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Experimental evaluation of temper aging embrittlement of cast austenitic stainless steel from PWR

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A B S T R A C T

Instrumented impact and nano-indentation tests were carried out to investigate the temper aging effect on the strength and toughness of a cast austenitic stainless steel from PWR primary pipe. SEM and TEM were used to investigate the fracture photography and the microstructure evolution during temper. From the instrumented Charpy impact tests, the dynamic ultimate strengths of the temper aged specimens increase while the impact energy reduces with the increment of the temper aging time. The fracture surface patterns are changed from the ductile fracture with shallow dimples to the cleavage fracture caused by the dislocations piling up in the ferrite matrix. TEM investigation reveals that mechanical behavior of aging effect is caused by dislocations and precipitate interactions in ferrite phase. The Cr-enriched δ' phase hindering the dislocations movement results in the increase of the internal stress and stress triaxiality, then causes an increment in strength/hardness and a sharp decline in the impact energy. The nano-indentation hardness increases while the nano-indentation plastic energy decreases and results of the ferrite phase changes much more than those of the austenite phase for temper aging.

1. Introduction

In the secondary generation PWR reactors, the primary pipe was made of the cast austenitic stainless steel. For long term service at high temperature, the typical temper aging embrittlement of the cast stainless steel will lead to the reduction of the toughness, which will affect the structure integrity of the reactor primary coolant pressure boundary [1]. Correspondingly the emergency response time will be reduced for the decreasing crack resistance properties according to the Leak-Before-Break designation theory, which has been more important to the safeguard reliability and extend life. The temper embrittlement of the cast stainless steel is of great safety concern and has been extensively investigated in these decades.

The non-equilibrium solidification in the cast austenitic stainless steel produces a two-phase microstructure of austenite and δ-ferrite which has better mechanical properties than the single phase austenitic stainless steel. The stainless steel is widely used in the PWR as the optimum materials selection for the higher strength, higher resistance to stress corrosion cracking and better weld ability [2,3]. However after serviced at 280–310 °C for a long term, the mechanical properties of the cast stainless steel can be degraded for the temper aging process [4], which typically produces increases in the Ductile Brittle Transition Temperature (DBTT) [1,5], while together with significant reductions in the impact energy, ductility and toughness [6–10]. Investigations find it is the decomposition occurring in the δ-ferrite phase and phase boundaries that

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