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Research Article

Effect of Tempering Heat Treatment on Medium Manganese Steels

Temperleme Isıl İşleminin Orta Manganlı Çelikler Üzerindeki Etkisi

Mehmet EROĞLU[1], Fatih DEMİR[2]

[1]Department of Metallurgical and Materials Engineering, Firat University
Faculty of Engineering, 23119, Elazig, TURKEY
[2]Department of Machinery and Metal Technologies, Batman University
Technical Sciences Vocational School, Central Campus, 72060, Batman, TURKEY

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Öz

Son yıllarda, özellikle otomotiv sektörü için önemi artan orta Manganlı çelikler, yeni nesil gelişmiş yüksek mukavemetli çelik olarak da değerlendirilmektedir. Bu çeliklerin sergilemiş olduğu üstün özellikler, kimyasal bileşime, ön şekillendirme yöntemine ve termal döngülere bağlıdır. Geleneksel, kritik ve temperleme ısıl işlemleri ve bu termal proseslerin kombinasyonları bu çelik türleri için sıkça araştırma konusu olmuştur. Bu çalışmada da geleneksel tavlama ile temperleme birlikte uygulanmış ve orta Manganlı çeliklerin mikroyapısı ve mekanik özellikleri üzerindeki etkileri araştırılmıştır. SEM, EDS ve XRD analizlerinden elde edilen veriler ile çekme ve sertlik deneylerinin sonuçları ilişkilendirilerek temperleme ısıl işleminin orta Manganlı çelikler üzerindeki etkisi incelenmiştir.

Anahtar Kelimeler
AHSS, Orta Manganlı, Isıl işlem, Temperleme, Kalıntı östenit

Abstract

Medium Mn steels, whose importance has increased especially for the automotive industry in recent years, are also considered as new generation advanced high strength steels. The superior properties exhibited by these steels depend on the chemical composition, preforming method and thermal cycles. Conventional, intercritical and tempering heat treatments and combinations of these thermal processes have frequently been the subject of research for these steels. In this study, conventional heat treatment and tempering were applied together and their effects on the microstructure and mechanical properties of mid-Mn steels were investigated. The effect of tempering heat treatment on medium Mn steels was investigated by correlating the data obtained from SEM, EDS and XRD analyses with the results of tensile and hardness tests.

Key Words
AHSS, Medium-Mn, Heat treatment, Tempering, Retained austenite

***Sorumlu Yazar:** fatih.demir@batman.edu.tr*

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1. Introduction

Medium manganese steels are defined as a type of steel containing approximately 4–10 wt.% Mn. As the main austenite stabilizer, Mn improves the hardenability of steel and causes a significant reduction in the volumetric quantity of ferrite [1–3]. The addition of Al, which is an important alloying element for mild steels, raises the Ae_1 and Ae_3 temperatures, allowing a higher intercritical annealing temperature and allowing shorter annealing times [4–6]. Si concentration (< 2 wt.%) is used to improve both strength and ductility. Si enhanced the hardenability and thermal decisiveness of austenite transformed from the martensite phase, resulting in a relatively high retained austenite fraction followed by an active TRIP mechanism [7]. Microalloying with Nb, Mo, V, and Ti allows to obtain fine-grained or ultrafine-grained multiphase microstructures containing a high retained austenite fraction with ideal stability for continuous strain-induced martensitic transformation during loads such as tensile, stretching and bending [8–11]. The internal structure of mid-Mn steels is characterized by being multiphase (ferrite, retained austenite, martensite), metastable, and multiscale [7, 12].

The production of mid-Mn steels requires critical annealing operations in the austenite and ferrite two-phase region, either straight after hot rolling of austenite or following cold rolling of the martensite phase in addition to hot rolling of austenite [12–17]. The stability of the austenite phase is a function of the critical annealing temperature and the concentration of Mn and C in austenite [18]. Nevertheless, the dimensional instability of cold-formed TRIP parts is very high due to the high plasticity at all deformation levels. This can be a problem during press forming. Alternatively, to overcome the major challenges associated with spring back of cold-formed mid-Mn steels, studies on hot forming of mid-Mn steels have recently been conducted and positive developments have been reported [19].

