## D. Ranking the Resistance of Wrought Superalloys to Strain-age Cracking

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### Introduction

High-strength, heat-resistant alloys are critical elements of modern gas turbines. Use of higher-strength alloys has long been limited by their propensity for strain-age cracking during post-weld heat treatment. No widely-accepted test method exists that provides an easy and economical method of ranking the resistance of alloys to strain-age cracking. Of the test methods that appear in the literature, the controlled heating rate tensile test (CHRT) stands out because it is simple and economical as well as having been correlated to restrained weldment test results. In the present investigation, the CHRT was used to rank several commercial alloys by their resistance to strain-age cracking, and alloy performance was correlated to chemical composition.

### Procedure

The materials tested were HAYNES[1] Waspaloy, R-41, X-750, 263, and 718 alloys, and NIMONIC PK33[2] alloy. All alloys were standard mill product; 0.063 inch (1.6 mm) thick sheet in the mill-annealed condition. The CHRT is a modified tensile test described by Fawley et al. (Ref. 1). The test specimen was heated to the test temperature in air at a controlled rate of 25 to 30 °F/min. (0.23 to 0.27 °C/s), then pulled to failure immediately upon reaching the test temperature. Elongation was measured from the specimen after testing. Each alloy was tested in duplicate over a range of temperatures from 1350 to 1550 °F (732 to 843 °C), and the alloys were ranked based on their minimum elongation value.

### Results and Discussion

Three heats of R-41 alloy were tested, and these gave the lowest elongation values in the test program at 2 to 3%. Two heats of Waspaloy alloy were tested, giving the next lowest elongation values at about 3.5%. PK33 alloy performed similarly to Waspaloy. The two heats of 718 alloy performed similarly to each other, but differed from the other alloys. Alloy 718 exhibited a ductility minimum of 7 to 8% elongation near 1450 °F (788 °C), then recovered to over 50 % elongation at 1500 °F (816 °C). Alloys that did not contain niobium exhibited low ductility over a greater temperature range than 718 alloy, approximately 1450 to 1600 °F (788 to 870 °C). Alloys X-750 and 263 gave greater elongation values than the other alloys, 12% and 19% respectively, owing to their lower volume fraction of gamma prime. Minimum elongation values for the alloys correlated well to the total atomic percentage of gamma prime forming elements, as shown in Figure 1. Intergranular cracking was apparent on the fracture surfaces of the more-susceptible alloys, which is consistent with the mechanism of strain-age cracking.

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[1] HAYNES is a trademark of Haynes International Inc.
[2] NIMONIC PK33 is a trademark of the Special Metals group of companies.

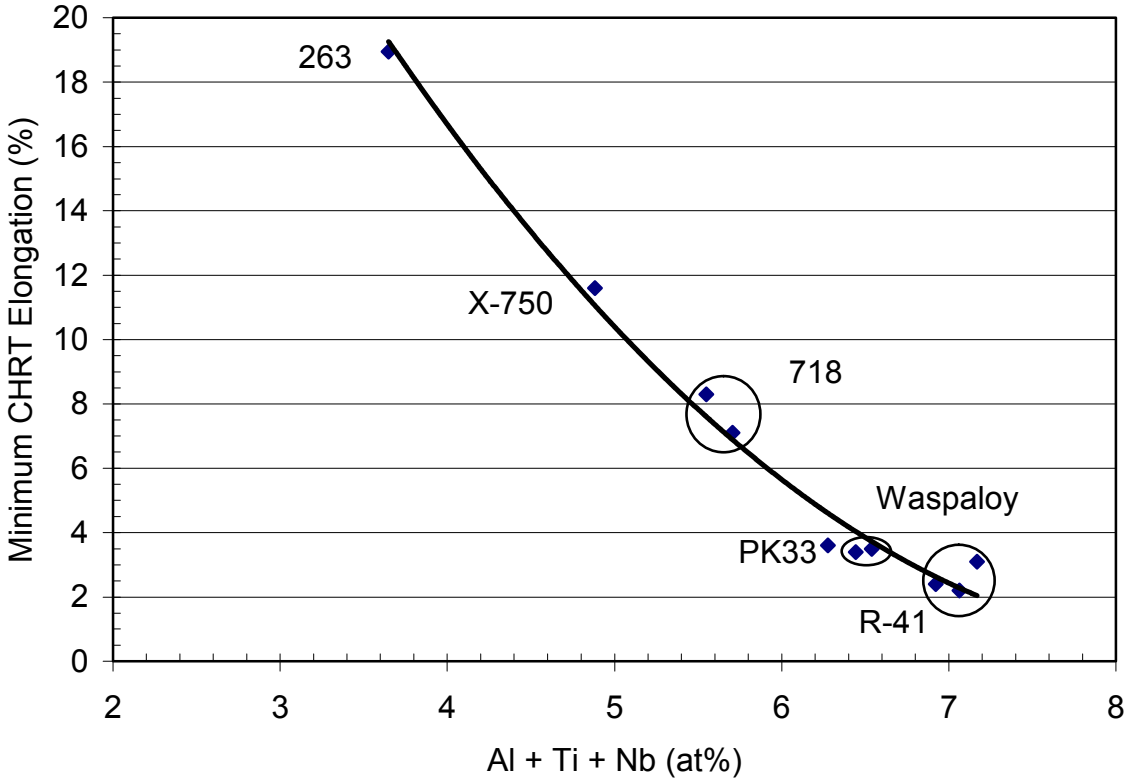


**Figure 1: CHRT minimum elongation as a function of the total atomic percentage of precipitation-strengthening elements in a set of commercial alloys.**

## Conclusion

The CHRT ranked the resistance of commercial alloys to strain-age cracking as follows from least to greatest: R-41, Waspaloy, PK-33, 718, X-750, and 263. The sum of Al+Ti+Nb on an atomic percent basis accurately predicted the ranking of alloys by CHRT minimum ductility. The CHRT provided an effective and economical means of ranking alloys, and gave a ranking that was consistent with expectations based on the literature.

## References

1. Fawley, R. W., Prager, M., Carlton, J. B., and Sines, G. 1970. Recent Studies of Cracking During Postwelding Heat Treatment of Nickel-Base Alloys. *WRC Bulletin No. 150*. Welding Research Council, NY.