International Journal of ISSI, Vol. 14 (2017), No. 2, pp. 33-37

Influence of Cu and Ni on the Microstructure and Mechanical Properties of an HSLA Steel

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Abstract

In this research the role of alloying elements on the microstructure and mechanical properties of an as cast and hot rolled high strength low alloy (HSLA) steel was studied. Different compositions with different amount of copper in the presence of nickel, hot rolled and quenched in oil. Tensile test, hardness test, scanning electron microscope (SEM) and optical microscope (OM) were used to evaluate different properties of each sample. The results showed that, all the samples revealed a ferrite-perlite structure in as cast structure, however finer structure with higher hardness was seen in the samples with higher amount of copper. Furthermore, in hot rolled samples, it was seen that addition of nickel and copper resulted in grain refinement. A remarkable drop was seen in elongation due to copper precipitation. Fractography also revealed that, increasing copper amount led to variation of fracture mechanism from ductile to shear ductile fracture.

Keywords: HSLA steel; Composition; Mechanical properties; Microstructure.

1. Introduction

The high strength low alloy steels (HSLA) with excellent mechanical properties based on the strengthening mechanisms of grain refinement, solid solution strengthening, dislocation strengthening, and particle precipitation have been paid increasing attention in the past decades [1, 2)]. Additionally, HSLA steels are used for structures such as bridge, building, pressure vessel, offshore and pipeline structures have steadily required to have higher strength as well as toughness and improved weld ability. In recent years, there has been a growing demand for improved mechanical properties in steel structures subjected to the progressive and abrupt displacements resulting from ground movement, earthquake, and load itself [3, 4)]. Thermomechanical processing and heat treatment techniques as well as alloying elements can be used as the most promising methods to achieve a good balance of mechanical properties such as strength, toughness, and formability. Multiphase microstructures consisting of polygonal ferrite (PF), pearlite, acicular ferrite (AF) bainite (Ba) and martensite (M) can be produced in a great variety of HSLA low carbon steels as a result of an appropriate combination of methods [3, 5, 6)].

Different alloying elements such as Ti [7)], Mo [8)], V [9)], Cu [2, 3, 10)] and Ni [11, 12)] were added to the steels in order to improve mechanical properties. Junhua et al. [8)], revealed that, addition of Mo up to 0.4 wt. % to an HSLA steel leads to formation of nonequilibrium phases such as AF and Ba. Consequently, mechanical properties of the steel improved comparing to Mo free sample. Staśko et al. [13)], reported that N promoted the grain growth of austenite. However, the microalloying addition of vanadium protected the austenite grain growth because of carbonitride V(C, N) precipitation and the grain boundary pinning effect of undissolved particles of V(C, N). Also, Bose-Filho et al. [7)], reported that with a further increase in the hardenability, by Ni, Mo and Cr additions, the microstructure has changed from a mixture of allotriomorphic ferrite, Widmanstätten ferrite, AF and microphases to a mixture of AF, Ba, low carbon M and microphases. Additionally, several research [2, 10, 14)], illustrated that the presence of Cu between 1 to 2 wt.% developed the mechanical properties through, grain refinement, solution hardening, increasing remaining austenite and enhancement the formation of AF. However hot rolling problems increase due to high amount of copper.

The present work focuses on the investigation of microstructure and mechanical properties of an HSLA steel by addition of different amount of Cu to the steel in the presence of Ni. Therefore, tensile test, hardness test, SEM and OM were used to evaluate the properties.

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2. Materials and Experimental Procedures

The chemical composition of the HSLA steels used in this study are shown in Table. 1. Ingots of 8 kg of S, S1, S2 and S3 steels were casted using an industrial induction melting furnace (150 kW, 150 kg, Sholekar Iran). In order to study the effects of copper and nickel, 0.2 wt. % of nickel was added to S1, S2 and S3. 0.1, 0.2 and 0.4 wt. % of copper were also added to S1, S2 and S3 respectively. The ingots were homogenized at 1200 °C for 2 h. Using a rolling mill at Isfahan university of technology (IUT) with loading capacity of 40 t (Ohno roll, 2419 Japan), samples were hot rolled in a single pass to 50% reduction between temperatures of 990 to 750 °C. Finally, hot rolled samples were quenched in oil.

