ESRF	**Experiment title:** Measurements of coherency strain and volume fraction of γ' in inertia friction welded nickel-base Superalloys	**Experiment number**: Me 539
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Report:

Measurements of the coherency strain between the matrix (γ) and precipitates (γ') have been successfully carried out in inertia friction welded nickel base Superalloys. In addition, the variation of the γ' volume fraction and the variation of the mean particle size could be determined.

Nickel-base Superalloys are widely used in turbine engines because of their high temperature capability. The key feature that imparts high temperature strength to Superalloys is a high volume fraction of the intermetallic γ' (Ni_3(Al, Ti)) phase that is coherently precipitated within γ (Ni). A larger volume fraction of γ' gives better high temperature properties but makes it more difficult to weld the alloy. A promising method to join conventionally unweldable alloys is inertia friction welding. It is a welding technique with one rotating piece attached to a flywheel and a stationary workpiece, which is forced into contact with the rotating piece under hydraulic pressure. The joint is formed with the energy generated by friction at the interface of the two pieces. During friction welding the material locally undergoes a severe temperature excursion. When γ' is exposed to high temperature, the chemical composition of γ' and the matrix might change. During cooling at the end of the welding process the high temperature chemical composition of both phases does not change, because of the severe cooling rates. This can cause significant coherency strain between γ and γ'.

The high energy/high flux ID11 beam line gives the unique opportunity to observe the (100) superlattice reflection of γ' with a high spatial resolution. Since this reflection is about 10^4 times weaker than the (200) reflection it is impossible to study the superlattice reflection by using a laboratory X-ray source. Mapping the (100) superlattice reflection together with the (200) reflection across the weld line gives a great deal of information about variation of γ' volume fraction, mean γ' particle size and coherency strain between γ and γ'. Since the main reflections like the (200) peak consist of two overlapping reflections, namely the $(200)_{\gamma}$ and a $(200)_{\gamma'}$ reflection, it is of interest to accurately determine the position of the two peaks. This can be either done by scanning the double-peak with a high resolution detector or combining the information from the superlattice (100) and main (200) peak.

The energy applied for this experiment was 50keV, which corresponds to a wavelength of about 0.241Å. Measurements were carried out in the first hutch of ID11 using the Kuma detector and a 2D-detector (Bruker) at the same time. The high resolution Kuma detector was used to seperate the double reflection ((200γ) and

(200γ′). The high dynamic range of the Bruker 2D-detector (16 bit camera) allowed measuring the weak (100) and the strong (200) reflections at the same time without saturating the camera. In this way, it was possible to combine the information of the two reflections and seperate the (200) double peak. This proofed to be a significant faster way of determining the two positions of the double peak than using the high resolution Kuma detector. For determining the coherency strain between γ and γ′ a new fitting routine was developed in Manchester. Since the (100) and the (200) reflections were measured simultaneously, the d-spacing of the (200)γ′ reflection could be determined from the (100) superlattice reflection. With this information, the (200) double reflection was fitted with the position of one peak known. In this way, the coherency strain between γ and γ′ could be measured as a function of position across the weld line of inertia friction welded nickel-base Superalloys.

Figure 1 displays the coherency strain in the heat affected zone of two different inertia welded nickel-base Superalloys. It can be seen that the powder alloy RR1000 develops a larger coherency strain in the heat affected zone than Alloy 720LI. This is probably related to different chemical compositions of the two nickel-base Superalloys. It is also interesting to note that in both alloys the largest coherency strain is observed not at the weld line but about 1 – 2 mm away from it. In the case of Alloy 720LI the coherency strain is almost zero at the weld line whereas RR1000 displays a negative coherency strain in this region. Since γ′ at the weld line went into solution during the welding process and only reprecipitated upon cooling (supercooling effect), this γ′ was not exposed to high temperature. This information is extremely valuable since coherency strain between the matrix and precipitates can have an impact on precipitation coarsening during post weld heat treatment or in service.
Figure 2 plots the integrated intensity of the (100) superlattice reflection normalised by the integrated intensity of the (200) reflection for Alloy 720LI in the as-welded and post weld heat treated condition. It can be seen that in the as-welded condition the normalised (100) integrated intensity starts to decrease at about 4 mm and displays a trough at about 1 mm from the weld line. This profile indicates that in the as-welded condition a γ′ depleted area is apparent between the weld line and 4mm from it with a minimum of the γ′ volume fraction at 1 mm from the weld line. In addition, Figure 2 plots the I(100)/I(200) profiles of the conventional and modified post weld heat treated condition. Both conditions exhibit no γ′ depleted zone. Again, this information is vital, because it shows that after conventional and modified post weld heat treatment, all γ′ has reprecipitated. As a result of this experiment, currently 2 papers are in preparation [1, 2].

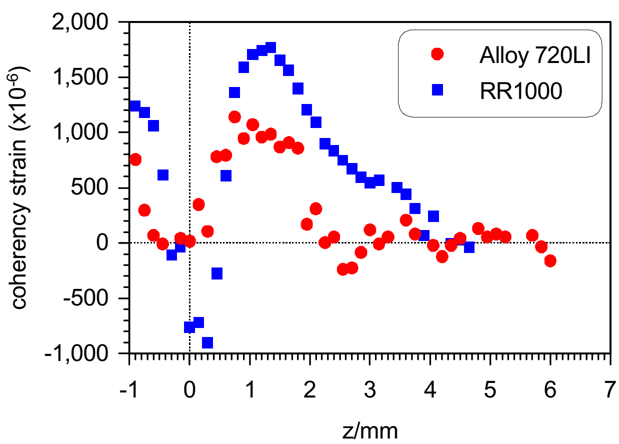

Fig.1:. Coherency strain profiles across the weld line for Alloy 720LI and RR1000, both in the as-welded condition

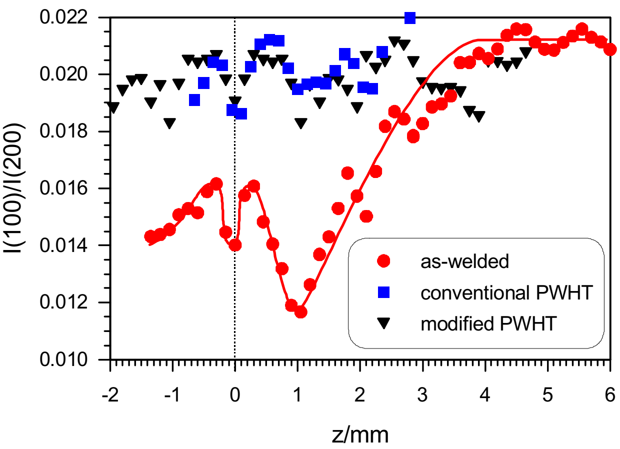

Fig.2: The normalized (I(100)/I(200)) integrated intensity of the γ′ superlattice reflection plotted against the axial distance from the weld line for Alloy 720LI

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[1]: M Preuss, J. Quinta da Fonseca, I. Kyriakoglou, P.J. Withers and G. Baxter: Coherency strain between γ and γ′ in inertia friction welded nickel-base Superalloys, abstract to be submitted to Superalloy 2004.
[2]: M. Preuss, J. Quinta da Fonseca, I. Kyriakoglou, P.J. Withers and G. Baxter: Characterisation of γ′ in inertia friction welded Alloy 720LI., to be submitted to Met. Trans. A.