In this study, the effects of tempering heat treatment on medium Mn steels were investigated. The produced medium manganese steels were evaluated microstructural and mechanically by tempering process applied at different temperatures after conventional heat treatment. Microstructure and retained austenite (RA) phase were investigated by SEM, EDS and XRD analyses. The mechanical performances of tempered medium Mn steels were evaluated by tensile and hardness tests. Finally, the effect of tempering on the fracture behavior was investigated with the SEM images taken from the rupture surfaces.

2. Experimental Studies

In this section, information is given about the manufacture of the experimental mid-Mn steel used in this study and the analysis and test methods applied to the samples. The results obtained from the analyses and tests are discussed in relation to each other.

2.1. Material and Method

In this work, medium Mn steel, whose chemical composition is given in Table 1, was used. A three-stage heat treatment cycle was applied to the samples taken from medium Mn steel, which was brought into sheet form by hot forging after casting.

Table 1. Chemical compound of experimental steel (wt.%)

C	Mn	Cr	Si	Mo	Ni	Al
0.16	5.54	1.19	0.3	0.26	0.12	0.11

The samples were first subjected to normalization at 900 °C. Subsequently, they were annealed at 800 °C for 60 minutes and cooled in water, then tempered at 250 and 300 °C for 60 minutes. The heat treatment conditions of the samples are given in Table 2. The microstructural changes were investigated by SEM, EDS and XRD analyses by comparing the tempered samples with the non-tempered sample. The mechanical performances of the samples were evaluated by hardness and tensile tests.

Table 2. Heat treatment conditions

Sample	Annealing Temperature (°C)	Annealing Time (min.)	Tempering Temperature (°C)	Tempering Time (min.)
S1	800	60	-	-
S2	800	60	250	60
S3	800	60	300	60

2.2. Results and Discussion

The SEM images of the untempered S1 sample and the S2 and S3 samples tempered at 250 and 300 °C respectively are given in Figure 1.

