Rhenium Additions on Aging Behavior of Haynes 242

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Introduction

Haynes 242 was studied for use as a structural material in magnets. This alloy is strengthened by long-range ordering (LRO) to form A_2B-type domains with sizes smaller than 100 nm by aging [1]. This report refers to the A_2B-type strengthening component as nanosized hardening domains (NSHD). Addition of other alloying elements can change the aging process. For magnet applications, the added alloy element is expected to promote the formation of the NSHD and cause no over-aging for prolonged aging. We have designed an alloy with Re additions. The added alloying element promotes formation of the NSHD. The alloy can be age-hardened in less than five minutes and behaves as a precipitate-hardened alloy.

Alloying Element Considerations

Re was selected as an important alloying addition element because it has a relatively large atomic diameter (0.27 nm), a high melting point (3459 K), a high modulus (329 GPa) and a large negative NSHD formation energy. Elements with large atomic diameters and high melting points diffuse relatively slow, so the kinetics of NSHD growth will be sluggish, and the alloy can be kept or used at high temperatures for a long period of time without over-aging. The high-modulus elements enhance the modulus of the material further so that a high strength will be achievable. If the added element can participate in precipitation due to a large negative NSHD formation energy, the large atomic diameter results in more distortion in the matrix lattice so that the added element is unstable in solid solution and promotes precipitation. Therefore, the doped atoms have the potential to accelerate NSHD nucleation.

Results and Discussion

Our ab initio calculation predicts that the Re addition not only can participate in formation of the A_2B type NSHDs but also reduces the NSHD formation energy from -12 to -15 kJ/mole. Our experimental results show that the Re accelerates the age hardening by almost 36 times compared with the alloys without Re additions via LRO hardening, as shown in **Figure 1**. Our atomic resolution Z-contrast image in **Figure 2** demonstrates that Re atoms occupy the B site in the A_2B NSHDs and very little Re or Mo atoms were found in disordered areas. Distinct interfaces can be observed between the Re/Mo rich phases and the matrix. Therefore, accelerated hardening is achieved by A_2B-type structured precipitation. The designed alloy shows stable hardness values without over-aging even after prolonged aging up to 500 hours. Unlike Haynes 242, cold work decelerates precipitation hardening in this new alloy.

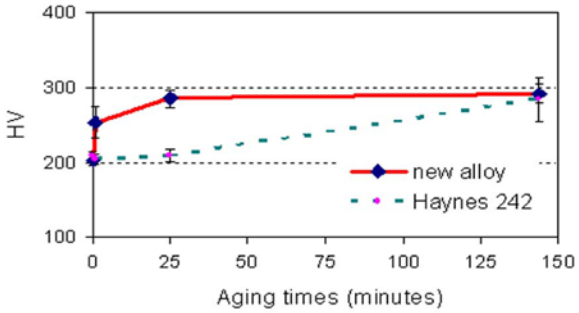

Figure 1. Comparison of the hardness response to the aging time at 923 K for Haynes 242 (bars) and the alloy with Re additions (blue diamonds connected with red lines).

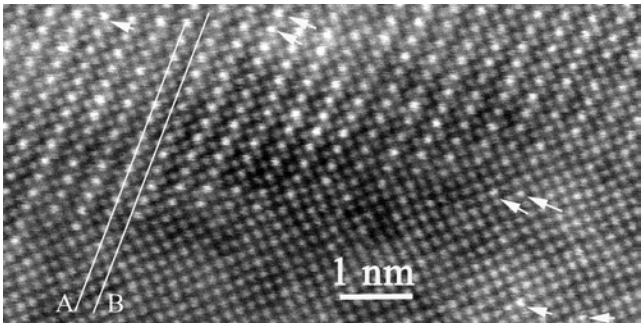

Figure 2. Z-contrast image of Re added alloy aged at 873 K for 50 hrs. Brighter dots represent the locations occupied by the atomic columns with large atomic numbers (either Mo or Re), and the arrows indicate the Re-rich atomic columns.

References

1. Tawancy, H.M., *et al.* Physica Status Solidi a-Applied Research. **99**(2): 461-466. (1987).