#511894 (20)

The Development of Microstructure in the Laser Cladding of Nickel Aluminum Bronze

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ABSTRACT

Laser Cladding with nickel aluminum bronze has much promise for the repair and surface engineering of components made from nickel aluminum bronzes and from other alloys. Until recently, comprehensive understanding of how microstructure develops in this alloy, under the rapid rates of cooling typical of laser methods, has been missing. This presentation will summarize our understanding of how microstructures develop in the as-deposited, re-heated and heat affected zones of laser clad nickel aluminum bronzes. Consideration of the effects of interpass temperature, nickel/iron ratio, and aluminum content will be given. The difficulties these microstructures impose for residual stress measurement and implications of these microstructures for properties will also be considered.

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Development of Microstructure in Low Heat Input Nickel Aluminum Bronze Weldments

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Outline

- Microstructure Development
  - applications
  - phase diagrams
  - structures
  - base material
  - as-deposited zone
  - re-heated zone
  - heat affected zone
- Implications and Questions to Answer
  - for Residual Stress Measurement
  - for Fatigue
  - for Toughness

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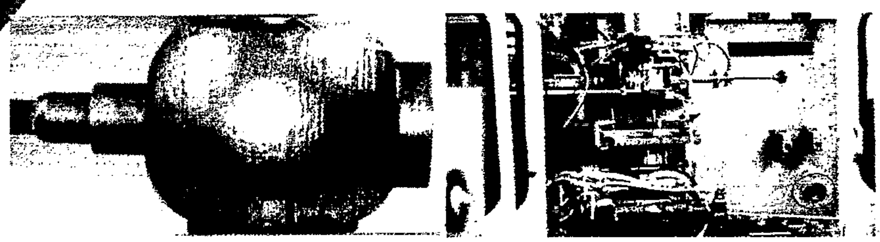
Applications and Classification



- Laser cladding improves surface properties (corrosion, erosion etc.)
- Deep Penetration welding for fabrication and repair with low distortion, low heat and low residual stress,

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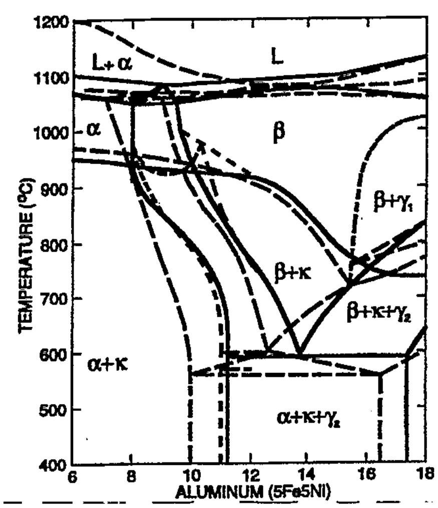

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Phases in nickel aluminum bronze

α	fcc	Cu solid solution
β, β'	bcc, ordered bcc	High temp phase
κ_I	Several structures	Cored, Fe rich, mel
κ_{II}	Fe_3Al	Fe rich, solid state
κ_{III}	NiAl	Ni rich, eutectoid
κ_{IV}	Fe_3Al	High Fe
Martensites	9R, (3R Cast),	Distorted, faulted fcc

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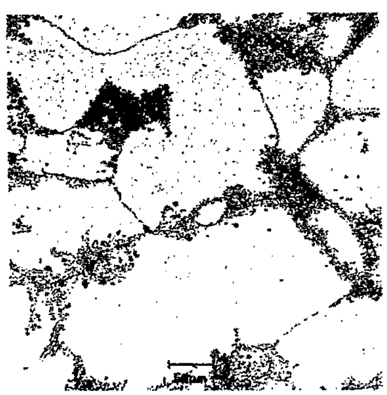
Nickel Aluminum Bronze As-cast structure, Base Material



- Liquid to β to $\alpha+\kappa_I,+\kappa_{II},+\kappa_{III},+\kappa_{iV}$ + Martensite (β*)
- homogeneity determined by composition, casting size, cooling rate and heat treatment

