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Local thermal expansion of Co-containing Invar alloys

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1 Introduction

Low thermal expansion materials are attractive from the viewpoints of both fundamental science and industrial technology. FeNi Invar alloys are quite familiar and have been applied to precision equipment as telescope, microscope, and nanodevice, and also been employed as core cables of electric high-voltage power lines to avoid sagging due to heat on high current conduction. Recently, Fujii *et al*. [1,2] developed a new stainless Invar alloy with the composition as $Fe_{39}Co_{50}Cr_9Ni_2$, which is employed for the cryogenic infrared space telescope in National Astronomical Observatory. In this work, we measured and analyzed EXAFS spectra of Co-containing Invar alloys of this newly developed stainless Invar, together with GX1Ni29-Co17 $Fe_{53}Co_{17}Ni_{29}X_1$ (Kovar) for comparison. We will focus our attention on how Co plays a role in the Invar effect from the local structure viewpoint, which is often different from the macroscopic points of view.

2 Experiment

Two stainless Invar foils with 10 μm thickness were prepared and the elemental compositions are found to be $Fe_{38.8}Co_{50.1}Cr_{9.2}Ni_{1.9}$ and $Fe_{37.8}Co_{51.3}Cr_{9.0}Ni_{1.9}$ by the X-ray fluorescence spectra. Cr, Fe, Co, and Ni K-edge EXAFS spectra of commercially available Kovar (10 μm) and the stainless Invar foils were recorded with the transmission mode in BL9C at 30-300 K using a He gas-circulating refrigerator installed at the beamline. The lattice thermal expansion coefficients of Kovar and stainless Invar were measured by the laboratory dilatometer.

We have also recorded Fe and Ni K-edge EXAFS of FeNi Invar alloys $Fe_{64}Ni_{36}$, $Fe_{58}Ni_{42}$, and $Fe_{55}Ni_{45}$ in the same beamtime, and the whole results will be discussed in detail elsewhere [3], by combining the previously obtained results of SUS304 and Elinvar alloys [4].

3 Results and Discussion

Temperature dependent EXAFS spectra were analysed with the standard method including the third-order cumulant to yield thermal expansion for the first-nearest neighbour (NN) shells correctly. Since the first-NN shell includes different atom pair contributions, the analysis yields only the average distances. Nevertheless, assuming that the interatomic distance is given as a sum of the atomic radii, all the interatomic distances are evaluated as long as all the corresponding EXAFS spectra provide the average distances. Figure 1 shows the thermal expansion at 200 K thus obtained for the interatomic distances and the lattice constant as a function of corresponding distances. Since the two stainless Invar alloys exhibit essentially the same results and the average values are given here. It is clearly found that in stainless Invar, thermal expansions of Fe-Fe, Fe-Co, and Co-Co are significantly smaller than in Kovar, associated with shortening of the corresponding interatomic distances. This implies a much more significant Invar effect on Co as well as Fe in stainless Invar, while the Invar effect on Co is negligibly small in Kovar. The path-integral effective classical potential simulations exhibit qualitative agreement with this finding, indicating that the Co magnetization is more noticeably suppressed with a temperature rise in stainless Invar, because of a smaller lattice constant and interatomic distances and also of the presence of Cr in stainless Invar, both of which favour antiferromagnetic coupling. The present study clearly demonstrates importance of local structure point of view to understand detailed low thermal expansion mechanism, in which microscopic local thermal expansion noticeably differs from macroscopic lattice thermal expansion.

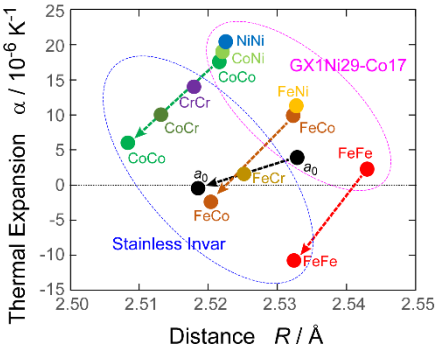

Fig. 1: Thermal expansion coefficients α (10^{-6} K^{-1}) at 200 K for the first-NN atom pairs obtained by EXAFS and the lattice constant a_0 versus corresponding distances in GX1Ni29-Co17 (Kovar) and stainless Invar.

References

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