The 57th International October Conference on Mining and Metallurgy
05 - 07 October 2026, Bor Lake, Serbia
https://ioc.irmbor.co.rs

DOI: 10.5937/IOC26311K Original Scientific Paper-Metallurgy

DESIRED CONCENTRATIONS OF COPPER AND BORON IN HSLA STEEL

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Abstract

The problem of desired concentration of any alloying element is one constant problem, either technical or economical. Boron and copper are not main alloying elements in many kinds of steel, but even though they may play an important role in HSLA (High Strength Low Alloy) steels. Boron is one of the typical interstitial elements while copper has larger atomic radius. Boron is using in production of many kinds of nonferrous alloys or steels for a microalloying, in recent years. Alloying with boron improves very desired properties of many kinds of steel and/or iron, as well in some copper alloys. Copper is added in some steels to improve particular properties, as anticorrosion properties and strength, but later is not enlarged at a great amount. Boron and copper are important as microalloying elements in some HSLA steels because they show synergetic effect.

Most users know for what the boron is added into copper and/or steel for improving the mechanical properties (yield or tensile strength), then fracture toughness, fatigue resistance, hardenability, corrosion resistance, etc. The list of improved technological properties after adding of those elements (boron and copper) during a production periode is long, beggining from the melting, dezoxidation, refining, crystallization and/or casting process (fluidity).

Keywords: *copper&boron in HSLA steel, metallurgical limitations*

1. INTRODUCTION

HSLA steels belong to a large group of microalloyed steels, in which the carbon contest is low (0.05-0.25%), with manganese in amount 1.2-2%, supplying good weldability and formability. Boron today is useful as an alloying element in many materials, not obviously with their metallic nature, so it needs further explanation and investigation. The presence of other (micro)alloying elements as: Cr, Ni, Mo, V, Nb. Ti, Zr and/or N, are welcome in various but limited concentrations, also could be said for the presence of copper, boron, or both of them.

The effect of boron addition and ausforming on the structure of low carbon low alloyed steel after the transformation of austenite has been investigated in a wide range of cooling rates. It is shown that boron hinders formation of polygonal ferrite in continuous cooling.

Their concentrations should be known and strictly controlled not only by providing chemical analysis, but also controlling mechanical properties and from metallurgical reasons is necessary to provide the metallographic monitoring over obtained microstructures.

Classical HSLA steels after hot forging or rolling and slow cooling possess ferrite-pearlite microstructure. Some microalloing elements can provide the precipitation strengthening. Formed precipitates consist of carbides, carbonitrides and/or intermetallic compounds.

The solubility of microalloying elements in ferrite is extremely low, only a few ppm or less. Microalloying elements may form precipitates from single carbides (VC, NbC, TiC), nitrides or carbonitrides [V(C,N), Nb(C,N)], while in multimicroalloyed steels may be formed complex precipitates as (Ti,Nb)(C,N), etc.

2. BRIEFLY ABOUT HSLA STEELS

There are a number HSLA steels with slightly differential contest of alloying elements, where copper and boron are not obligate but welcome. In comparison to conventional carbon steels, HSLA steels with copper show better resistance to atmospheric corrosion, so these steels are widely used for flat and/or long products, as pipes for oil and gas transport, in shipbuilding industry, at automotive industry for auto frames, Fig. 1a), or other automotive parts.

