Alloy 706

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Purpose

- The purpose of this project was to investigate INCONEL 706 superalloy, which is derived from the INCONEL 718 composition in order to improve the producibility of large forgings.
- It has been reported that cracking has occurred on Alloy 706 gas turbine discs due to Stress Accelerated Grain Boundary Oxidation.

Objectives

- Comprehensive investigation of the following:
  - Key Characteristics
  - Microstructure
  - Manufacturing Methods
  - Critical Properties
  - Stress Accelerated Grain Boundary Oxidation (SAGBO)

Key Characteristics

- Precipitation-hardenable alloy (primary constituents are Niobium and Titanium).
- Balanced content of Nickel, Chromium and Aluminum provide good hardenability and resistance against oxidation and corrosion.
- Excellent mechanical strength in combination with good fabricability.
- Easier fabrication than 718, particularly by machining
- Delayed hardening response during exposure to precipitation temperatures, which gives the alloy excellent resistance to postweld strain-age cracking.
- Used for applications requiring high strength and ease of fabrication:
  - Aerospace fields: turbine discs, shafts, and cases; diffuser cases; compressor discs and shafts; engine mounts; and fasteners.
  - Non-Aerospace fields: turbine discs in industrial gas turbines.

Microstructure of IN 706

- IN706 is a Nickel-Iron-Based superalloy, which is used for high temperature applications where creep and oxidation resistance are the main design criteria.
- Aluminum and Titanium are the vital solutes, which make up a total concentration of typically less than ten atomic percent.
- High temperature strength due to precipitation hardening by coherent intermetallic particles of γ’ and γ” phases.

Microstructure of IN 706

- Typical Microstructure of IN 706

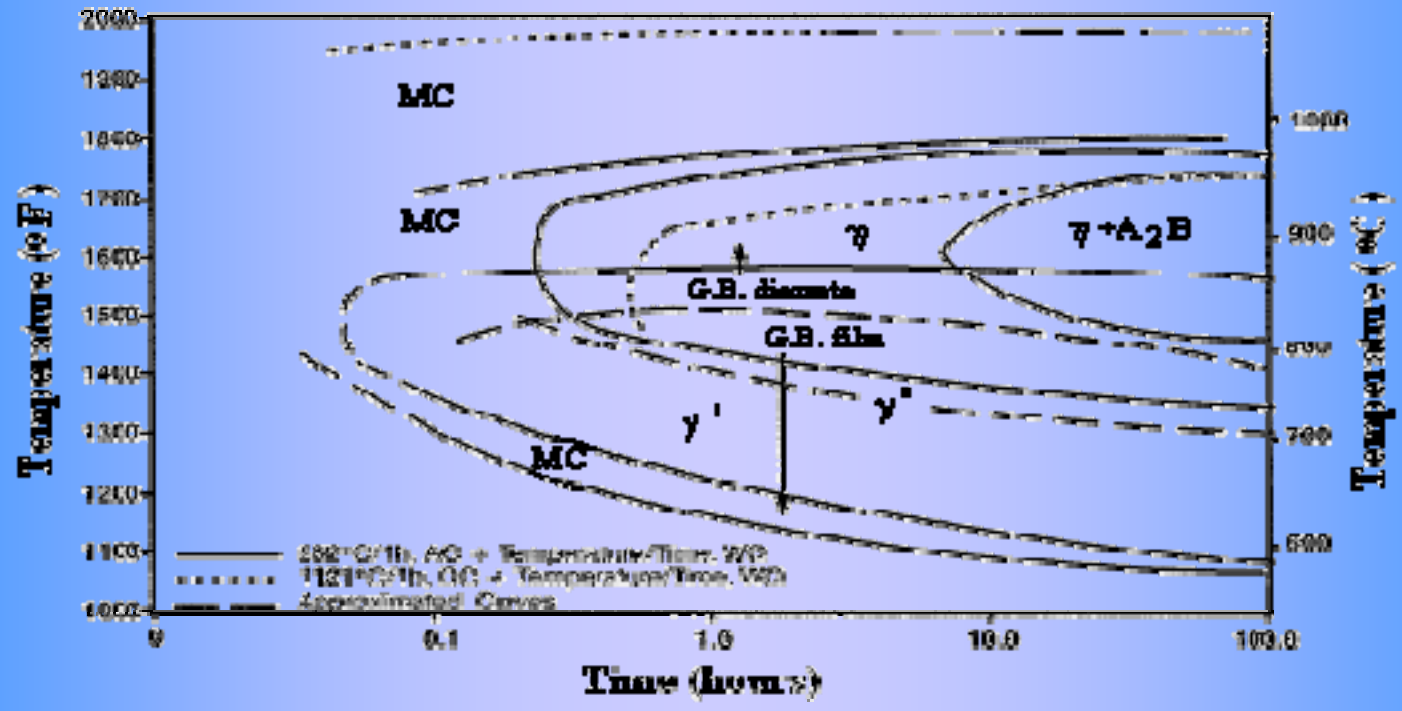
  - The microstructure reveals relatively coarse austenite grains (γ phases), γ' phases, γ" phases, a few MC type carbides, Laves, η phases, and some unresolved grain boundary constituents

