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Size Distribution of γ' Precipitates in Ni-Cr-Co-Al-Ti Alloys

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Nickel based superalloys that are currently in use or under development for several aerospace applications derive their properties from their suitably tailored microstructure composed of distributions of the ordered γ' precipitates ($L1_2$ crystal structure) in the γ matrix (fcc). In order to possess the stringent optimal property combinations, usually these superalloys are alloyed with a large number of alloying elements and several alloys such as Waspalloys, Udimet alloys, CM247, MC2, René series, IN 100 etc. contain substantial amounts of Cr and Co. The morphology and distribution of the γ' precipitates present in the heat-treated alloys play a very important role in determining the properties the alloy. In several alloys, γ' precipitates having two or three different average sizes co-exist. In this study, we present preliminary results on the bimodal size distribution of γ' precipitates observed in a model Ni-Al-Ti alloy containing Cr and Co. A Ni-23at%Cr-17at%Co-4at%Al-1at%Ti alloy was prepared by arc melting the constituent elements (better than 99.95% pure) by non-consumable Ar arc melting. Samples were heat-treated by encapsulating them in Ar atmosphere in quartz tube. The samples were solutionized at 1160ºC and then isothermally heat-treated at various temperatures before rapid water quenching the quartz tubes that were broken upon their entry in water. Specimens for TEM examination were prepared by electro-polishing them in a solution containing 10% $HClO_4$ in methanol at 20V and a temperature <-40ºC.

TEM examinations revealed that water-quenching the alloy from 1160ºC was sufficient to suppress the formation of the γ' precipitates. However, as shown in the SAD patterns in Figure 1, diffuse intensity as well as strong rel-rods were observed. The diffuse intensities pointed out by arrows in Figure 1 do not conform to SRO or LRO from the $L1_2$ structure and these features are currently under more detailed investigation. Isothermal aging of the alloy led to the precipitation of spherical-shaped γ' precipitates uniformly distributed throughout the matrix γ phase. Prolonged aging maintained the shape of the γ' precipitates as illustrated in Figure 2. A careful examination of these microstructures shows that these microstructures contain a bimodal distribution of the γ' precipitates after the heat-treatment. Preliminary quantitative measurements of the size distribution of these γ' precipitates were carried out on a Windows NT workstation using the UTHSCSA *ImageTool* program and examples are shown in Figure 3. These figures clearly indicate that fine γ' (that formed during the quench) co-exist with larger γ' precipitates (~ 10 nm in diameter in the shortest aging time employed here) that appear to grow as the aging time increases. It must be cautioned that the high density of small particles must simply be interpreted as "there are a lot of particles with diameter < 5 nm" since thresholding to analyze the particles is probably subject to large errors here. As the aging time increases, it appears that the standard deviation associated with the size distribution of the larger γ' precipitates also increases. As aging progresses, though fresh nucleation initially occurs, growth and coarsening occurs rapidly. The development of the larger γ' precipitates could best be described by a $size \propto t^{1/3}$ coarsening law, as indicated by the curve fit lines in Figure 4. SKM gratefully acknowledges the support from Air Force contract No. F33615-01-C-5214.

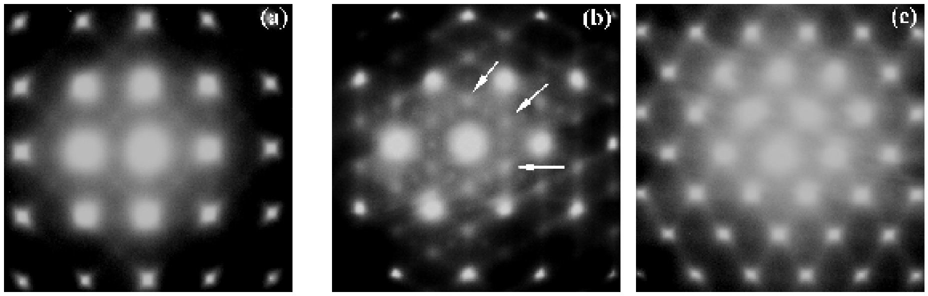

Figure 1: SAD patterns from Ni-23.27at%Cr-16.49at%Co-4.30at%Al-1.22at%Ti alloy solutionized at 1160ºC and water-quenched. Beam directions are [100], [111] and [110] for (a), (b) and (c) respectively. Notice the strong diffuse intensities distinctly different from the intensities from the $L1_2$ superlattice at 100, 110 etc.

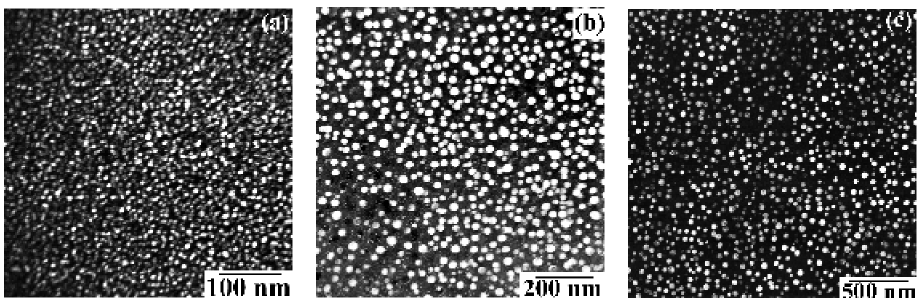

Figure 2: Dark field (g_{110}; ~[111] zone axis) micrographs from Ni-23.27at%Cr-16.49at%Co-4.30at%Al-1.22at%Ti alloy solutionized at 1160ºC and isothermally reacted at 760ºC for (a) 15 minutes (b) 24 hours and (c) 5 days. A careful examination shows that two distinct sets of spherical γ' precipitates sizes are evident in all these micrographs.

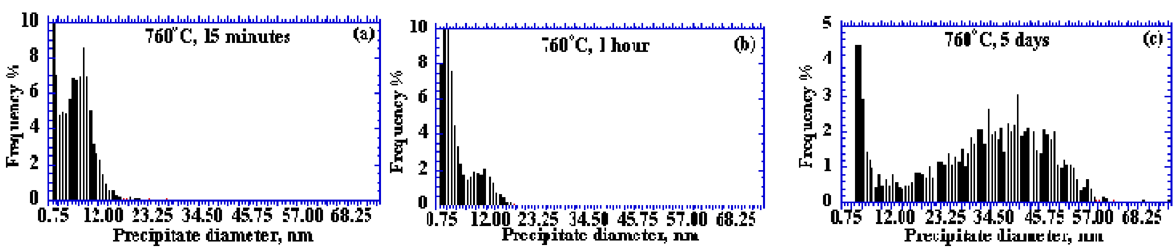

Figure 3: Histograms showing the changes in particle size distribution during aging of a Ni-23.27at%Cr-16.49at%Co-4.30at%Al-1.22at%Ti alloy solutionized at 1160ºC and isothermally reacted at 760ºC.

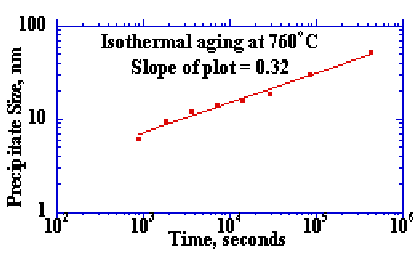

Figure 4: Log-log plot showing the rate of growth of the γ' precipitates.

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