number of studies of similar alloys (e.g. [2, 6, 7]), the morphological sequence described by Footner and Richards may be explained by the gradual increase in local strain energy as the γ' particles coarsen, causing the development of cuboidal precipitates, followed by either coherency loss or impingement which results in a "degenerate" morphology.

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A. J. PORTER
R. A. RICKS
R. C. ECOB
Department of Metallurgy and Materials Science,
University of Cambridge,
Pembroke Street,
Cambridge,
UK

Reply to 'Comments on "Long term growth of γ' particles"'

Porter *et al.* [1] make some interesting comments on our recent paper [2], some of which require further clarification. These authors state that in our paper we were discussing a coarsening rather than a growth process. However, the semantic distinction depends on a knowledge of the constancy of the γ' volume fraction. In our experiments precise measurements of volume fractions were not made, due mainly to the large number of samples involved and the techniques adopted. Hence we were unable to comment on the constancy, or otherwise, of the γ' volume fraction or on whether the increase in average size of particles was due to coarsening alone. It was therefore thought prudent to use the more generalized term. However, it is possible in our case, over the extreme times involved, that local compositional changes or repartition of component elements might have occurred, in which case growth (or perhaps re-solution) is the more appropriate term. In this context it should be emphasized that whilst we investigated ageing times up to 15 000 h, the work of Porter *et al.* involved ageing times of only 24 h. Moreover, in the latter work no evidence was presented that equilibrium conditions and constancy of γ' volume fraction and composition had been obtained within the times of heat treatment.

Porter *et al.* state that in any study of precipitate growth or coarsening, it is essential that the nature of the interphase boundary be characterized, and this information used in any development of a model for the process. This is undeniably true, and for this reason we attempted, albeit unsuccessfully, to use a number of analytical techniques at our disposal to obtain such relevant information. As a result of this lack of data we stated "the causes of the changes in γ' morphology during ageing have been discussed, but lack of accurate data with regard to lattice parameters and compositions has prevented firm conclusions".

It was therefore surprising that Porter *et al.* should credit our work with having an unambiguous interpretation stating "their interpretation is questionable . . . it is inconceivable that the morphological transitions are associated with changes in the precipitate/matrix mismatch resulting from a time dependent composition of the matrix". We presented no such conclusion. Instead we discussed a number of possibilities and suggested additional techniques which could be used to resolve the ambiguities of interpretation. Having rejected our tentative suggestions, Porter *et al.* subsequently attempt to interpret our experimental data based on their work on ageing times up to 24 h. However, there must be a considerable question mark on the applicability of such short time data to our long term (15 000 h) study.

Since we made no firm interpretation of our observed morphological changes of spherical to cuboidal, we cannot comment on the suggestion that this was due solely to the degree of mismatch. However, it is interesting to note that the misfit values quoted by Porter *et al.* [3] were measured at room temperature. As noted by these authors the degree of mismatch probably changes at high

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ageing temperatures. The misfit–coherency relationship quoted must therefore be regarded with some reserve. With respect to the detailed explanation of the transition to "degenerate" γ' shapes, in spite of a complete lack of their own data, Porter *et al.* state that this is associated with precipitate coherency loss. Unfortunately, since we have no data on coherency, we cannot comment on this suggestion. However, it should be noted that the data of Porter and his colleagues give substantial support to our own suggestion that the transition to "degenerate" γ' shapes is due, in part at least, to a re-solution effect; a suggestion not commented on by Porter and his colleagues. For Nimonics 80A and 90 the solution temperatures quoted by Porter *et al.* [3] are 963 and 967° C respectively. It might be expected therefore that treatment at 930° C for times between 350 and 15 000 h might permit some re-solution to occur, as observed by us. Moreover, there is a considerable weight of practical experience from industrial users of these superalloys that re-solution effects do occur over long times at working temperatures of this level. This is less likely in the case of Nimonic 105 for which the solution temperature is 107° C higher than the treatment temperature. In our case, little or no degenerate shape was observed.

As stated above, it is interesting to note that some of the techniques suggested by us have been successfully used by Porter *et al.* to obtain information relevant to an explanation of at least one of the morphological transitions. Our arrangements to use FIM-atom probe techniques unfortunately foundered, but in order to attempt to provide the necessary data our long term aged samples could be made available for a collaborative study with Porter and his colleagues.

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P. K. FOOTNER
B. P. RICHARDS
GEC Research Laboratories,
Hirst Research Centre,
Wembley, UK