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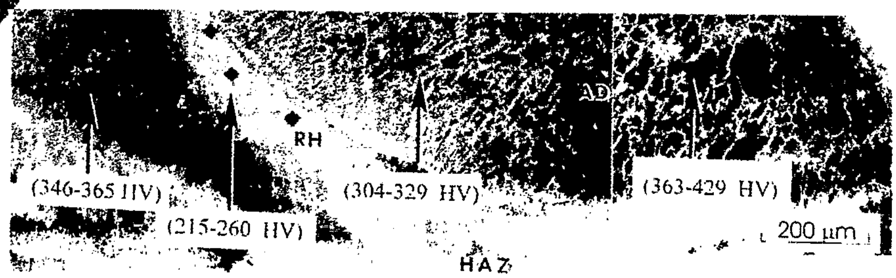
Sample Clad Weld



Laser power = 3300 W
Defocus 10.2 mm
Argon gas shielding

Travel speed=21 mm/s
Wire diameter =0.25 mm (Cu-9Al-4.6Ni-3.9Fe)
Heat Input 150 J/mm

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Heat Affected Zone

- Transforms between 1040 and 400°C, $\Delta t_{800\text{-}500°C} < 1$sec
- Prior cast structure not homogenized, little coarsening, even in small castings
- regions of α phase remain
- regions of κ_I, κ_{II}, κ_{III}, κ_{IV}, and martensite, undergo partial or complete retransformation to β followed by martensite formation at ~150°C (Widmanstattan α, κ, for higher heat inputs/interpass)
- Martensite in heat affected zone phases may cause trouble in fracture and fatigue of penetration welds (even low Al)

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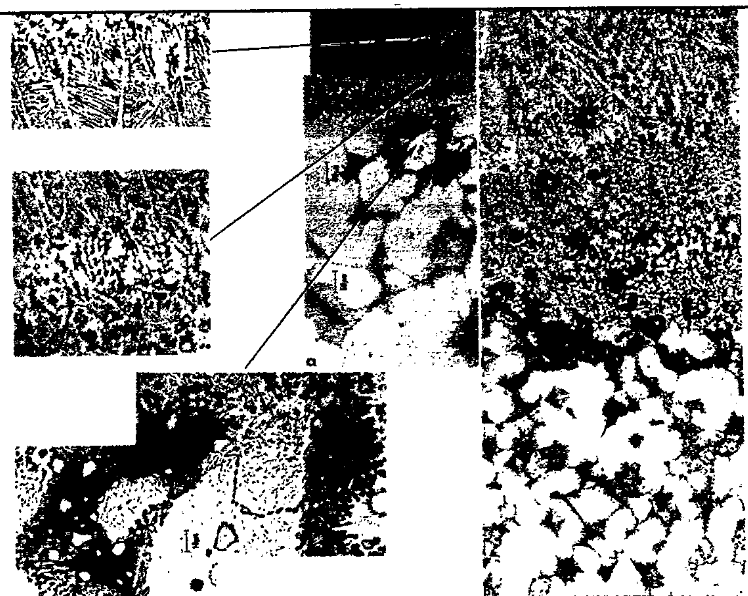

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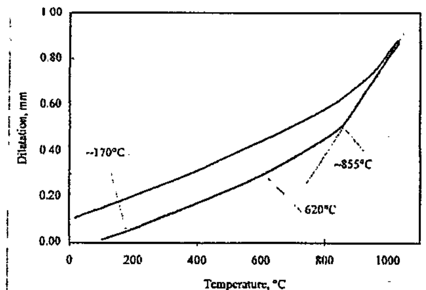
Simulated Heat Affected Zone



- A reasonable (but coarser) simulation of a Heat Affected Zone showing a similar 2 phase structure
- Dilatometry: β to α transformation (855 °C) κ precipitation (565 °C) and martensite start (170°C)