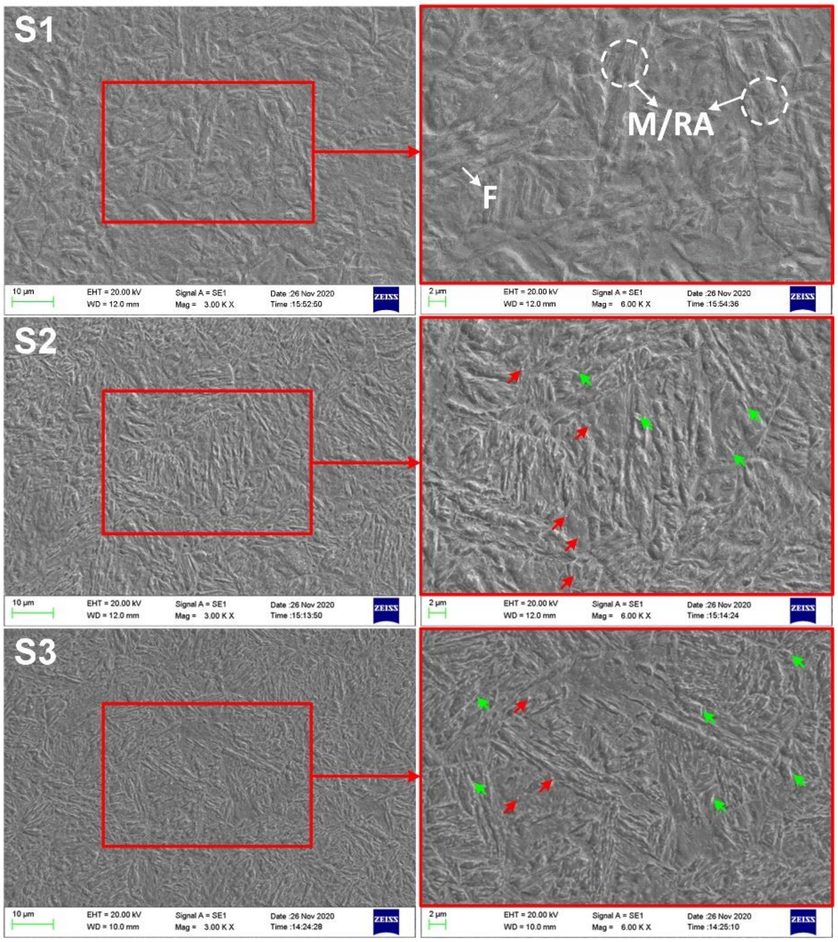

Figure 1. SEM images of S1, S2 and S3 samples.

When the SEM images of the samples were examined, it was observed that the internal structure of the non-tempered S1 sample occurred of the martensite matrix with a small amount of ferrite and RA phases. In the microstructure images of the tempered samples, it was determined that the martensite phase was tempered and cementite was formed in the internal structure. Cementite carbides were observed to be in both globular and lath form, and in the SEM micrograph of the S2 sample tempered at 250 °C, these carbides are indicated by red and green arrows, respectively (Figure 1). When the tempering temperature was increased to 300 °C, it was observed that the amount of tempered martensite increased, and an increase in cementite density and size was observed. It was determined that especially the lath-shaped cementite carbides increased and some carbides became bigger. The presence of cementite (ϴ) in the microstructure after tempering was also observed in the XRD analysis results (Figure 2).

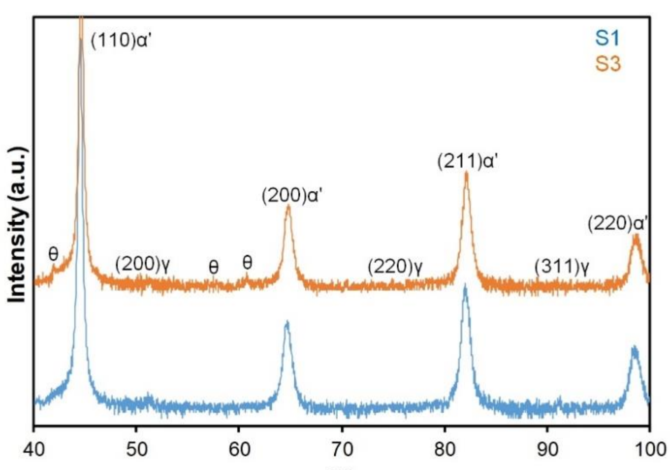

Figure 2. XRD patterns of S1 and S3 samples.

The retained austenite phase continued to exist in the internal structure after tempering. According to the results obtained from the XRD analyses, it was determined that a significant part of the retained austenite was not dissolved, although there was a reduction in the volumetric quantity of the RA phase. It has also been stated in different studies in the literature that the retained austenite phase is unstable at higher tempering temperatures [20, 21]. EDS analyses show that the retained austenite is somewhat enhanced in terms of Mn and C due to the reduction in the volumetric quantity of RA. The changes in the volumetric quantity and compound of the retained austenite phase depending on the tempering temperature are given in Table 3.

Table 3. Volumetric quantity and compound of RA

Sample	Volumetric Quantity of RA (%)	Compound of RA (wt.%)	
		Mn	C
S1	8.1	5.52	0.18
S2	7.0	5.79	0.20
S3	6.7	5.89	0.21

When the results obtained from the tensile and hardness tests applied to the samples are examined; It was determined that the tensile strength and hardness values of the samples decreased, while the elongation amount increased due to the tempering of the martensite phase depending on the tempering heat treatment (Table 4).

