elements such as Cu and Ni [3]. The graphite, which is added to the powder mixture before the pressing and sintering, creates a reducing environment. In this case, there are two options for oxide reduction, direct reduction by C or indirect reduction by CO in the atmosphere [4]. Because of these reactions, the amount of alloy C may be lower than the amount added.

In this study, six different steel samples with different ratios of Cr-Ni were produced to observe the effects of alloying elements. The mechanical properties of the samples were characterized with microhardness measurement and tensile testing methods. The metallographic analyzes were performed to correlate mechanical properties with microstructural properties, such as alloy elements, grain sizes and morphology.

II. EXPERIMENTAL PROCEDURE

Six different steel sample containing about 0.56% of carbon were used in this study. 99% pure Iron, 99% pure chromium natural graphite and 99.7% pure Ni powders were used. Chemical compositions of the alloys are shown in Table 1. The first sample was produced as a reference for comparison. For obtaining a homogeneous powder mixture the required Fe, graphite, Cr and Ni powders were mixed with a Turbula mixer for 2 hours. The blended powders were then compacted in a standard tensile test specimen's (ASTM E8M) mold at room temperature. An example of the tensile samples with deformation zone and dimensions of specimen is given in figure 1. The samples were compacted with 750 MPa pressure by a hydraulic press (100 tons capacity). The samples in the form of tensile bars were sintered for 60 min at 1400 ˚C in an atmosphere of Argon. The samples were then cooled to 700 ˚C in the oven at 5 ˚C min−1, then taken out of the oven and allowed to cool to room temperature. The sintered density of samples was measured according to the Archimedes principle. Density measurements are given by theoretical density.

Table 1. *Composition of the samples.*

Sample No	Cr (*wt.%*)	Ni (*wt.%*)	C (*wt.%*)	Fe (*wt.%*)
Alloy 1	-	-	0.55	Bal.
Alloy 2	0.5	0.5	0.55	Bal.
Alloy 3	1	1	0.55	Bal.
Alloy 4	2	2	0.55	Bal.
Alloy 5	3	3	0.55	Bal.

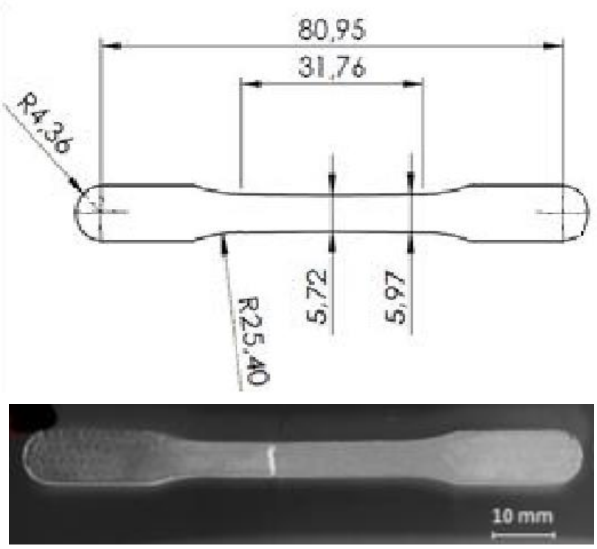

Figure 1. *An example of tensile test specimen* and dimensions of specimen.

Tensile tests (Shimadzu) were carried out at room temperature at speed of 1 mm min^{-1} to measure of the ultimate tensile strength (UTS) and percentage of elongation (% El). The average hardness from each of the samples was obtained by making six measurements placed randomly on the surface. Measurements were made with Shimadzu HMV-2, under a small load of 50g to avoid the effects of pores. The samples were then grinded, polished and then etched in 2% Nital solution. Metallographic examinations were carried out by light optical microscopy (LOM). Grain size measurements was carried out by grain boundary intersection counting.

III. RESULTS AND DISCUSSION

A. MICROSTRUCTURE CHARACTERIZATION

To compare the microstructural features with the mechanical properties, images were taken from each sample. Etched microstructures after sintering show that the material is mostly ferritic, but there is also some perlite. Examined specimens have roughly the same microstructure appearance after etching. However, it is observed that the amount of bainite increases with the amount of alloying elements. As Ni is an austenite stabilizer element, it decreases Ac_1 and Ms conversion temperatures. For this reason, locally occurring Ni-rich areas promote the formation of austenite islands in the intercanthal annealing zone [5]. The microstructure of the alloy 3, where the highest mechanical properties are measured, is shown in figure 2.