- Major Precipitating Phases found in IN 706

Precipitating Phase	Composition	Structure	Morphology
γ'	$Ni_3(Al, Ti)$	Ordered FCC	Spheres
γ"	Ni_3Nb	Ordered BCT	Disks
Laves	$(Fe, Ni)_2Nb$	HCP	Globular
η	Ni_3Ti	HCP	Platelets/ Cellular

Microstructure of IN 706

- Time-Temperature-Transformation Diagram of IN 706



Manufacturing Methods

- Alloy Chemistry
  - IN 706 chemistry is derived from the IN 718 composition
- Nominal Compositions of Related Alloys

Alloy	Al	C	Cr	Fe	Mn	Mo	Nb+Ta	Ni	Si	Ti
718	0.5	0.04	19.0	18.5	0.2	9.0	5.1	52.5	0.2	0.9
706	0.2	0.03	16.0	40.0	0.2	-	2.9	41.5	0.2	1.8

Manufacturing Methods

- Melting/ Casting Methods
  - In order to develop large, high quality Alloy 706 ingots, a triple melt process is utilized
    - Vacuum Induction Melting (VIM)
    - Electroslag Remelting (ESR)
    - Vacuum Arc Remelting (VAR)
- Forging Methods
  - Multiple upset and draw operations of the ingot are used in order to break up the initial large as-cast grain size.
  - Special handling and lubrication are used to maintain the working of all forging areas and avoid die lock.
  - A large press is used for recrystallization in a large land-based turbine wheel in order to minimize the forge temperature while attaining uniform working of the full part.

Manufacturing Methods

- Heat Treatment
  - **Heat Treatment A**: The typical commercial heat treatment given to the alloy for optimum creep and rupture properties :
    - Solution Treatment- 1700-1850°F (925-1010°C) for a time commensurate with section size, air cool
    - Stabilizing Treatment- 1550°F (845°C)/ 3 hr, air cool
    - Precipitation Treatment- 1325°F (720°C)/ 8 hr, furnace cool at 100°F (55°C)/hr to1150°F (620°C)/ 8 hr, air cool
  - **Heat Treatment B**: The typical commercial heat treatment for tensile-limited applications
    - Solution Treatment- 1700-1850°F (925-1010°C) for a time commensurate with section size, air cool
    - Precipitation Treatment- 1350°F (730°C)/ 8 hr, furnace cool at 100°F (55°C)/hr to 1150°F (620°C)/ 8 hr, air cool

Properties of IN 706

- Chemical Properties

Element	Composition (%)
Aluminum	0.40 max
Boron	0.006 max
Carbon	0.06 max
Chromium	14.5-17.5
Cobalt	1.00 max
Copper	0.30 max
Iron	Balance
Manganese	0.35 max
Nickel (plus Cobalt)	39.0-44.0
Niobium (plus Titanium)	2.50-3.30
Phosphorous	0.020 max
Silicon	0.35 max
Sulfur	0.015 max
Titanium	1.50-2.00

