Proceedings of the 72nd World Foundry Congress
21-25th May 2016, Nagoya, Japan

Effect of Nb and W addition on heat-resistance of austenitic cast steel

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This study is to clarify the combined effect of solid - solution strengthening by W and precipitation strengthening by Nb on thermal-shock resistance of austenitic cast steel at elevated temperature. It was found that simultaneous addition of Nb and W to cast steel retards the decomposition of crystallized $M_{23}C_6$. Also, precipitation of the fine secondary carbide ($M_{23}C_6$) and solid-solution by W lead to improvement of thermal-shock resistance of Nb-W steel, as compared with JIS SCH21 steel and Nb steel.

Keywords: *Austenitic cast steel, heat-resistance, carbide.*

1. Introduction

SCH21 steel, one of heat resistant austenitic cast steels, is widely used as heat treatment jigs, furnace components, etc. which are operated in range of 850 to 1000°C in oxidizing or carburizing environment. Exposure at the service temperature promotes the precipitation of sigma phase leading to high temperature brittleness. Increment of Ni content can improve heat-resistance of the steels, but it is not best choice due to high cost performance. Recently, it has been reported that Nb, Ti, Zr (precipitation strengthening elements) [1)] or W (solid solution strengthening element) [2)] provides higher creep-resistance for the steels. However, effect of simultaneous addition of Nb and W on heat-resistance of the steels has been little reported.

The aim of this study is to present the results of thermal-shock resistance and microstructure evolution of Nb-W steel during aging, as compared with Nb steel and SCH21 steel.

2. Experimental

All experimental steels used were alloy-designed by Thermo-Calc software (database: TCFE5) before casting. Carbon, which affects high temperature properties, was set as 0.32mass%, while the amount of other elements were adjusted to prevent high temperature embrittlement. The main component of the alloys are 1) Nb-W steel [Fe-19.9Ni-23.5Cr-0.5Nb-0.9W-0.32C], 2) Nb steel [Fe-18.9Ni-22.3Cr-1.3Nb-0.33C] and 3) SCH21 steel [Fe-20.2Ni- 23.0Cr-0.32C] .

Thermal-shock test was performed at 950°C up to 300cylces. Each cycle was heated for 0.6ks, and then water-quenched for 0.12ks. Disc-shape samples (diameter: 25mm and thickness:7mm) were cut from Y-block casting, as shown in Figure1. Coefficient of thermal expansion was measured by thermo-mechanical analyzer (TMA). Microstructural analysis of as-cast state and steels aged at 950°C for 50h, 100h and 200h was conducted in optical microscope, scanning electron microscope with energy dispersive spectrometry (SEM-EDS) and TEM, X-ray diffraction analyzer (XRD) and differential scanning calorimetry (DSC).

3. Results and Discussion

Figure1 shows results of deformation rate of samples after conducting thermal-shock test. Deformation rate was evaluated by equation, shown in Figure1 (a). The micro-cracks were found at around 120times in all samples. However, deformation rate of Nb-W stee1 is smallest as compared with Nb steel and SCH21 steel. Under condition of thermal-shock test (equivalent to steel aged for 50h), deformation rate of SCH21 steel is up to 6%, larger 6 times than that of Nb-W steel. As TMA result measured in the range of 150 to 950°C, the thermal expansion coefficient of Nb-W steel is smallest among steels. At the temperature of 950°C, the measured thermal expansion coefficient of Nb-W steel, Nb steel and SCH21 steel are 18.6, 18.9 and 20.5($\times 10^{-6}$/°C), respectively. It means that the simultaneous addition of Nb and W is effective to improvement of thermal shock-resistance of austenitic cast steel.

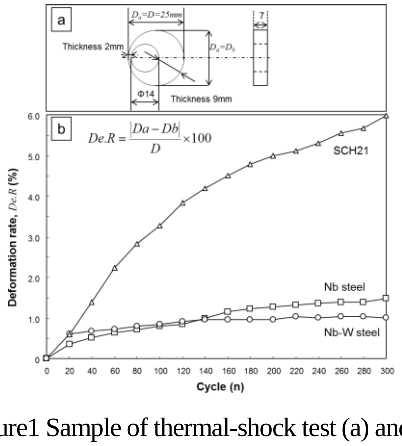

Figure1 Sample of thermal-shock test (a) and its deformation rate after thermal- shock test (b).

The microstructures of as-cast state and steels performed by 300cycles thermal-shock test are shown in Figure2. The microstructures of as-cast steels are composed of an austenitic matrix with network of crystallized carbides. It is found that secondary carbides precipitate in the vicinity of network, but appearance of void and crack is different in thermal-shocked steels. Cracks severely develop at not only dendrite boundary but also trans-granular boundaries in SCH21 steel, whereas micro voids appear along dendrite boundary and crystallized carbide. Juncture of void which develops crack is difficult to occur in Nb steel and Nb-W steel.