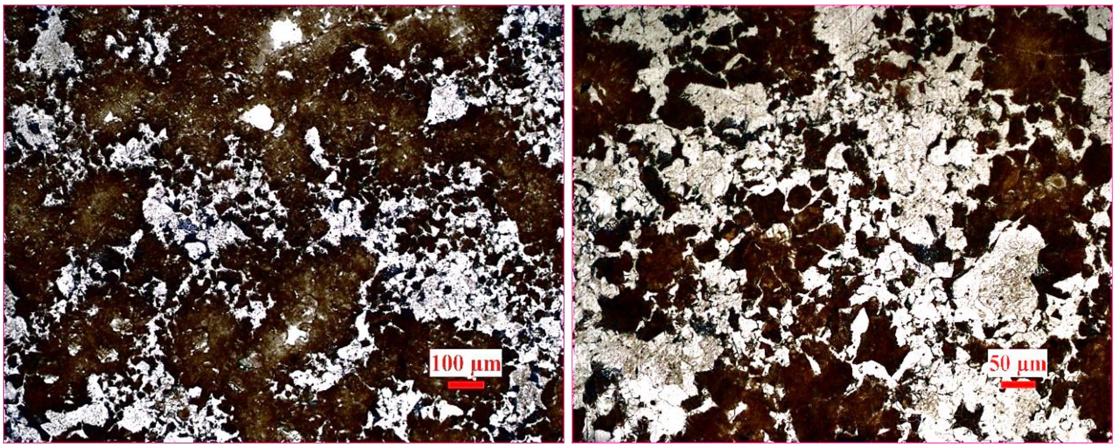

Figure 2. *As polished microstructure of alloy 3 (wt. %1 Cr-Ni) after sintering.*

The sintered properties of steels are given in Table 2. When the Cr-Ni content of the alloys decreases, the density increases after sintering. The total density of nickel and chromium is approximately same with iron. But the addition of alloying elements reduces the compressibility of powders and also in spite of Argon atmosphere Cr has high oxygen affinity and so it can be oxidation [3]. Consequently, the porosity of P/M steel after sintering was about 10 % and it increased with the addition of alloying elements.

In Table 2, it is seen that the grain size decreases with increasing alloying element amount. It is thought that this effect is caused by chromium. Because Nickel remains in the solid solution and does not form any second phase with carbon [6]. However, Cr combines with carbon and forms chromium carbide precipitates [6]. These precipitates create a thinner grain size than unalloyed steel by forming a stabilizing effect (Zener pinning) at the grain boundaries. Grain size measurement revealed the same phenomenon predicted by microstructural observations. Considering the experimental error, it can be said that the highest Cr alloy steel has the smallest average grain diameter (~37 µm).

Table 2. *Density and average grain size values of samples.*

Alloys	Density (%)	Grain size (μm)
alloy 1	90.723	40.67
alloy 2	88.982	40.12
alloy 3	87.300	39.57
alloy 4	86.058	38.18
alloy 5	84.673	37.65

B. TENSILE PROPERTIES

Tensile test results from the specimens of steels are shown in figure 3 and table 3. It is evident from the figure that alloy 3 has the highest ultimate tensile strength and yield strength (UTS) and the alloy 1 has the highest ductility. The low alloying element and high density contributed to the ductility of the alloy 1. Mechanical behavior of sintered PM alloys is significantly influenced by porosity. Typically, two types of porosity as interconnected and isolated were observed in PM materials. Interconnected porosities cause small sinter bonds between particles and it has a more significant effect on ductility than isolated porosity [7]. In our samples, both of porosity types are seen.

