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Lattice Strains in Stainless Steel 316

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1 Introduction

It is well known that metallic alloys inevitably contain local lattice strains in the crystal due to different metallic radius in different elements, even when the average lattice provides well-defined x-ray diffraction. In the previous EXAFS study on stainless steel 304 and Elinvar alloys [1], the lattice strain is found to be concentrated around Cr: noticeably smaller nearest neighbor distances around Cr than around Fe and Ni. In this work, we have investigated the lattice strains in stainless steel 316 by measuring temperature dependent EXAFS around Mo [2].

2 Experiment

Temperature dependence of Fe, Ni, Cr, and Mo K-edge EXAFS of stainless steel 316L ($Fe_{67}Cr_{18}Ni_{12}Mo_2Mn_1$) were recorded at BL9C and 12C with the transmission mode. The measurement temperatures were 20-300 K.

3 Results and Discussion

Figure 1 shows temperature dependence of the first-NN interatomic distances in the Invar [3], Elinvar [1], SUS304 [1], and SUS316. The Invar alloy exhibits almost no thermal expansion around Fe and small expansion around Ni [-0.03×10^{-5} (Å/K) for Fe and 1.02×10^{-5} (Å/K) for Ni]. In the Elinvar alloy, thermal expansion around Fe is noticeably smaller than those of Ni and Cr [1.33×10^{-5} (Å/K) for Fe, 2.17×10^{-5} (Å/K) for Ni, and 2.32×10^{-5} (Å/K) for Cr], while in SUS304, all the thermal expansions around Fe, Ni, and Cr are essentially similar and quite normal [2.39×10^{-5} (Å/K) for Fe, 2.40×10^{-5} (Å/K) for Ni, and 2.85×10^{-5} (Å/K) for Cr]. The local thermal expansion around Fe, Ni, Cr, and Mo are not extraordinary showing a normal thermal expansion behavior [2.50×10^{-5} (Å/K) for Fe, 2.32×10^{-5} (Å/K) for Ni, 2.16×10^{-5} (Å/K) for Cr, and 3.19×10^{-5} (Å/K) for Mo]. The metallic radii of all the elements in the alloys can be estimated by using the EXAFS results. In SUS304 and SUS316, the Fe atomic radii are estimated to be 1.264 and 1.266 Å, respectively, which are slightly larger than that of bcc Fe (1.239 Å) and are quite reasonable because of larger coordination numbers in fcc alloys. The Ni atomic radii are given as 1.268 Å for SUS304 and 1.265 Å for SUS316, again slightly larger than that of fcc Ni (1.243 Å). It is consequently remarked that Fe and Ni atoms have essentially the same interatomic distances for the first-NN shells and form alloy structures with high commensurability. In contrast, the environment around Cr significantly differs from those around Fe and Ni. As shown in Fig. 1, the first-NN interatomic distances around Cr in SUS304 are shortened by ~0.015 Å compared with those around Fe and Ni, and in the present SUS316, this trend is more prominently observed. The Cr atomic radii are estimated to be 1.251 and 1.235 Å for SUS304 and SUS316, respectively, which are similar to that of bcc Cr (1.246 Å) or even shorter. The fact that in the fcc lattice with larger first-NN coordination numbers yields similar or shorter interatomic distances around Cr implies the presence of large compressive lattice strain around Cr. On the other hand, the Mo atomic radius in SUS316 is given as 1.319 Å, being shorter by as much as 0.04 Å than that of bcc Mo (1.358 Å), indicating more significant compressive lattice strain in Mo atoms with inherently larger atomic radii. It is interesting to note that the thermal fluctuation around Cr is larger than those on the other metals, which may reasonably coincide with a large compressive lattice strain on Cr, while the thermal fluctuation around Mo is smaller with a more significant compressive lattice strain, probably due to a heavier atomic weight and a larger cohesive energy. It can be concluded that although the Invar, Elinvar, SUS304, and SUS316 alloys are recognized to form fcc lattices with completely random atomic distributions, the real interatomic distances are considerably dependent on the elements.

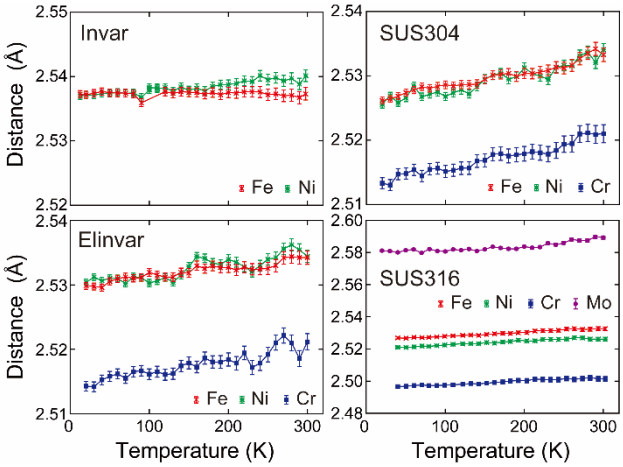

Fig. 1: The first-nearest neighbor interatomic distances of Invar, Elinvar, SUS304, and SUS316 (present work) alloys determined by Fe, Ni, Cr, and Mo K-edge EXAFS (points with error bars). Note that the coordinated atoms (scatterer) are not elementarily distinguished, while the central atoms (x-ray absorber) are clearly distinguished.

References

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