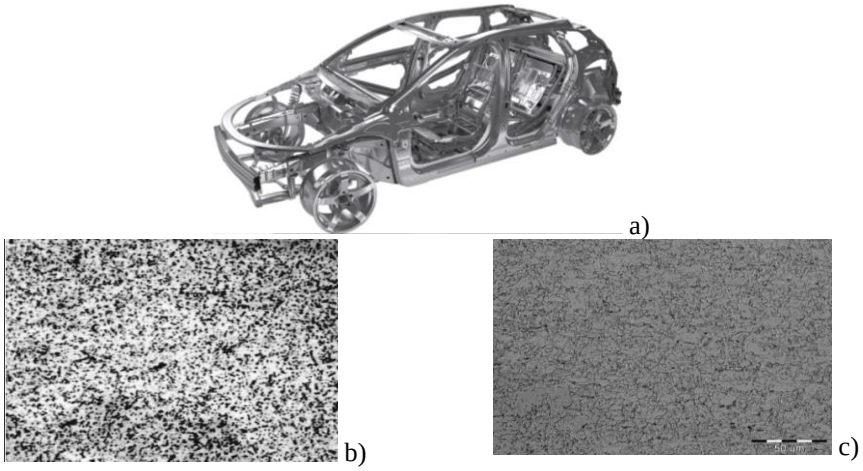

Fig. 1. *a) SSAB automotive steel frame from HSLA steel; microstructures of: b) normalized x500 and c) quenched and tempered; Note: steels from Figs. b) and c) are not identical in contest*

At the beginning of processing, it means after normalizing, the „classical“ HSLA steel consist of ferrite, and carbide globules, Fig. 1b). Those steels are available for quenching and tempering [4 6], when the structure is refined into multiphase microstructure of bainite in ferrite matrix with fine carbides and tempered martensite, in Fig. 1c) is presented just one case. The amount of martensite in structure after quenching, however, depends on the cooling rate

3. COPPER & BORON IN HSLA STEEL

Copper in steel Copper has a mild effect on the transformation behavior of steels. Copper in concentrations above 0.5% acts as a strengthening element, particularly at

low-carbon steel, increasing the yield strength during tempering/aging, forming a dense but protective layer from corrosion in atmospheric or marine conditions. In HSLA steels copper typically is present in amounts 0.2-0.5%, enhances strength through precipitation hardening, changing the micro- structure [4-6] without significant loss of ductility. The enhance of yield strength is achieved through forming of nanoprecipitates (1-10nm), which are formed in aging treatment usually at 450-600^{0}C. At early stage, these precipitates possess BCC lattice which converts into FCC lattice.

How hardness values are changed during aging for group of multialloyed HSLA steels [5] are shown in Fig. 2a) for S1 steel, where Charpy values also are complex, aged for 1h, Fig. 2b).

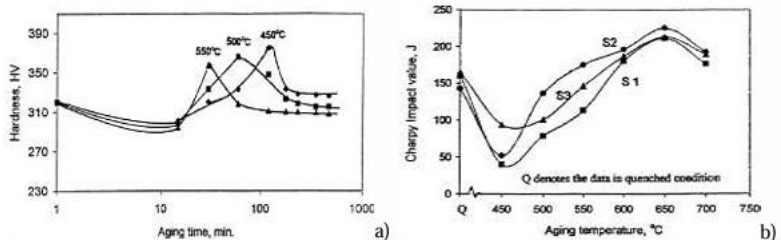

Fig. 2. *a) Hardness changes vs aging time and b) Charpy values vs aging temperature for 1h*

Boron in steel An expanding area of boron usage is in HSLA, together with other structural steels. Boron shows a small solubility into iron, also at other alloying elements from steel, forming two borides (Fe_2B and FeB). Those borides, in comparison to other carbides or nitrides from steel, possess greater values of hardness, oxidation resistance at high temperatures, and from that reason could be explained good properties of steel against creeping. Boron is added in steels almost in small quantities, usually around 10-100ppm, rarely in greater amounts about 0.2%, only in few rare cases up to 3% [5].

Boron requires careful addition during steel or other alloy production to ensure effectiveness. Reaction of oxygen against boron could be prevented by previously killed steel. If strong nitride formers as Al, Ti and Zr were used, they protect boron to react with N. Boron as a microalloying element may be present at various carbon steels, carbon manganese, other microalloyed steels including HSLA, sometimes at tool steels. These steels are supplying as hot rolled or quenched and tempered (the latter being more common for boron grades). In the automotive industry, boron steel gained popularity, with improved weldability, some weldable bainitic steels micro-alloyed with boron may reach tensile strength in range 530–1200 MPa.

The HSLA steel without boron exhibits a low creep rupture strength about 1000h at 650°C, but with boron, the time to rupture significantly increases under [3-5].