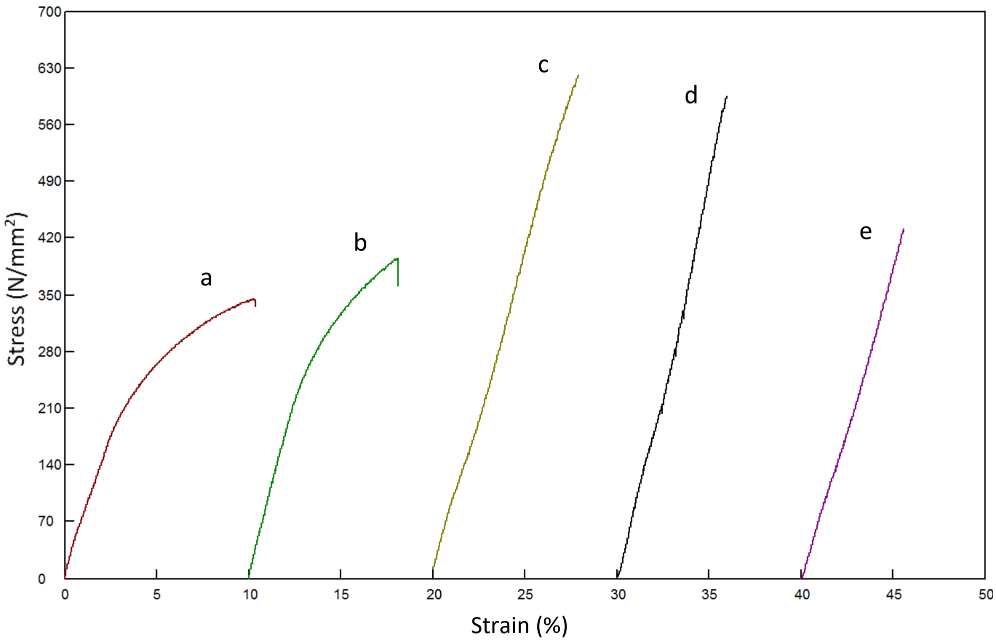

Figure 3. *Tensile test graphs of alloys; a (alloy1), b (alloy2), c (alloy3), d (alloy4), e (alloy5)*

The higher strength is measured on alloy 3 because of alloy addition and density balance. Chromium becomes chromium carbide precipitates and these particles makes dislocation movement more difficult and so increased the strength of material [6]. For examples Erden and Gündüz [7] were investigated that effect of Cr content (wt.% 0.1, 1, 3) on the microstructures and tensile behaviors of non-alloyed powder metallurgy (PM) steels. Results showed that 3 wt. % Cr added PM steel has the highest values yield and ultimate tensile strength. Nickel does not form a second phase and it is mostly become of solid solution in the ferrite [8]. So, Ni addition increases the strength of the steel by solid solution strengthening [5]. Erden were investigated on the effect of Ni content on the microstructures and tensile behaviours of powder metallurgy (PM) steels and the results showed that 0.8 wt. % Ni added PM steel has the highest values in yield ultimate tensile strength [9]. Measured strength values of alloys were lower than casted and wrought alloys. Due to the residual porosity of the pressed and sintered PM materials, mechanical properties such as tensile, yield strength and ductility are lower than comparable forged ones [10,11].

C. HARDNESS MEASUREMENTS

Hardness values is given with comparing tensile test values in table 3. Microhardness tests of PM steels showed that, based on Cr-Ni content, the average value of hardness increase was about 70 HV. Molinari et al. analyzed the effect of Cr and Mo on the microstructure of steels and concluded that the addition of Cr improved the mechanical properties by carbide precipitation and solution hardening [12]. In another study, the addition of Ni has been shown to help protect the residual austenite in the alloy.

Table 3. *Tensile strength (UTS), percent elongation and hardness values of samples.*

Specimens	UTS (*MPa*)	Elongation (%)	Hardness ($HV_{0.5}$)
alloy 1	346	10.28	101
alloy 2	396	8.12	135
alloy 3	623	7.95	177
alloy 4	596	5.99	139
alloy 5	433	5,60	154

Shanmugasundaram and Chandramouli stated that the addition of 1% Cr to the flat carbon steel alone resulted in an increase in tensile strength of about 60% and a hardness of 24% [13]. They also revealed that hardness and tensile strength decreased slightly after 2% N added to Fe- 0.2%C - 1% Cr steel.

IV. CONCLUSIONS

The addition of the Cr and Ni alloying elements has increased the tensile strength of plain carbon steels produced by PM. The hardness of the specimens also is increased with addition of alloying elements. However, after the alloy 3, where the highest tensile strength and hardness were measured, the mechanical properties were reduced by the increasing alloying element. This is due to the negative effect of the alloying elements on the TM production method.

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