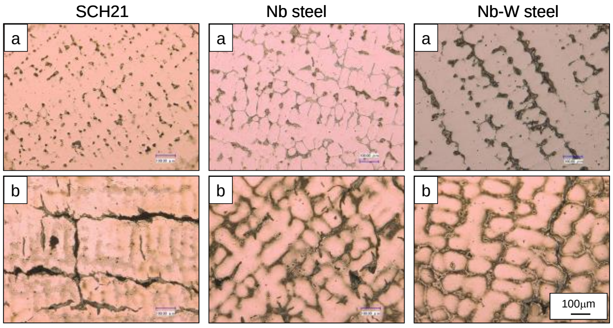

Figure2 Microstructures in as-cast steels (a) and steels thermal-shocked at 950°C for 300 cycles (b).

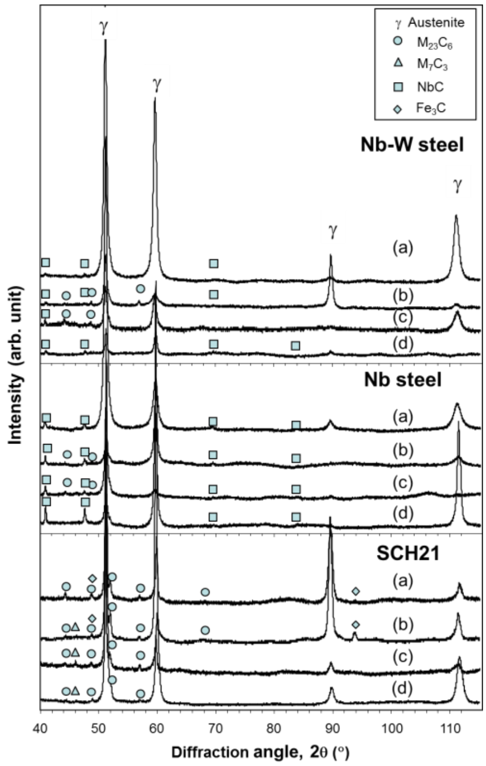

Figure3 Phase identification of as-cast steels (a) and steels aged at 950°C for 50h (b), 100h (c) and 200h (d) by XRD.

Microstructural evolution during aging is identified by XRD analysis, as shown in Figure3. Addition of Nb promotes rather crystallization of NbC than $M_{23}C_6$ in as-cast steel. As DSC results, two exothermic peaks appears at 500 and 600°C in Nb steel, which are reported as precipitation of secondary carbide NbC and $M_{23}C_6$, while only one peak appears at 600°C in Nb-W steel. Occurrence of secondary carbide ($M_{23}C_6$) could be detected in SEM-EDS microstructure of steels aging for 100h (Figure4). However, peaks of secondary carbide of $M_{23}C_6$ disappear and there is only peaks of NbC in Nb steel and Nb-W steel aged for 200h. Thermal stability of NbC plays role as increment of thermal shock resistance. On the other hand, W is completely dissolved in Nb-W steel; WC or W_2C was not found in matrix under the experimental conditions through XRD analysis, SEM-EDS and TEM. As a result, it is considered that the simultaneous addition of Nb and W to the steels restrains the development of crack during heating - cooling stage.

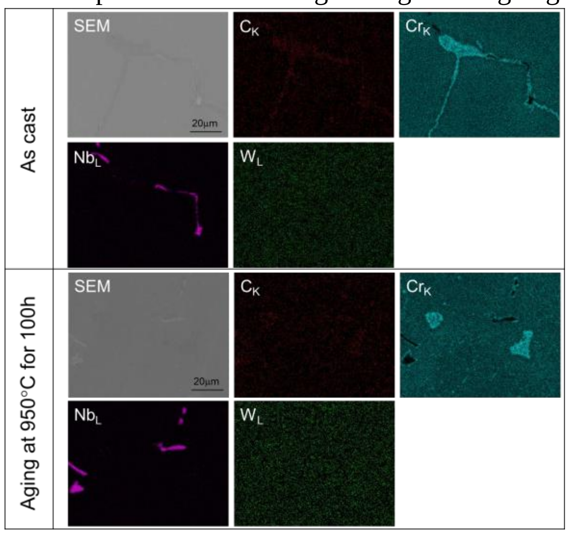

Figure4 Microstructures (SEM-EDS) of Nb-W steel.

4. Conclusion

The results obtained are as follows:

1) The simultaneous addition of Nb and W to austenitic cast steel restrains shape deformation and the development of crack during thermal shock as compared with the steel added Nb singly.

2) NbC crystallizes rather than $M_{23}C_6$ in as-cast steel. NbC is also thermally stabler than $M_{23}C_6$ at high temperature.

3) During aging or thermal-shock test, W distributes homogeneously in matrix as solid-solution. No occurrence of WC and W_2C was found in Nb-W steel.

References

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