Properties of IN 706

- Physical Properties

Density	
Annealed, lb/in^3	0.291
Mg/m^3	8.05
Precipitation-Hardened, lb/in^3	0.292
Mg/m^3	8.08
Melting Range, °F	2434-2499
°C	1334-1371
Specific Heat, 70°F, Btu/lb-°F	0.106
21°C, J/kg-°C	444
Permeability at 200 oersted (15.9kA/m)	
Annealed	
74°F (23°C)	1.011
-109°F (-78°C)	1.020
-320°F (-196°C)	Magnetic
Precipitation-Hardened	
74°F (23°C)	1.010
-109°F (-78°C)	1.040
-320°F (-196°C)	Magnetic
Curie Temperature, °F	<-109
°C	<-78

Properties of IN 706

- Thermal Properties

Temperature	Specific Heat	Electrical Resistivity	Thermal Conductivity	Coefficient of Expansion
°F	Btu/lb-°F	Ohm-circ mil/ft	Btu-in/ft^2-hr-°F	10^{-6} in/in-°F
-320	-	527	55	-
70	0.106	592	87	-
200	0.110	610	96	7.40
300	0.113	622	103	7.83
400	0.117	635	110	8.07
500	0.120	647	117	8.25
600	0.124	659	124	8.42
700	0.127	671	130	8.50
800	0.131	683	136	8.57
900	0.134	695	141	8.64
1000	0.138	707	147	8.73
1100	0.141	717	152	8.84
1200	0.145	-	-	8.97
1300	0.148	-	-	9.11

Properties of IN 706

- Mechanical Properties

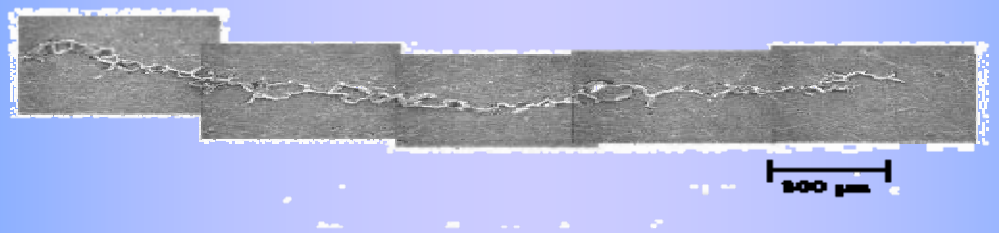
Temperature	Tensile Modulus	Shear Modulus	Poisson's Ratio
°F	10^3 ksi	10^3 ksi	-
-320	31.6	11.6	0.362
70	30.4	11.0	0.382
200	29.5	10.8	0.387
400	29.0	10.4	0.393
600	27.5	10.0	0.395
800	27.0	9.6	0.405
1000	25.5	9.3	0.395
1200	24.7	8.8	0.403
1300	24.0	8.5	0.417

- Forged Disc Properties

Temperature		Heat Treatment	Tensile Strength		Yield Strength (0.2% Offset)		Elongation	Reduction of Area
°F	°C	-	ksi	Mpa	ksi	Mpa	%	%
70	20	Solution Treated	108.0	745	41.7	288	50	55
70	20	A	180.5	1245	142.0	979	17	19
1200	650	A	143.5	989	119.5	824	21	27
70	20	B	183.0	1262	157.4	1085	22	43