Microstructure of the as cast and hot rolled samples were observed by optical microscope (Olympus, BH2-UMA, Japan) and scanning electron microscope (Philips, XI30, Netherland). Also, SEM characterization was performed to investigate the fracture behavior of the samples after the tensile test from the top view on the center of fracture surfaces.

Uniaxial tensile test using a Hounsfield (H50KS, England) machine was performed on the samples in order to investigate mechanical properties. The tensile test samples were machined from the hot rolled specimens according to the ASTM E8M standard, to get oriented along the rolling direction. The thickness, gauge width and length of the tensile test samples were 3, 6 and 25 mm respectively. Three tests were done at the room temperature for each sample. Vickers hardness test was also done on the samples under a load of 30kg and time of 30 s.

3. Results and Discussion

Fig. 1 shows the OM micrographs of the as cast samples. It can be seen that, all the structures consist of ferrite and perlite phases. Needle-shaped perlite grows up in different directions in a ferrite structure. In order to have a better look, Fig. 2 reveals the structure of a white needle shape. In Fig. 1a it is obvious that, white needle shapes are perlite phase in the ferrite matrix.

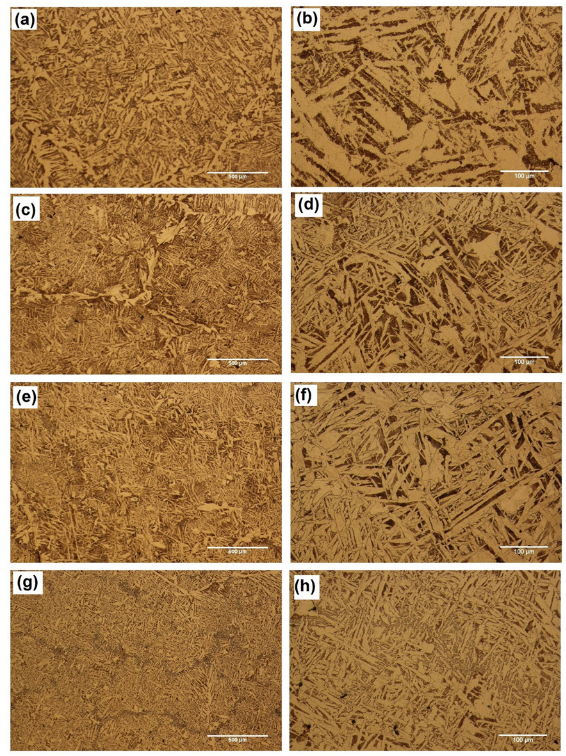

Fig. 1. OM micrographs of the as cast samples with different amount of copper, a and b) without copper, c and d) 0.1 wt. %, e and f) 0.2 wt. % and g and h) 0.4 wt. %.

Table. 1. Chemical compositions of the as cast steels.

Steel	Fe (%)	C (%)	Mn (%)	Si (%)	P (%)	S (%)	Ni (%)	Cu (%)	Ti (%)	V (%)	Nb (%)	Al (%)
S	97.5	0.14	1.5	0.30	0.02	0.005	0.02	0.03	0.001	0.002	0.004	0.2
S1	97.1	0.15	1.4	0.40	0.02	0.005	0.23	0.12	0.001	0.002	0.005	0.2
S2	97.4	0.16	1.4	0.40	0.02	0.004	0.23	0.21	0.001	0.002	0.004	0.2
S3	97.2	0.15	1.4	0.40	0.02	0.006	0.23	0.44	0.001	0.002	0.005	0.1

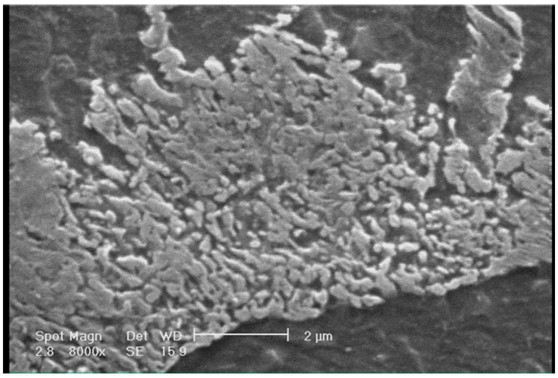

Fig. 2. High magnification image of a needle shape perlite in S sample.