Copper – boron system For a complete monitoring of possible action of alloying elements, it is needed to know the reaction between copper and boron, even at still. Boron with copper does not forms any hard compound, but boron could be used for improving a lot of properties in copper, as: improving fluidity, reducing gas holes, castings quality, refining grain structure, increasing strength, hardness, minimizing reduction of electrical conductivity, etc. Other deoxidants in copper markably reduce conductivity. Copper alloys with boron are not in wide use The optimal amount of residual boron at almost alloys is at level of 150 ppm (0.015%), in copper it means achieving the best combination of strength, elongation, and conductivity. Other large group of boron alloys are copper master alloys, commonly with 2% B.

4. CONCLUSION

HSLA steels have been used in a wide range of applications from automotive to ship building industry, etc. due to their low weight, formability and good weldability. The high strength is achieved by good combination of grain refinement and precipitation strengthening, with minor additions of microalloying elements (V, Nb or Ti). Copper is added in HSLA steels for enhancing mechanical properties, when ductility was not endangered, with improved corrosion resistance. Boron steels were originally designed for hard and wear resistant machine components. Additional alloying of this kind of steel by boron and copper improving the properties of HSLA steels. The microstructures of the HSLA steels markably depend on the cooling ragime after hot deforming, i.e. from the provided quenching and temperaing/ageing.

Desired concentrations in HSLA steels for copper and boron usually are: for copper up to 0.5wt%, and for boron maximum increasing of hardenability is achieved after adding 10 30wt.ppm, but in majority of reviews may be found recommend boron contents between 5 20wt.ppm. Concentration limits, however, depends on the presence of other alloying elements.

REFERENCES

[1] T.G. Digges, C.R. Irish, N.L. Carwile: Effect of Boron on the Hardenability of High-Purity Alloys and Commercial Steels, U.S. Department of Commerce, National Bureau of Standards, J. of Research, Vol. 41/1948/p. 545-562.
[2] M.R. Krishnadev, G.J. Sojka, I.J. May, L.McD. Schetky, S.K. Banerji: Copper-Boron Low Alloy High Strenght Steels, Specialty Steels & Hard Materials, Proceed. of the Int. Conf. on Recent Developments in Specialty Steels and Hard Materials, Pretoria - South Africa 1982, Pergamon Press 1983, p. 195-200.
[3] N.P. Ljakišev, Ju.I. Pliner, S.I. Lappo: Borosoderžaščie stalji i splavi, in Russian, Moskva 1986, Metallurgija, p. 60-148.
[4] Z. Janjušević, Z. Karastojković et al: The influence of annealing parameters on microstructure of a HSLA steel, 43th IOC Kladovo- Serbia 2011, Proc. Book, p. 529-532.
[5] A.N. Bhagat, S.K. Pabi, S. Ranganathan, O.N. Mohanty: Aging behaviour in copper bearing high strength low alloy steels, ISIJ Int. 44/2004/1, p. 115-122.
[6] W. Wanlin, C. Dawei, et al.: Microstructure evolution and mechanical property of Cu-bearing high-strength steel produced by stimulated strip casting, Metallurgical and Materials Transactions B, 54/2023, p. 833-850.
[7] M. Opielka: Effect of boron microaddition on hardenability of new-developed HSLA-type steels, Archives of Materials Sci. and Engineering, 99/2019/p. 13-23.
[8] M.K. Banerjee, D. Gosh, S. Data: Effect of composition and thermomechanical processing on the aging characteristics of copper-bearing HSLA steel, Scandinavian J. of Metallurgy, 29/2000, p. 213-223,
[9] S. Gorsse, B. Ouvrard, M. Gouné, A. Poulon-Quintin: Microstructural design of new high conductivity – high strength Cu-based alloy, J. of Alloys and Compound, 2015, 633, p. 42-47. 10.1016/j.jallcom.2015.01.234. hal-01122713
[10] Zh. Changle, L. Shouhai, L. Yinghua, J. Jiang, F. Hanguang: Effect of boron on microstructure evolution and properties of wear-resistant cast Fe-Si-Mn-Cr-B alloy, J. of Materials Research Technology, 9/2020/3, p. 5564-5576.