Table 4. Mechanical test results of samples

Sample	Tensile Strength (MPa)	Total Elongation (%)	TS x TE (GPa.%)	Hardness (HRC)
S1	1553	8.9	13.8	47.4
S2	1099	19.9	21.9	39.7
S3	1067	16.2	17.3	39.2

When the tensile strength (TS) and total elongation (TE) of the samples are considered together, it was observed that the tempering heat treatment significantly improved the TSxTE combination in S2 and S3 samples. However, as a result of the decrease in the total elongation along with the tensile strength in the S3 sample, the TSxTE combination fell behind the S2 sample (Figure 3). Despite the increase in the tempering temperature, the reduction in the TE can be attributed to the coarsened lath-shaped cementite carbides in the microstructure [20, 22].

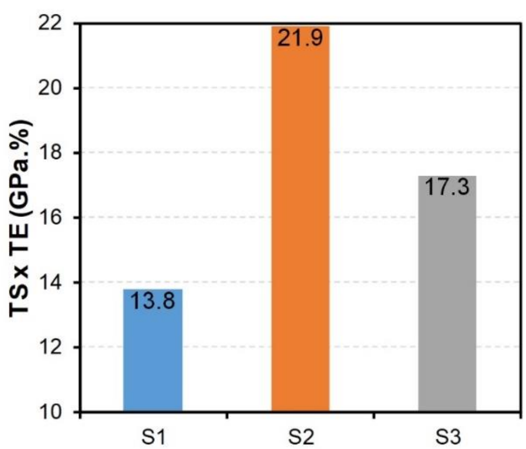

Figure 3. TS x TE combination of samples

When the SEM images taken from the fracture surfaces of the samples are examined, it can be said that there are mixed type fractures in all of the samples (Figure 4). In addition, it was observed that the brittle fracture mechanism was more dominant in the S1 and S3 samples, and the ductile fracture mechanism was more dominant in the S2 sample. This situation is also compatible with the total elongation values.

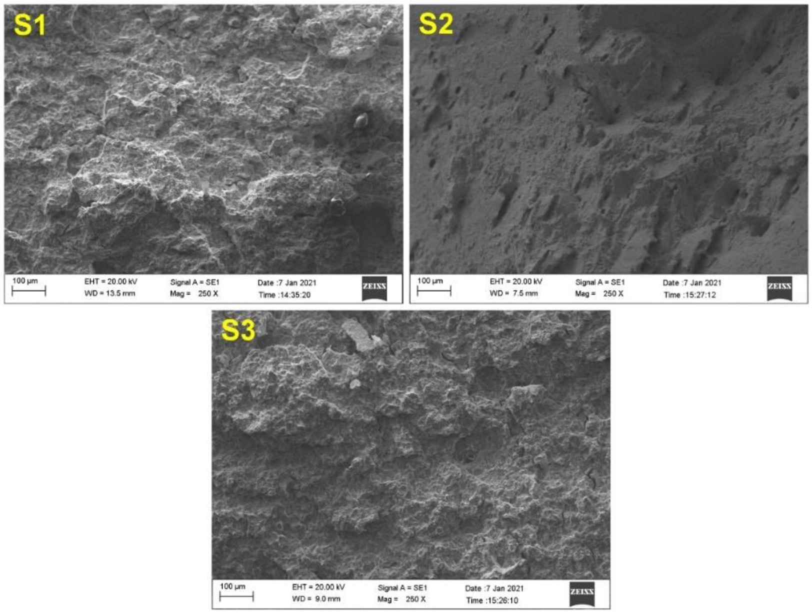

Figure 4. Fracture surface images of samples

3. Conclusions

In this work, the effects of the tempering process on the internal structure and mechanical properties of experimental medium Mn steel were investigated and the following results were obtained:

- The microstructure before tempering consists of a martensite matrix with small amount of ferrite and retained austenite phases. After tempering, the martensite matrix began to be tempered and cementite carbides were formed in the internal structure.
- It has been observed that higher tempering temperatures are required for the retained austenite phase to become unstable.
- The tempering heat treatment has improved the TS x TE combination. The best combination of TS x TE was obtained by tempering heat treatment at 250 °C (21.9 GPa.%).
- Mixed type fracture was observed in all samples. The tempering heat treatment increased the efficiency of the ductile fracture mechanism.

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