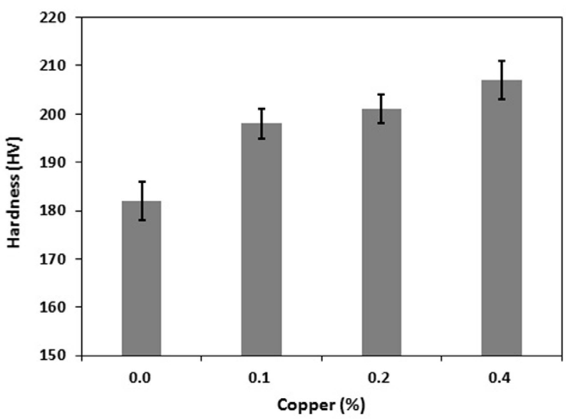

Fig. 3. Hardness variation with copper amount.

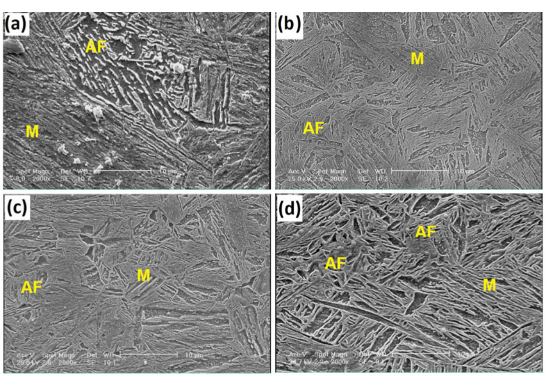

Fig. 4. SEM micrographs of the a) S, b) S1, c) S2 and d) S3 after hot rolling and quenching in oil.

Furthermore, Fig. 1 illustrates that by addition of 0.2 wt. % nickel and 0.1 wt. % copper, the grain refinement and decrease in ferrite and perlite size occur (see Figs. 1c and d). Additionally, increasing in copper amount also, lead to decreasing in needle shape size. Comparing Figs. 1a and g, obviously shows the reduction in gran size and also the needle shape size.

Generally, the presence of copper in the steels lead to finer structures [5, 11, 15, 16)]. Mechanical properties of the steel can be affected due to this grain refinement. Fig. 3 reveals the variation of hardness with amount of copper for S to S3 samples. It can be seen that addition of 0.2 wt. % nickel and 0.1 wt. % copper to S sample results in 9% enhancement in the hardness. However, by increasing the amount of copper to 0.2 and 0.4 wt. %, the hardness of the S1 and S2 samples increase about 10 and 14% respectively, comparing to S sample. The presence of the nickel, increases the hardness of the steels [11, 12)]. However, as shown in Fig. 1, increasing in copper amount in S1 to S3 samples led to refinement in ferrite-perlite structure, which has a great impact on increasing the hardness.

In order to study the effects of alloying elements on the mechanical properties of the HSLA steel, S, S1, S2 and S3 samples were hot rolled and quenched in oil. Fig. 4 depicts the microstructure of these samples. An almost fully martensitic structure can be seen for the S and S1 samples (see Figs. 4a and b). Growth of M phase from the grain boundaries in specific directions is obvious in this figure. By increasing the copper amount in the sample, variation in structure can be seen. Reduction in M portion and increasing in AF ladle which grows in different directions is obvious in Figs. 4c and d. Enhancement in AF phase in steels due to increasing in copper amount was also reported elsewhere [5, 17)].

