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Physico-metallurgical Study for Recycling Steel (Suppression of Surface Hot Shortness by Cu)

Koji Shibata, Seok-Jong Seo*, Kentaro Asakura** and Yoshikazu Akiyama***
Department of Metallurgy, The University of Tokyo, 7-3-1, Hongo Bunkyo-ku, Tokyo 113-8656
Fax:81-3-5802-8861, e-mail:kshibata@steel.mm.t.u-tokyo.ac.jp
*Superconductivity Research Laboratory, International Superconductivity Technology Center,
1-16-25, Shibaura, Minato-ku, Tokyo 105
fax : 03-3454-9287, e-mail:seo@istec.or.jp
**Department of Metallurgy, The University of Tokyo, 7-3-1, Hongo Bunkyo-ku, Tokyo 113-8656
Fax:81-3-3815-8363, e-mail:asakura@steel.mm.t.u-tokyo.ac.jp
***Graduate course student (Lab. of steel materials)
Department of Metallurgy, The University of Tokyo, 7-3-1, Hongo Bunkyo-ku, Tokyo 113-8656
Fax:81-3-3815-8363, e-mail:akiyama@steel.mm.t.u-tokyo.ac.jp

The most serious problem in recycling steel is surface hot shortness due to Cu in scrap iron. That is to say, Cu tends to be enriched at steel/scale interface by the preferential oxidation of Fe and causes liquid embrittlement at the steel surface during hot working. Many attempts to remove Cu from scrap iron or liquid steel have been done. But unfortunately the low-cost removal of Cu is not an easy task. Therefore, efforts must be made to reduce the problem due to Cu in mechanical working. Objective of the present research is to examine how to suppress the surface hot shortness due to Cu by physical metallurgy. The effects of alloying elements, working temperature, grain size etc. on the hot shortness susceptibility are discussed.

Key words : Steel, Recycling, Physical metallurgy, Cu, Surface hot shortness

1. INTRODUCTION

Accumulation of steel stock in Japan is estimated to have reached a billion tons. Together with such an enormous increase in steel accumulation, the occurrence of waste scrap of iron and steel is also increasing. Following the investigation of the future trend of scrap by JRCM (The Japan Research and Development Center for Metals) [1], generation of waste scrap of iron and steel is about fifty hundred million tons/year in 1995 and it is estimated to increase up to sixty five million tons/year in 2010. The maximum utilization of such a large amount of iron/steel scrap is desirable for global environmental protection. In these years, however, the quality of the scrap as steel making raw material has greatly worsened, making it difficult to recycle the scrap.

The most serious problem is the difficulty in removing Cu and Sn from the scrap. In addition, copper tends to be enriched at steel/scale interface by the preferential oxidation of Fe and cause liquid embrittlement at the steel surface during hot working. This phenomenon is called as surface hot shortness and Sn enhances sensitively this shortness by Cu. From such reasons, intense researches on reclamation technologies have been carried out by "New Steelmaking Process Forum" since 1991 in Japan and fruitful results have been obtained. As Noro et al. [1] has concluded in one of the reviews on the activities of this Forum, however, steel recycling cannot be pursued smoothly only by reclamation technologies and it must be supported by easily recyclable machine design and steel composition design capable to facilitate the removal of tramp elements together with the improvement of the social system of discarding and collecting the scrap. The present authors are agree with them, but like to insist that steel recycling must be supported also by technologies based on physical metallurgy which suppress the deteriorate effects of the tramp elements in processes after refining, especially in the hot deformation process. Objective of the present paper is to examine the ways to suppress the surface hot shortness due to Cu by physical metallurgy.

2. PROCEDURES

The base composition of steels used is 0.1%C-0.5%Mn-0.5%Cu and the compositions of Si, P, Ni, C, Mn and S were changed. Susceptibility to the surface hot shortness was evaluated by values of the parameters calculated from total elongation and maximum load obtained by tensile tests in air and in Ar gas at elevated temperatures (1373K not for especially mentioned). For instance, one of the parameters is calculated by the following Eq. (1).

$$Ep\,(\%) = [P(Ar) - P(air)] \times 100 / P(Ar) \quad \ldots\ldots\ldots (1)$$

where P (air) and P (Ar) were the maximum loads obtained by the tensile tests in air and in Ar gas, respectively. The feasibility of such parameters was examined in detail by the present authors in the previous paper [2].

3. RESULTS

3.1 Effects of Si, P, C , Mn and S in steel on susceptibility to the surface hot shortness

Effects of Si and P is shown in Fig.1. Ee and E'p are other parameters similar to Ep [2]. Alloying Si is useful to suppress the surface hot shortness. Extreme dephosperization enhances the shortness.

Figure 2 shows effects of Si, P and C on the surface hot shortness in the series of 0.45%C-0.5%Mn-0.5%Cu steel together with the effect of carbon. Silicon, P and C seem to be effective to suppress the shortness similarly to the case of 0.1%C-0.5%Mn-0.5%Cu steels. Manganese showed a suppressive effect and S enhanced this effect of Mn [3].

