Optimization of ODS-Alloy Properties

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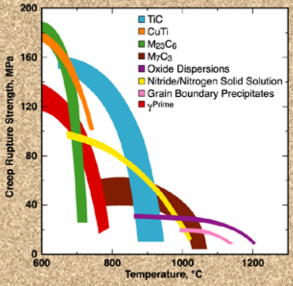
Oxide-Dispersion-Strengthened Alloys: ODS-Fe_3Al and ODS-FeCrAl

Oxide-dispersion-strengthened (ODS) alloys represent a viable alternative to the nickel-base superalloys currently used for engine hot-section components. ODS alloys exhibit superior environmental durability and excellent resistance to oxidation and sulfidation over an extended temperature range. Thermodynamically stable phases in the matrix ensure prolonged creep life.

Further research will enable improved matching of the intrinsic material properties of ODS alloys with the expected in-service design stresses. Further work is also needed to develop and validate joining processes that will preserve the ODS microstructure.

- Material options: mechanically alloyed Y_2O_3-strengthened Fe_3Al or FeCrAl (MA-956^{TM}).
- Target product: 10-ft.-long, 1- to 3-in.-diameter heat-exchanger tubes for high-temperature (1000 to 1100°C), high-pressure (1000-psi) oxidizing/sulfidizing environments.
- Scientific approach: innovative compact consolidation and processing, creep strengthening via grain fibering, and validation of component-specific joining methods.

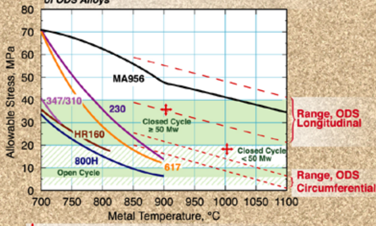
R&D challenges: reconciling the inherent grain-shape-dependent anisotropic properties of ODS alloys with in-service creep-strength anisotropy and preserving microstructure during joining.



ODS Alloy Product Forms

Application Range for ODS Alloys

Objective: to improve the limited hoop creep performance of ODS Alloys



+ Current hoop performance metrics for ODS-Fe_3Al Alloys

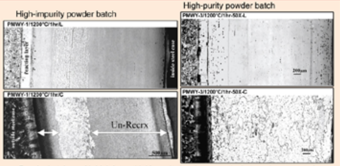
Effects of Impurities

Impurity Issues in Powder-Milling Processes

Element	As received HM	PM	Milled powder batches PMWY-1	PMWY-2	PMWY-3
Fe	Bal.	79.6			
Al	16.3	18.20			
Cr	2.4	2.18			
Zr	20 ppm	26 ppm			
O (total)	60 ppm	110 ppm	1800 *ppm*	1900 *ppm*	1400 ppm
O (in Y_2O_3)			1025 *ppm*	1053 *ppm*	1080 ppm
O balance			775 *ppm*	847 *ppm*	320 ppm
O pickup			*665 ppm*	*737 ppm*	*210 ppm*
N	18 ppm	7 ppm	1264 *ppm*	145 *ppm*	88 *ppm*
N pickup			*1257 ppm*	*138 ppm*	*81 ppm*
C		24 ppm	667 *ppm*	360 *ppm*	303 *ppm*
C pickup			*643 ppm*	*336 ppm*	*279 ppm*
H		16 ppm	115 *ppm*	40 *ppm*	29 *ppm*
C+N+O pickup			*2565 ppm*	*1211 ppm*	*570 ppm*

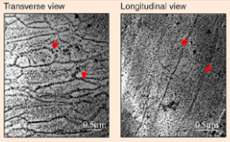
Bulk compositions are identified in wt %; HM and PM are two separate analyses of atomized Fe_3Al powder.

Milling-Induced Impurities Affect Recrystallization



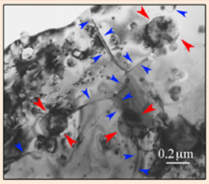
Powder batches with high interstitial impurity levels are particularly resistant to static recrystallization treatments. Efforts to increase time-temperature combinations have met with only marginal success. Further gradient annealing efforts are under way.

Recrystallization Microstructures



Specimens extracted from the high-purity powder chemistry (PMWY-3) heat-treated tubes (HT: 1200°C, 1 h in air). Red arrows indicate prior particle boundaries in transverse and longitudinal views.

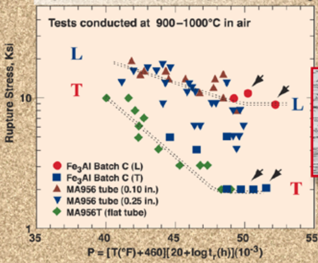
Restricted Grain Growth

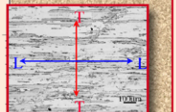


Grain boundary (blue arrows) pinned by Al-oxide, Al-nitride (red arrows) impurities.

L vs T Creep Comparison for ODS Materials

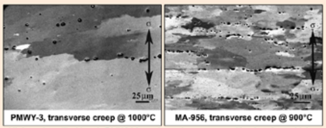
Longitudinal and Hoop Creep Anisotropy in MA956 and ODS-Fe_3Al





Microstructure-Property Relationships

Transverse Creep: Failure Microstructures

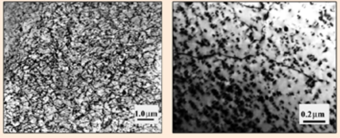


PMWY-3, transverse creep @ 1000°C **MA-956, transverse creep @ 900°C**

High-purity milled batch PMWY-3 produces large recrystallized grains, which respond better in transverse creep testing. Creep void formation is suggested to occur in the vicinity of large impurity oxide particles and/or stringers.

Transverse Creep: Deformation Structure

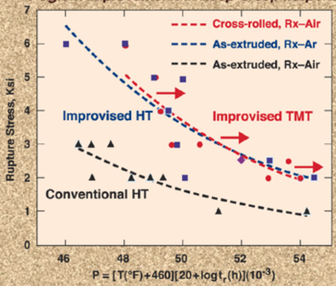
MA-956: high-stress, short-term exposure PMWY-3: low-stress, long-term exposure



Transverse tensile tests and high-stress, short-term creep tests reveal the ability of the ODS-alloy microstructure to sustain an extremely high density of dislocation activity. Nonetheless, long-term creep tests indicate very low dislocation activity in the bulk of the microstructure. This is indicative of extremely high climb rates and/or extremely localized failure origin. Low creep ductility supports the latter possibility.

The elongated grain shape produces a creep performance anisotropy. Thus, while the material has sufficient intrinsic strength, it is not as strong in the hoop direction, where it is most required for the end-use tube applications.

Program Improvements in Hoop Creep Response



Hoop Creep Response in As-Extruded and Cross-Rolled ODS-Fe_3Al

Hoop creep response is improved via control of recrystallization environment and temperature. Initial tests of cross-rolled materials show significant improvements.

Summary of Results

- Longitudinal creep exhibits a threshold failure stress of the order of 8 to 9 Ksi at 1000°C.
- A firm threshold has been established for transverse creep for testing at 2 Ksi at 1000°C. Larsen-Miller parameter >54.4* at 2 Ksi and >53.9* at 2.5 Ksi (*tests continuing).
- Recrystallization temperature and environment play a dominant role in improving hoop creep response. Sustained exposures of 5 Ksi hoop stress have been achieved at 900°C.
- Cross rolling shows significant promise towards enhancing hoop creep response. Further improvements are projected via controlled-environment recrystallization processes.

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