Fig. 5a reveals the stress strain curves for the S to S3 samples. It can be seen that strength of the samples increases by the copper amount. Tensile properties with addition of nickel and copper are shown in Fig. 5b. By addition of 0.2 wt. % nickel and 0.1 wt. % copper, the UTS increased about 35% and the elongation decreased about 30 %. However, by increasing the copper amount to 0.2 and 0.4 wt. %, small increase in the UTS and elongation was seen simultaneously. The presence of copper and nickel can improve the mechanical properties of steel [5, 11, 12, 16-19)]. As shown in Fig. 4 enhancement in copper amount leads to formation of AF in steel structure. Generally, AF blades nucleate and form from inclusions and precipitates and grow up in different directions, however martentisic blades nucleate in the grain boundaries and grow up in a same direction into the grains. Consequently, crack path increases significantly and as a result, crack growth between AF blades decreases comparing to M, which leads to enhancement in strength [20, 21)]. In addition, formation of the copper precipitates can affect the mechanical properties of the steel. Generally, during deformation, nano-sized precipitates can impede dislocation motion and grain boundary migration, which lead to an increase in the strength and decrease in elongation.

Hardness variation of hot rolled samples with copper amount is shown in Fig. 6. About 8% enhancement in

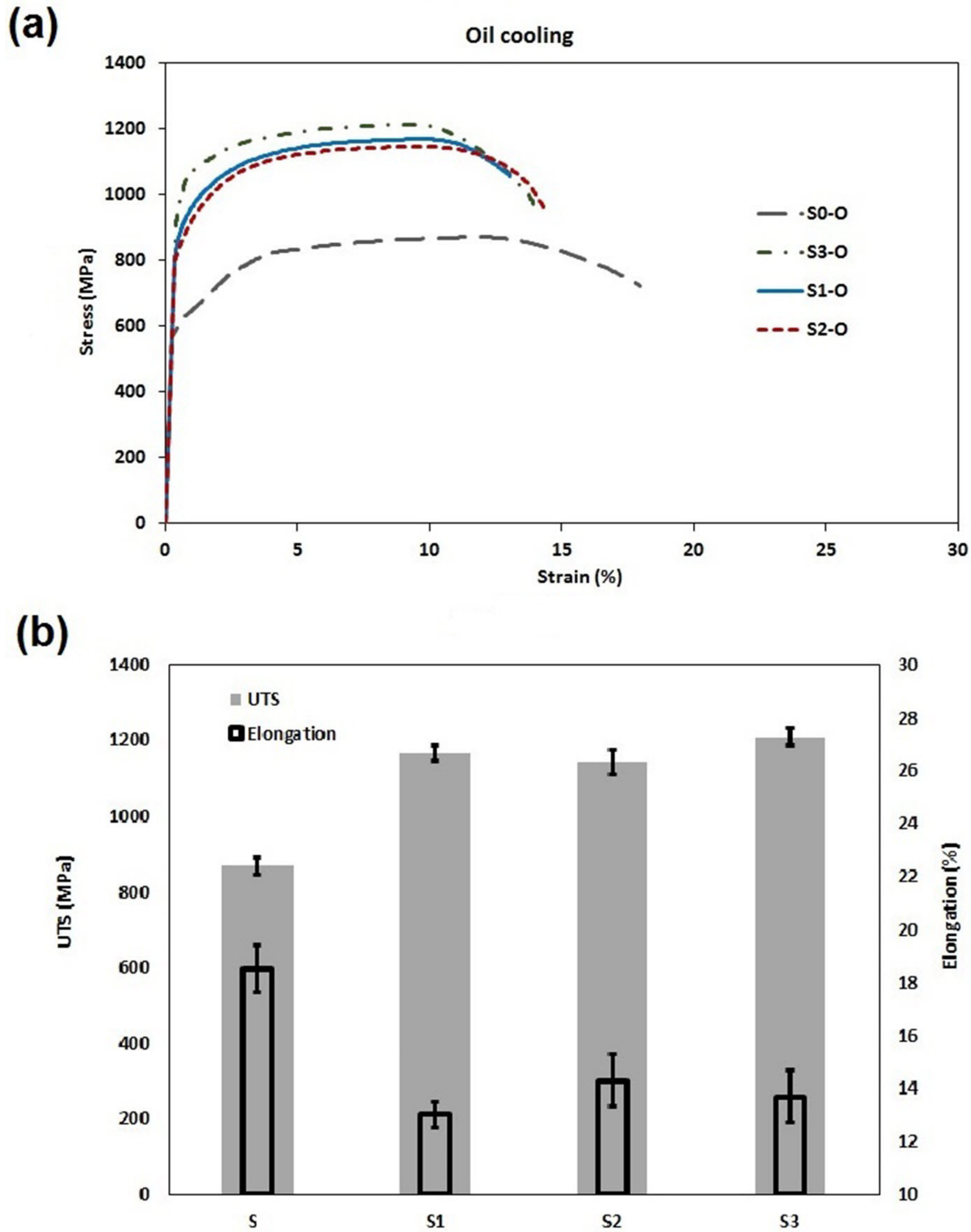

Fig. 5. a) Stress-strain curve and b) tensile properties of the S to S3 samples quenched in oil.

the hardness was achieved due to the presence of 0.2 wt. % nickel and 0.4 wt. % copper. As explained, formation of AF and copper precipitate are the main reasons for increasing in the hardness.