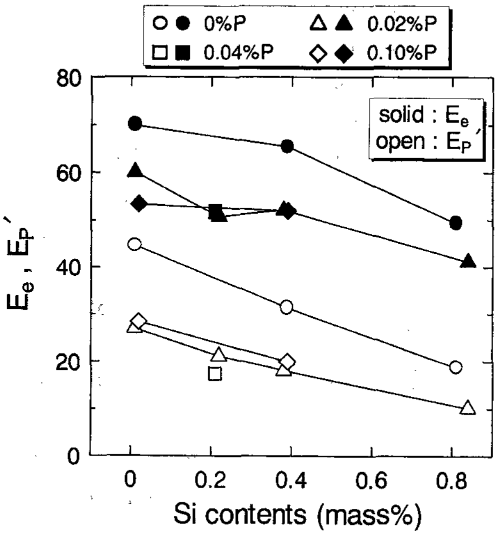

Fig.1 Effects of Si and P on susceptibility to the surface hot shortness of 0.1%C-0.5%Mn-0.5%Cu steels.

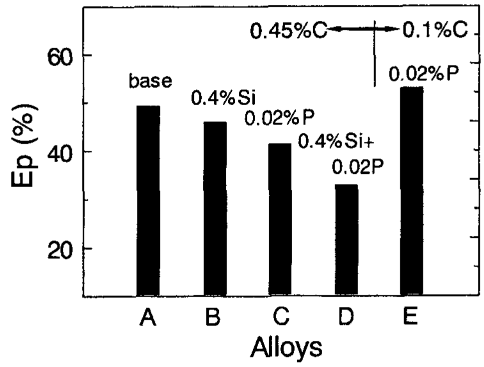

Fig.2 Effects of Si and P on susceptibility to the surface hot shortness of 0.45%C-0.5%Mn-0.5%Cu and 0.1%C-0.5%Mn-0.5%Cu steels.

3.2 Effects of Si and P in steel on morphology of the Cu enriched phase at steel/scale interface region

From micrography, it has been known that the amount of the Cu enriched phase at steel/scale interface is small in steels alloyed Si and the scale on the surface of steels containing Si seems to absorb Cu as shown in Fig.3 schematically. It is well known that Ni shows similar effects and Ni is used to suppress the surface hot shortness due to Cu for many years [4] - [6]. But Ni is expensive and also one of the elements which are most difficult to be removed by the present steelmaking process.

Figure 4 compares the susceptibility to the surface hot shortness between steels which are alloyed only Ni and steels which are alloyed Si together with Ni. By alloying Si with Ni, a smaller Ni amount can be used to reduce the susceptibility to the levels obtained by single , larger addition of Ni.

Recently the mechanism of the effects of Ni was examined and the details have been made clear [7] - [10]. Silicon does not decrease oxidation rate [11]. Internal oxidation is contributable to the occlusion of the Cu enriched phase into the scale layer but mechanisms of the effects of Si should be examined much more.

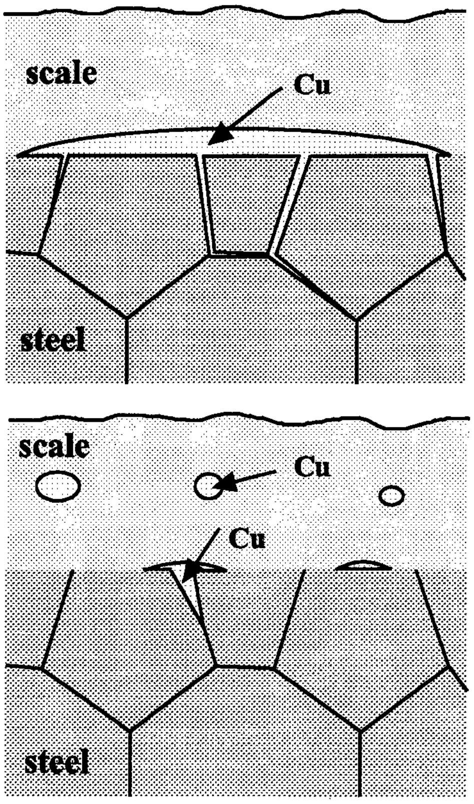

Fig.3 Schematic draws showing effects of Si in steel on Cu enriched phase near steel/ scale interface and in the scale. Bottom is for Si containing steel.

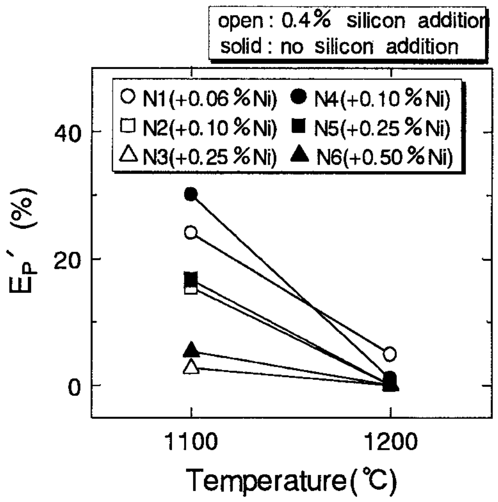

Fig.4 Effects of Si and Ni on the susceptibility to the surface hot shortness of 0.1%C-0.5%Mn-0.5%Cu steels.