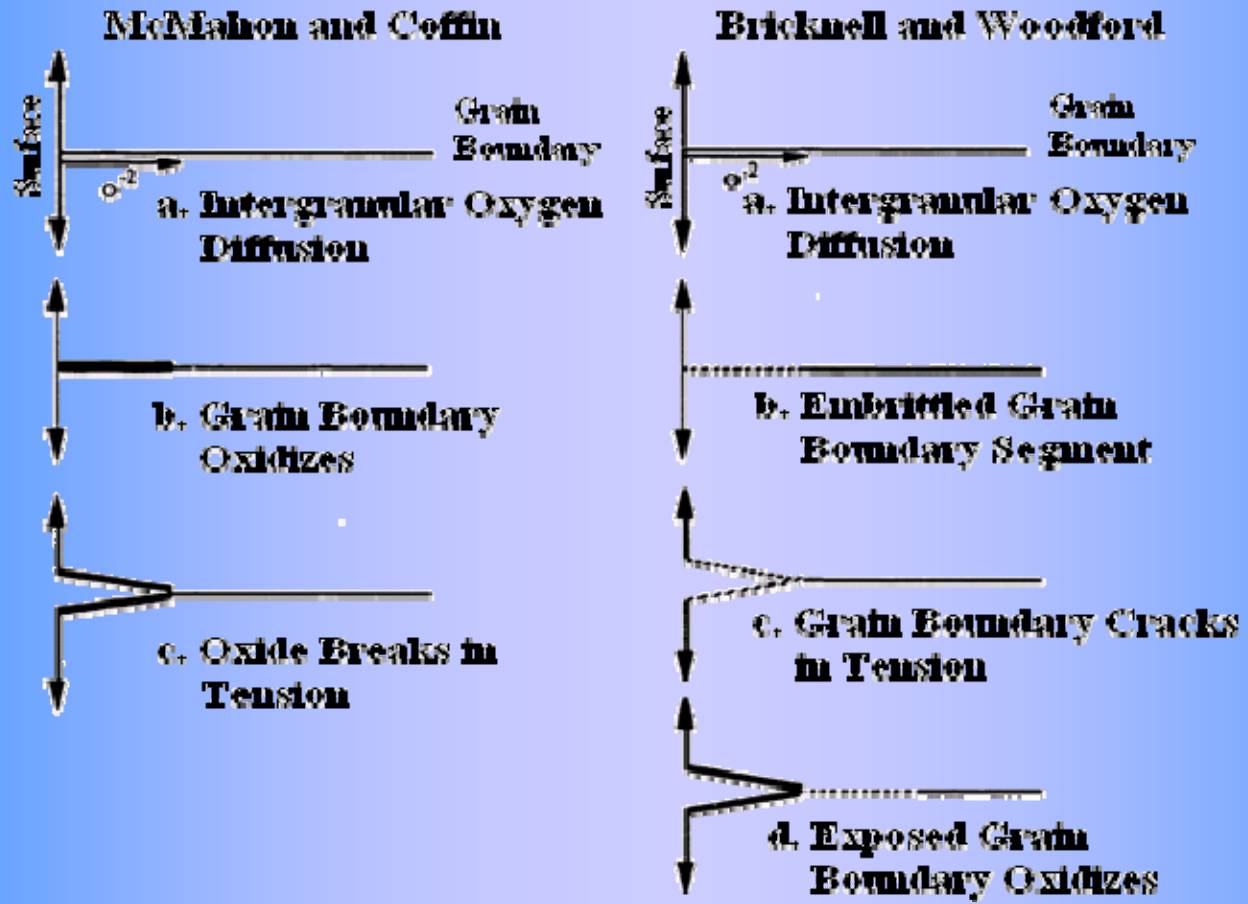
Stress Accelerated Grain Boundary Oxidation (SAGBO)

- SAGBO is a subclass of stress corrosion cracking (SCC), which occurs for a susceptible material under a high tensile stress in a corrosive environment, and is usually path specific.
- SAGBO involves the embrittlement along the grain boundaries due to oxygen diffusion which causes cracking.
- It has been reported that SAGBO is responsible for much of the intergranular cracking that has occurred in INCONEL alloys 718 and 706 at elevated temperatures.



Stress Accelerated Grain Boundary Oxidation (SAGBO)

- SAGBO Mechanisms



Stress Accelerated Grain Boundary Oxidation (SAGBO)

- Remedial Actions for SAGBO
  - Reduction of Applied Tensile Stress
  - Reduction of Oxygen Content
  - Modification of Chemical Composition
  - Modification of Microstructure
  - Thermomechanical Processing
  - Oxidation Resistant Coatings

Summary

- INCONEL Alloy 706 is a precipitation-hardenable alloy with excellent mechanical strength, good fabricability and resistance against oxidation and corrosion. Stress Accelerated Grain Boundary Oxidation (SAGBO) in Alloy 706 has been reported as the cause of cracking in the gas turbine discs.

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