Fracture surface of the tensile test samples were studied using SEM in order to evaluate fracture mechanism. Fig. 7 reveals the fractographs of the S to S3 samples quenched in oil. It can be seen that the S and S1 samples reveal almost ductile fracture with deep equiaxed dimples. Generally, ductile fracture happens by the formation and coalescence of microvoids ahead of the cracks and very limited dislocation activity. Small microvoids form in the material due to plastic deformation during tensile test, mostly between different phases and besides inclusions. Then, these microvoids grow and begin to join together (coalesce), final failure occurs when the walls of the material between the growing voids finally break [22]. Crack growth with excessive plastic deformation and formation of a rough fracture surface with equiaxed, deep dimples are generally seen in the fracture surfaces of the ductile samples [22]. As shown in Figs. 7a and b, a rough fracture surface with a large num-

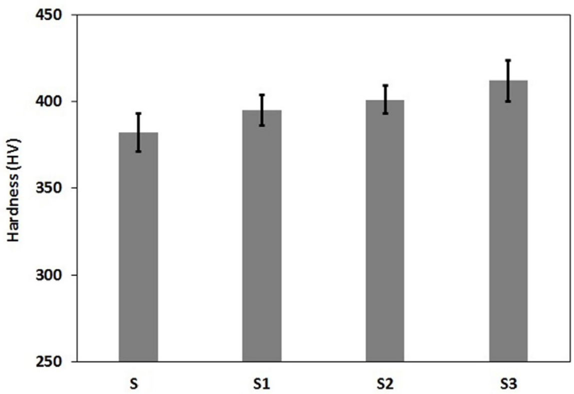

Fig. 6. Hardness variation for S to S3 samples.

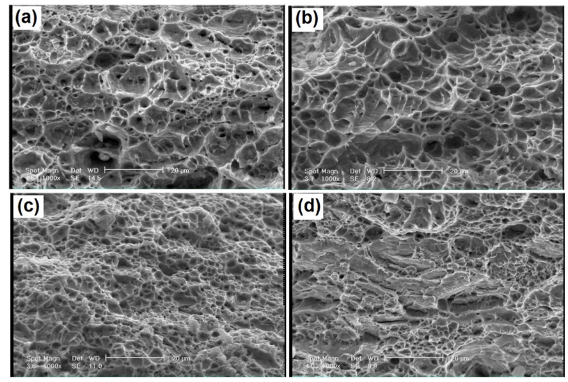

Fig. 7. Fractographs of the a) S, b) S1, c) S2 and d) S3 samples after quenching in oil.

ber of equiaxed dimples form for these two samples. However, by increasing the copper amount, the size and depth of the dimples are reduced in S2 sample. By increasing the copper amount to 0.4 wt. %, the equiaxed dimples were changed to shear dimples (shear ductile fracture). The shear ductile fracture was characterized by shallow small elongated shear dimples oriented along the shear direction. This fracture mode involved internal shearing between voids. In shear ductile fracture, slip bands impinge on the impurities and inclusions, causing local strain concentrations which nucleate the voids. The growth of the formed voids decreases due to the dominating shear stress state, the voids will undergo substantial shearing and the final failure is then caused by the internal void shearing mechanism [22, 23]. Therefore, by increasing the copper amount, fracture mechanism changed from ductile to shear ductile fracture.

