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Role of Minor Alloying Elements on Long Range Ordering in Ni-Cr Alloys

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ABSTRACT:

High Cr, Ni-based alloys are an important class of structural materials due to their strength, toughness, and excellent corrosion resistance. Alloys such as 690 and 625 are already used in existing LWR plants in steam generators and core internals. The Ni-Cr binary system exhibits an ordered phase at temperatures below 583°C at the stoichiometry Ni_2Cr. There is concern that alloys with a similar Ni to Cr ratio as the ordered Ni_2Cr binary may undergo an embrittling phase transformation after many years in service at elevated temperatures or under irradiation.

Previous thermal aging studies on Ni-Cr model alloys show that Ni_2Cr can order in as little at 2000 hours at 475°C. The addition of Fe to the Ni-Cr binary system suppresses the critical temperature of the ordering transformation. The slow diffusion kinetics at lower temperatures requires long thermal aging to observe any phase transformation. However, irradiation provides a way to accelerate the ordering phase transformation in Fe containing alloys while still maintaining a low temperature.

The focus of this work is to understand the role of different minor alloy elements in the formation of order phases. Additionally, the range of stability of the ordered phase is investigated by changing the Ni-Cr stoichiometry. This work proposes the irradiation of commercial alloy 690 and model Ni-Cr-Fe-X alloys (where X=Si, P) to understand the role of minor elements and stoichiometry in the ordering phase transformation kinetics.

The scope of work in this project includes the proton irradiation of ten (10) Ni-Cr-Fe commercial and model alloys at three doses and Ni ion irradiation of one alloy at two dose. All irradiations will take place at University of Wisconsin Tandem Accelerator Ion Beam through NSUF access. Post-irradiation examination (PIE) of the specimens will be conducted at the PI's university and will include nano-hardness testing and transmission electron microscopy (TEM). These irradiations supplement an existing project, which provides data at different chemistries. Together these data set will help to map out the Ni-Cr-Fe ternary phase diagram at low temperatures alloying us to determine which alloys are at risk for this phase transformations.

There are three main project objectives:

1. Identify the range of stability of the ordered phase in the Ni-Fe-Cr ternary system. Due to the lack of low temperature phase data the extent of the ordered Ni_2Cr-type phase is unknown. This work will help to define the extent of the order phase at low temperatures, where no data presently exists, using irradiation to enhance the phase transformation.

2. Understand the role of alloying elements Fe, Si and P on the ordering rate. By studying both model and commercial alloys we will identify the importance of different chemical additions and how they impact phase transformations in these commercial alloys. This knowledge can be leveraged to design future alloys that are more resistant to phase transformations under irradiation.

3. Include irradiation data in Grizzly degradation model to predict in-service degradation of commercial alloys. In the existing sponsored project, a Grizzly model will be developed to simulate thermal aging and ion irradiation-induced degradation in Ni-based alloys. The new data generated in the proposed work can also be incorporated into the degradation model to include the role of minor alloying elements. The addition of this data will improve the predictive capabilities of the model to simulate component degradation.