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Thermal and mechanical effect during rapid heating of astroloy for improving structural integrity

A.P.I. Popoolaa [a, **], K.M. Oluwasegun [b], O.E. Olorunniwo [a, b, *], P.O. Atanda [b], V.S. Aigbodion [a, c]

[a] Department of Chemical, Metallurgical and Materials Engineering, Tshwane University of Technology, Pretoria, South Africa
[b] Department of Materials Science and Engineering, Obafemi Awolowo University, Nigeria
[c] Department of Metallurgical and Materials Engineering, University of Nigeria, Nsukka, Nigeria

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ABSTRACT

The behaviour of γ′ phase to thermal and mechanical effects during rapid heating of Astroloy(Turbine Disc alloy) a Powder metallurgy (PM) nickel base superalloy has been investigated. The thermo-mechanical affected zone (TMAZ) and heat affected zone (HAZ) microstructure of an inertia friction welded Astroloy were simulated using a Gleeble thermo-mechanical simulation system. Detailed microstructural examination of the simulated TMAZ and HAZ and those present in actual inertial friction welded specimens showed that γ′ particles persisted during rapid heating up to a temperature where the formation of liquid is thermodynamically favoured, and subsequently re-solidified eutectically. The result obtained showed that forging during the thermo-mechanical simulation significantly enhanced resistance to weld liquation cracking of the alloy. This is attributable to strain-induced rapid isothermal dissolution of the constitutional liquation products within 150 μm from the centre of the forged sample. This was not observed in purely thermally simulated samples. The microstructure within the TMAZ of the as-welded alloy is similar to the microstructure in the forged Gleeble specimens.

1. Introduction

For more than 50 decades, precipitation hardened nickel base superalloys have been widely used as high temperature structural materials in gas turbine engines. The drive towards improving the overall efficiency of gas turbines in modern aircraft engines and power generation systems by the higher operating temperatures has led to a significant progress in the development of nickel-based superalloys containing increasing amounts of volume fraction of the main strengthening phase, ordered L12 intermetallic Ni3(Al, Ti) γ'. Segregation during melting of this highly alloyed material has been overcome by the use of innovative production method i.e powder metallurgy technology. Astroloy is a new P/M alloy that is used as turbine disc due its good tensile and creep propertied and microstructural stability for extended periods of exposure. However, this alloy and other precipitation hardened nickel base superalloys that contain substantial amount of Al + Ti (>6wt.%) are very difficult to weld by conventional methods due to their high susceptibility to HAZ hot cracking during welding [1]. Cracking during conventional welding of nickel base superalloy has been attributed mostly to large shrinkage stresses. These stresses occur as a result of rapid thermal gradient and rapid re-precipitation of γ′ particles during cooling from welding temperature [1–3], and also to liquation.

during welding [4,5]. Solid state welding has recently been adopted as an attractive process in joining this class of materials, since it is claimed not to involve and to produce a high joint integrity [6–8].

However, it is known generally that weld cracking results from competition between mechanical driving force for cracking (stress/strain generation) and the material's intrinsic resistance to cracking. It has been reported that liquation which could occur by different mechanisms, is the primary cause of low heat affected zone (HAZ) crack resistance in most austenitic alloys including precipitation hardened Ni base superalloys [2]. The combined effect of thermally induced welding strain and very low ductility in the alloy due to localized melting of particle at grain boundaries results in HAZ liquation cracking. HAZ liquation is known to occur either by

* Corresponding author. Department of Chemical, Metallurgical and Materials Engineering, Tshwane University of Technology, Pretoria, South Africa.
** Corresponding author.
E-mail addresses: popoolaapi@tut.ac.za (A.P.I. Popoolaa), segun_nniwo@yahoo.com (O.E. Olorunniwo).

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non-equilibrium interface melting below an alloy's solidus or by equilibrium supersolidus melting. Subsolidus HAZ liquation which commonly occurs by constitutional liquation of second phase particles is generally considered more detrimental to crack resistance. It extends the effective melting range of an alloy and also influences the nature of supersolidus melting by pre-establishing non-equilibrium film at a lower temperature which changes the reaction kinetics during subsequent heating [2]. This process was proposed by Pepe and Savage [3] and observed by different investigators in various alloy system [9–11]. This occurs by a eutectic-type reaction between a second phase particle and the matrix producing a non-equilibrium solute rich film at the particle/matrix interface. Understanding the thermo-mechanical history of solid state welding is particularly important if weld microstructures are to be optimized for subsequent joint integrity. The removal of the constitutional liquation products prior to weld cooling will assist in the production of crack free welds. The present work study the role of forging in the elimination of constitutional liquation products during rapid heating of Astroloy.

2. Material and method

2.1. Materials

The material used in this study is Astroloy, a well-established powder metallurgy nickel base superalloy having the following chemical composition (wt%): 14.6Cr, 16.6Co, 5.0Mo, 4.0Al, 3.5Ti, 0.028B, 0.068Zr, 0.028C balance nickel.