3.3 Effects of Si and P in steel on the liquid brittleness due to pure Cu

In order to examine effects of alloying ellements on the degree of penetration of liquid Cu, tensile test and micrography were performed using specimens implanted a tough-pitch Cu rod as shown in Fig.5.

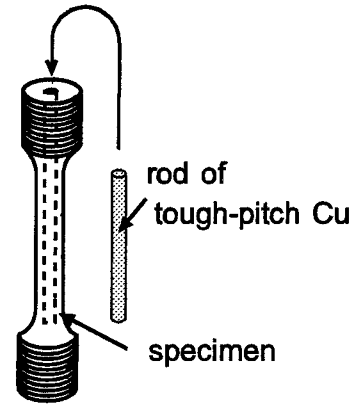

Fig.5 Schematic draw of a Cu-implanted specimen used to examin effects of alloying elements on the penetration of liquid Cu

Fig.6 shows effects of alloying elements on a stress-time curve with implanting a Cu rod. Silicon and P in steels delay the brittle fracture. This means that these two elements in steels are tought to decrease the penetration ability of liquid Cu. Following optical micrography, this effect of P is larger than that of Si [12].

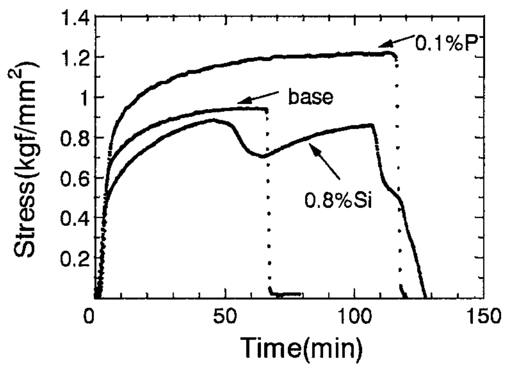

Fig.6 Effects of alloying elements Si and P on a stress-time curve of the tensile test of a specimen implanted a tough- pitch Cu rod.

3.4 Effects of grain size of steel on the surface hot shortness

Figure 7 shows load- elongation curves obtained in air for another 0.1%C-0.5%Mn-0.5%Cu steels of which grain size of austenitic phase were changed by heat treatment in Ar gas. It seems that the smaller grain shows the lower susceptibility to the surface hot shortness. The reason for this fact is shown schematically in Fig.8: in steels of smaller grain size the number of grain boundaries where liquid Cu penetrates is larger but the depth of the penetration is shallower than in steels of larger grain size.

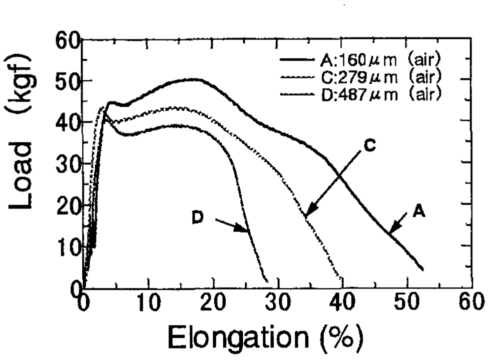

Fig.7 Comparison of load-elongation curves obtained in air for 0.1%C-0.5%Mn-0.5%Cu steels of which grain size are changed by heat treatment.

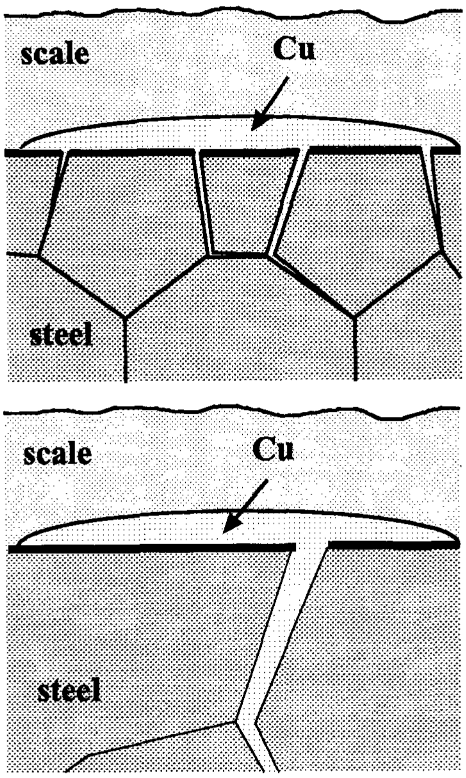

Fig.8 Schematic draw showing effects of grain size on penetration of liquid Cu enriched phase into grain boundaries.

4. CONCLUSION

It is concluded from the present research that the physico-metallurgical methods are feasible to suppress the surface hot shortness and to promote the usage of waste iron scrap. It is important to enhance such researches to reduce the deteriorate effects of tramp elements like Cu and Sn together with researches how to reclamate them and how to design recyclable steel compositions using the minimum contents of tramp elements.

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