4. Conclusions

Microstructure and mechanical properties of an HSLA steel were investigated by addition of copper and nickel during controlled rolling. The following conclusions could be drawn from this research:

- All the samples revealed a ferrite-perlite structure in as cast structure, however finer structure with higher hardness was seen in samples with higher amount of copper.
- Addition of nickel and copper to the sample resulted in grain refinement, enhancement in AF phase and copper precipitation.
- Mechanical properties of the steel improved by copper amount, however elongation decreased.
- Enhancement in copper amount led to variation of the fracture mechanism from ductile to shear ductile fracture.

References

[1] L. Baker, J. Parker, S. Daniel: Mater. Sci. Technol., 18(2002), 541.

[2] A. Guo, X. Song, J. Tang, Z. Yuan: J. Mineral. Metall. Mater., 15(2008), 38.

[3] B. Hwang, C. G. Lee: Mater. Sci. Eng. A., 527(2010), 4341.

[4] L. F. Porter, P. E. Repas, JOM, 34(1982), 14.

[5] M. Avazkonandeh-Gharavol, M. Haddad-Sabzevar, A. Haerian: Mater. Des., 30(2009), 1902.

[6] I. Tamura, H. Sekine, T. Tanaka, C. Ouchi: Thermo-mechanical processing of high-strength low-alloy steels, Butterworths London, 1988.

[7] W. Bose-Filho, A. Carvalho, M. Strangwood: Mater. Charact., 58(2007), 29.

[8] K. Junhua, Z. Lin, G. Bin, L. Pinghe, W. Aihua, X. Changsheng: Mater. Des., 25(2004), 723.

[9] J. H. Park, Y. G. Kweon, H. J. Kim, I. B. Kim: ISIJ. Int., 40(2000), 1164.

[10] A. Ghosh, B. Mishra, S. Das, S. Chatterjee, Mater. Sci. Eng. A., 396(2005), 320.

[11] R. DePaul, A. Kitchin: Metall. Mater. Trans. B., 1(1970), 389.

[12] N. Imai, N. Komatsubara, K. Kunishige: ISIJ. Int., 37(1997), 224.

[13] R. Staśko, H. Adrian, A. Adrian, Mater. Charact., 56(2006), 340.

[14] A. Ghosh, S. Das, S. Chatterjee, B. Mishra, P. Ramachandra Rao: Mater. Sci. Eng. A., 348(2003), 299.

[15] M. Fine, D. Isheim: Scripta. Mater., 53(2005), 115.

[16] S-J. Kim, C. G. Lee, T-H. Lee, C-S. Oh: ISIJ. Int., 42(2002), 1452.

[17] A. Das, S. K. Das, S. Tarafder: Metall. Mater. Trans. A., 40(2009), 3138.

[18] S. Lee, J. Kim, S-J. Lee, B. C. De Cooman: Scripta. Mater., 65(2011), 1073.

[19] Mintz B, Abushosha R, Crowther D, Mater. Sci. Technol., 11(1995), 474.

[20] F. Barbaro, P. Krauklis, K. Easterling: Mater. Sci. Technol., 5(1989), 1057.

[21] R. Ricks, P. Howell, G. Barritte: J. Mater. Sci., 17(1982), 732.

[22] A. Shabani, M. R. Toroghinejad: J. Mater. Eng. Perform., 24(2015), 4746.

[23] D. P. Fairchild, D. G. Howden, W. A. T. Clark: Metall. Mater. Trans. A., 31(2000), 641.