# Evolution of lattice parameters with composition of quinary Ni-Co-Al-Ti-Cr alloys

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New designs of gas turbines are targeting elevated gas stream temperatures and increased rotation speeds, as methods of increasing efficiency and reducing aerospace emissions. However, existing materials are already operating at their temperature and strength limits. Meeting this need therefore requires the development of superior materials. Nickel superalloys are currently the only class of materials able to meet service requirements of components in the hottest sections of gas turbines. Their exceptional high temperature properties are derived from the precipitation of coherent $L1_2$ – $Ni_3Al$ ($\gamma'$) in the A1 – Ni solid solution matrix ($\gamma$). The strength of such alloys is controlled by a combination of factors including the $\gamma'$ volume fraction and size, the anti-phase boundary energy and coherency strains [1,2].

Recent work [3] has highlighted that considerable benefits may be achieved through the simultaneous addition of Co and Ti in controlled ratios to nickel superalloys. Whilst the original concept proposed that the strength benefits obtained were a result of increased APB energies of the $\gamma'$, Jones *et al.* [4] have presented data suggesting that the contribution of coherency strain might in fact be the dominating strengthening mechanism in alloys of this type. Additionally, the lattice misfit between $\gamma$ and $\gamma'$ phases, has been found to have a strong correlation with the morphology of $\gamma'$ particles as well as the creep behaviour of the alloy [5-7]. Therefore, determining the effect of composition on the lattice parameters of the $\gamma$ and $\gamma'$ phases is particularly important in the development of novel alloys for gas turbine applications.

To this end, a series of twenty-seven $\gamma/\gamma'$ alloys with compositions based on $(Ni,Co)_{90-x}(Al,Ti)_{10}Cr_x$, with x=10,15 and 20, where tested on the C2 High Resolution Powder Diffractometer at room temperature. The analysis of the results was performed using the Pawley method on the Topas software package.

The results obtained show that all alloys display positive misfits. As shown in Figure 1, the lattice misfit increases with increasing Ti content in the alloy. This arises as titanium increases the lattice parameter of the $\gamma'$ more than that of the $\gamma$. Similarly, chromium additions were determined to produce an increase in both the $\gamma$ and $\gamma'$ lattice parameters, although, the overall lattice misfit was reduced as the lattice parameter of the $\gamma$ phase increases more potently with Cr additions. These observations offer unique insight into the effects of individual alloying additions on the lattice parameter and misfit evolution and hence, are invaluable in the development of novel superalloys for applications in gas turbines.

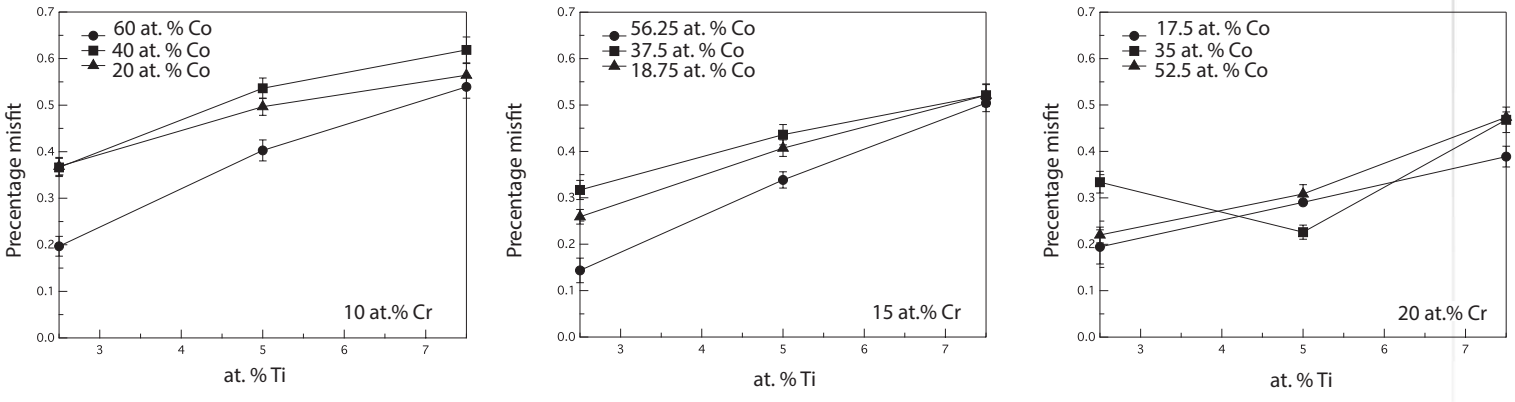



**Figure 1: Dependence of misfit on Ti concentration in the alloy at different Cr levels**

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**Bibliography**

[1] V. Gerold and H. Haberkorn, “On the critical resolved shear stress of solid solutions containing coherent precipitates,” *Phys. Status Solidi B*, vol. 16, p. 675, 1966.

[2] C. T. Sims, N. S. Stoloff, and W. C. Hagel, *Superalloys II*. John Wiley & Sons, Inc., 1987.

[3] C. Y. Cui, Y. F. Gu, D. H. Ping, T. Fukuda, and H. Harada, “Phase constituents and compressive yield stress of Ni-Co base alloys,” *Mater. Trans.*, vol. 49, no. 3, pp. 424–427, 2008.

[4] N. G. Jones, K. A. Christofidou, P. M. Mignanelli, J. P. Minshull, M. C. Hardy, and H. J. Stone, “Influence of elevated Co and Ti levels on polycrystalline powder processed Ni-base superalloy,” *Mater. Sci. Technol.*, vol. 30, no. 15, pp. 1853–1861, Dec. 2014.

[5] R. C. Reed, *Superalloys Fundamentals and Applications*. Cambridge University Press, 2006.

[6] R. A. Ricks, A. J. Porter, and R. C. Ecob, “The growth of gamma prime precipitates in nickel-base superalloys,” *Acta Metall.*, vol. 31, pp. 43–53, 1983.

[7] H. Mughrabi, “The importance of sign and magnitude of $\gamma/\gamma'$ lattice misfit in superalloys—with special reference to the new $\gamma'$-hardened cobalt-base superalloys,” *Acta Mater.*, vol. 81, pp. 21–29, Dec. 2014.