2.2. Method

Hot extrusion of argon atomised powders followed by forging was used to produce the alloy. The base alloy has been heat treated for 4 h at 1100 °C, cooling at 100 °C/min, ageing for 24 h at 650 °C and 8 h at 760 °C with subsequent air cooling. The as-received inertia friction welded samples were sliced to dimensions 20 mm × 12 mm x 10 mm. The solid state dissolution behaviour of γ′ within the inertia friction welds was studied exclusively under thermal environment and under thermal environment with imposed compressive strain, both within a Gleeble thermo-mechanical simulation system. For the exclusively thermal environment, cylindrical specimens of 8 mm diameter and 12 mm length were prepared from the base alloy, heated to 1150, 1175, 1200 and 1225 °C temperature at a rate of 20 °C/s and held for 3 s at all temperatures followed by water quenching. Under thermal plus imposed compressive strain condition, samples were heated to 1225 °C, held for 1 s, then subjected to 10% compressive strain in 2 s followed by air cooling. Some other sets of samples were subjected to 25% compressive strain in 2 s.

The thermal simulation peak temperatures were determined according to the work of Wang et al. [12]. The specimen temperature was controlled with a nickel-chromium thermocouple spot welded to the specimens at the midsection of the gauge length. The microstructural changes that occurred at the simulation temperatures were preserved by water quenching of the specimens subsequent to rapid heating. The as-received inertial friction welded samples were sectioned parallel to the weld axial

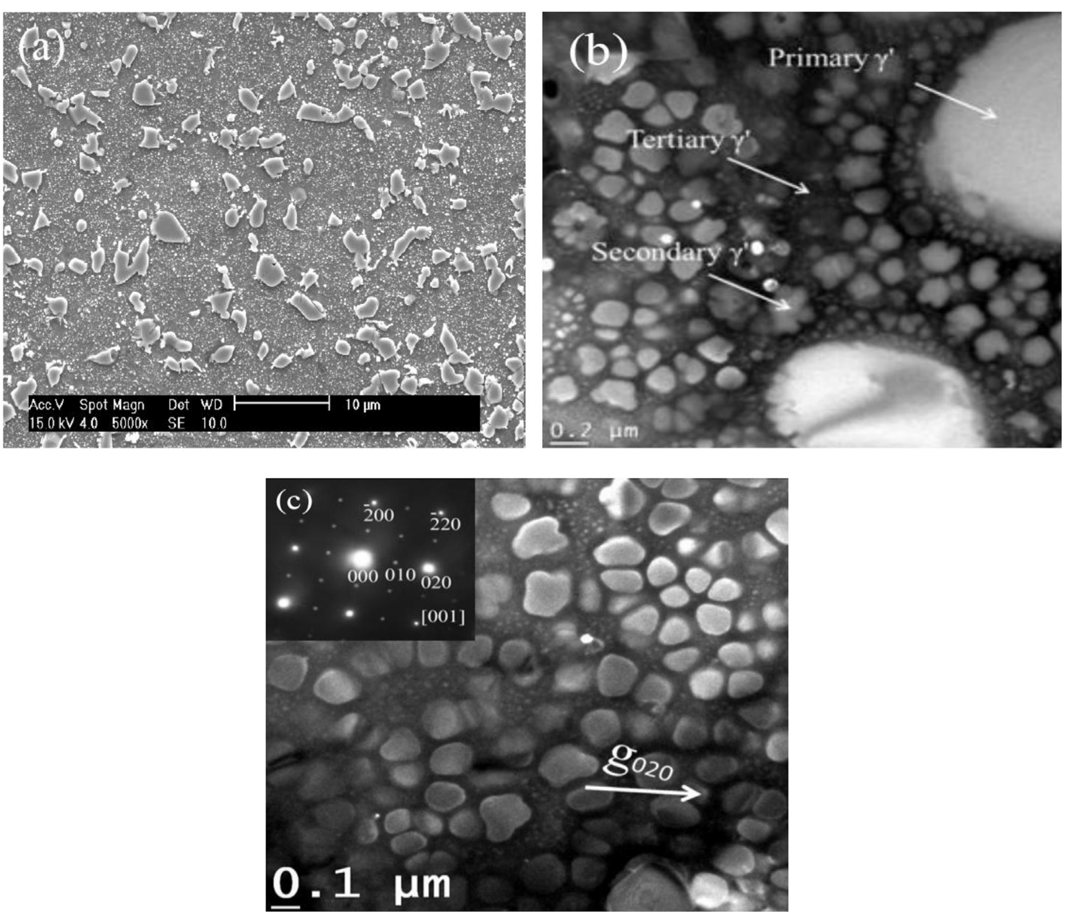

Fig. 1. (a) Optical micrograph showing the distribution of primary γ′ in γ matrix (b) TEM DF image showing primary, secondary and tertiary γ′ (c) Higher magnification of the image in 'c' with inset selected area diffraction pattern (SADP).