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EXAFS Analysis on Carbide Precipitation in High Strength Steel

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Introduction

Precipitation-strengthened steel is a kind of high strength steel using fine precipitation of carbides and/or nitrides. It is important to understand the kinetics of precipitation during the heating process to design products and optimize the thermomechanical processes. However, it is difficult to quantify the amount of precipitates with a size of less than a few nanometers.

We have already reported that it is possible to quantify the fraction of the precipitations by analysis of extend X-ray absorption fine structure (EXAFS) spectra taken with the X-ray fluorescence yield method [1,2]. In this report, we present the carbide precipitation of Ti and Mo, added in small quantities to steel, based on an analysis of Ti-K edge and Mo-K edge EXAFS.

Experiments

0.045%C-1.3%Mn steel sheets containing Ti and Mo, and also steel sheets containing only Mo were prepared for this study. They were soaked at 1523 K and hot-rolled with a finishing temperature of 1173 K, and then cooled to 898 K and kept at the temperature for a range of time from 0 to 3600 seconds followed by water quenching.

The Ti-K edge and Mo-K edge EXAFS spectra were measured by the X-ray fluorescence yield method using a seven-elements solid-state detector (SSD).

The fractions of precipitation of Ti and Mo atoms were estimated by analyzing the Ti-K edge and Mo-K edge EXAFS oscillations. Fig.1 shows the change in Fourier transforms (FT) of Mo-K EXAFS of the Ti-Mo added steel annealed at 898K. FT of the sample at a keeping time of 0 seconds clearly showed typical bcc coordination for both Ti and Mo, which means substitutional solid solution of Ti and Mo atoms in the bcc-Fe matrix. The coordination number of Fe atoms surrounding the Ti and Mo atoms decreases according to the progress of precipitation with the heating time (Fig.1). The decrease of the coordination number of Fe atoms was used to determine the fraction of precipitation of Ti or Mo atoms.

Results and Discussion

Fig.2 shows the variations of fraction of precipitated Ti and Mo atoms as a function of heating time. The fraction of precipitation of Ti atoms quickly increases and almost all the Ti atoms precipitate until 1000 seconds. The other side, precipitation of Mo proceeds even after precipitation of Ti saturate, and the fraction of precipitation increases up to 60 % in 3600 seconds. For Ti and Mo added steel with high strength, it is reported that the precipitates are nanometer-sized complex carbides, (Ti,Mo)C, which have NaCl-type structure [3,4]. In the case of the Mo added steel, Mo atoms do not precipitate even when the steel is heated for 3600 seconds. It is concluded that the Mo precipitation is caused when Mo added with Ti to the steel. Although the reason why thermodynamically unstable nanometer-sized (Ti,Mo)C complex carbides can precipitate in steel is still unclear, we presumed that the slow precipitation of Mo dragged by Ti controls the growth of the complex carbide.

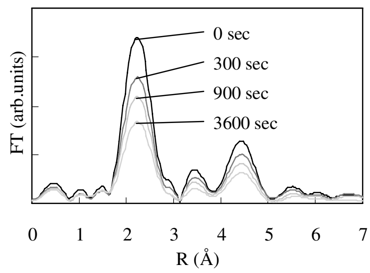

Fig.1 Change in FT of Mo-K EXAFS of Ti-Mo steel annealed at 898K.

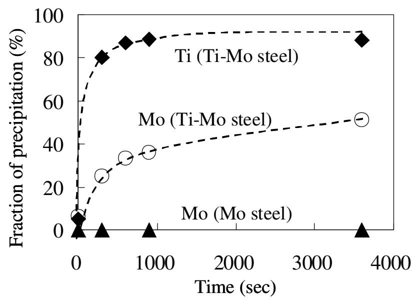

Fig.2 Fractions of precipitated Ti and Mo estimated from EXAFS spectra plotted as a function of annealing time.

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References

[1] M. Nagoshi *et al.*, CAMP-ISIJ, 15, 1368 (2002).
[2] M. Nagoshi *et al.*, Physica Scripta, T115, 480 (2005).
[3] K. Sato *et al.*, CAMP-ISIJ, 15, 1219 (2002).
[4] Y. Funakawa *et al.*, ISIJ International, 44, 1945 (2004).

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