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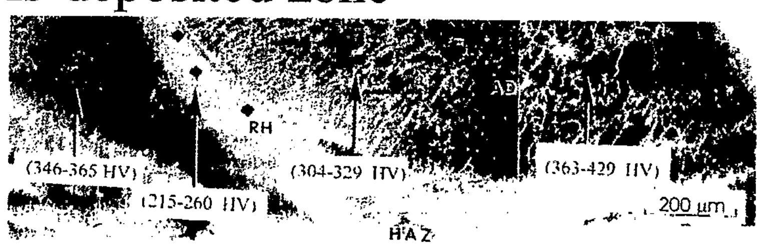
As-deposited zone



- Effect of base casting near near fusion zone gives undissolved κ_I, κ_{II}, intermetallics, regions of cellular structure near fusion line with base metal and also, sometimes, previous pass.
- Mostly β transformation products, but often with cellular understructure
- Strong heat input effect, also substrate (interpass) temperature

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Effect of Heat Input

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β transformation products in the as-deposited material

- Low heat input 9-R martensite plus strengthening κ_{IV} precipitates (42 J/mm, $\Delta t_{800\text{-}500°C} < 0.4$s)
- Precipitates nucleate before martensite (600-400°C?)
- With Increased heat input, increasing amounts of allotriomorphic (prior β boundary) and Widmanstattan α form. Only slight differences in composition from martensite, but contain fewer precipitates. Also eutectoid.
- As heat input increases different martensite morpoholgy also forms (not a bainitic product)—order in β?
- Higher Ni, Al favor martensite; lower Al, higher Fe α

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Reheated Zone

- Only scale depends strongly on heat input…near fusion line, structure consists of allotriomorphic (prior β boundary) and Widmanstattan α and martensite
- Differences in α and martensite compositions and diffusional coarsening kinetics. Only a few large pptes in α
- Hint of order in martensite,
- dominated by diffusional coarsening of pre-existing alpha between 800 and 1040°C

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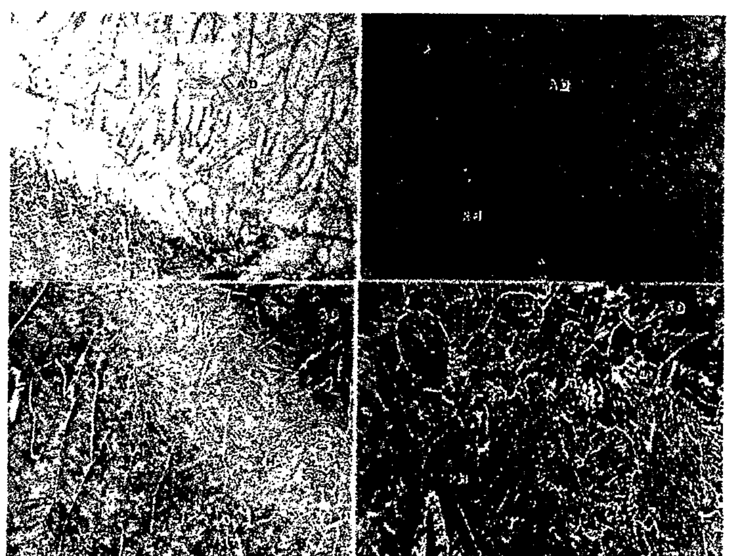

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Implications and Questions to Answer

- How do we make x-ray residual stress measurements if α composition changes from deposit to reheated zone and β' has a faulted 9-R structure? Do we need to measure non-hardenable alloy
- Will martensitic regions of heat affected zone crack on cooling or in fatigue or fracture test? Something to look for in this years testing.
- What is the role of planar boundaries in fatigue?

Conclusions

- Heat affected zone structure influenced by prior cast structure
- As-deposited zone very sensitive to heat input (9-R martensites plus allotriomorphic and Widmanstattan α, precipitates and eutectoid)
- Reheated zone dominated by diffusional coarsening of α