Elemental Effects on Nickel-Base Superalloy Powders

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Aeromat 2012
June 20, 2012
Outline

1. **Genesis of PM superalloy design**
2. Processing Constraints
3. Application Needs
4. Future Potential
Development of PM Disk Alloys

• 45 years ago, powder metal superalloys became forgeable
• PM disk alloys originated from blade alloys
• Original disk heat treatments intended to coarsen microstructure for high strength

To restore the particular alloy to its normal condition of high strength and hardness subsequent to the forging operation, the conventional solution, stabilization, precipitation heat treatment is required. In the case of the IN100 alloy having a normal recrystallization temperature of about 2100F., the preferred heat treatment involves solution heat treatment at about 2175F. to produce grain growth which is followed by stabilization and precipitation heat treatment. The solution heat treat temperature of the various other alloys specifically mentioned herein are set forth in Table VIII.
PM Processing Provided Alloy Sandbox

Powder metal processing permitted the production of micro ingots capable of almost any composition.
PM Alloys Utilize Small Area on Table

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* La  Ce  Pr  Nd  Pm  Sm  Eu  Gd  Tb  Dy  Ho  Er  Tm  Yb  Lu
| 138.9|140.1|140.9|144.2|145.0|150.4|152.0|157.3|158.9|162.5|164.9|167.3|168.9|173.0|175.0|    |

** Ac  Th  Pa  U  Np  Pu  Am  Cm  Bk  Cf  Es  Fm  Md  No  Lr
| -227.0|232.0|233.0|233.0|233.0|237.0|244.0|243.0|247.0|247.0|250.0|256.0|257.0|258.0|259.0|262.0|

• Gamma Prime Formers: Al, Ti, Ta, Nb
• Gamma Formers: Mo, W, Nb, (Ni)
• Oxidation Resistance: Cr
• Grain Boundary Conditioners: B, C, Hf, Zr
  • From Pollock and Tin
High Gamma Prime Alloys

- Gamma Prime Solvus
- Gamma Prime Fraction

Year Developed:
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010

Gamma Prime Solvus (F):
- 1950
- 2000
- 2050
- 2100
- 2150
- 2200
- 2250

Gamma Prime Fraction (%):
- 0%
- 20%
- 40%
- 60%
- 80%
## Modern Powder Metal Disk Alloys

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Outline

1. Genesis of PM superalloys
2. Processing Constraints
3. Application Needs
4. Future Potential
Powder to Parts Conversion Routes

- HIP
- HIP and Press
- Extrude
- HIP and Extrude
- HIP and Forge

Atomize
Fill
HIP
Extrude
Press
Isoforge
Constraining Grain Growth

- On heating for consolidation, Carbon and Boron can migrate to powder surfaces
- C / B / O particles serve as grain boundary constraints

Furrer JOM Jan 1999
### Elemental Concerns with Powders

**Gamma Prime Formers:**
- Oxidation Resistance: Y, La

**Gamma Formers:** Re

**Grain Boundary Conditioners:** N

|   | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1 | H  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | He |
|   | 1.0|    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 4.0|
| 2 | Li | Be |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | B  |
|   | 6.9| 9.0|    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 10.8|
|   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 12.0|
| 3 | Na | Mg |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | O  |
|   | 23.0|24.3|    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 14.0|
|   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 16.0|
|   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 19.0|
|   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 20.2|
| 4 | K  | Ca | Sc | Ti | V  | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
|   | 39.1|40.1|45.0|47.9|50.9|52.0|54.9|55.8|58.9|58.7|63.5|65.4|69.7|72.6|74.9|79.0|79.9|83.8|
|   | 85.5|87.6|88.9|91.2|92.9|95.9|98.0|101.1|102.9|106.4|107.9|112.4|114.8|118.7|121.8|127.6|126.9|131.3|
| 5 | Rb | Sr | Y  | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I  | Xe |
|   | 132.9|137.3|178.5|180.9|183.8|186.2|190.2|192.2|195.1|197.0|200.6|204.4|207.2|209.0|-209.0|-210.0|-222.0|
|   | 223.0|226.0|261.0|262.0|263.0|262.0|265.0|266.0|269.0|272.0|277.0|    |    |    |    |    |    |    |

- **La**  
- **Ce**  
- **Pr**  
- **Nd**  
- **Pm**  
- **Sm**  
- **Eu**  
- **Gd**  
- **Tb**  
- **Dy**  
- **Ho**  
- **Er**  
- **Tm**  
- **Yb**  
- **Lu**

- **Ac**  
- **Th**  
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- **U**  
- **Np**  
- **Pu**  
- **Am**  
- **Cm**  
- **Bk**  
- **Cf**  
- **Es**  
- **Fm**  
- **Md**  
- **No**  
- **Lr**

**Gamma Prime Formers:**
- Oxidation Resistance: Y, La

**Gamma Formers:** Re

**Grain Boundary Conditioners:** N

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Precipitate Nucleation and Growth

As part of advanced powder compositional studies, heat treatment plays a critical role.

From Gabb, 2003-212086

From Jian Mao, WVU
Several Dual Grain Size Processes Exist
Outline

1. Genesis of PM superalloys
2. Processing Constraints
3. Application Needs
4. Future Potential
Peak loading cycles have increased from relatively short peak cycle loads of 2 – 10 minutes to 20 minutes as fuel and flight efficiencies increase as well as environmental concerns are addressed.
Advancing the Current Alloys System

One trend in current alloy systems concerns balancing the solid solution strengtheners for creep resistance and oxidation resistance at the crack front while avoiding detrimental TCP phases.
Control of Refractory Type Elements

Hicks – Rolls Royce

Ellingham Diagram for Selected Oxides: Part-2

Critical Inclusion Size and Frequency

- Increased size and content of these inclusions can lower PM fatigue life, especially in situations where they intersect a stressed disk surface.
- PM material has been seeded with extra inclusions to quantify these effects.
Hold Time Crack Growth

- Hold time crack growth in air can be influenced with heat treatment.
- However, heat treatments must attain a balance of numerous mechanical properties.
Disk alloy fatigue behavior is a product of a complex interrelationship of a number of key variables.
1. Genesis of PM superalloys
2. Processing Constraints
3. Application Needs
4. Future Potential
### Composition-Property Tailoring

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<td>Increased Ductility for Burst</td>
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**PW4000 from ONERA paper**
Dual Alloy HP Turbine Disk
Calibrated Models Will Provide Opportunities

- **Tensile Creep Dwell Crack Growth LCF Life**
- **ASTM 8 ASTM 6 ASTM 3.5 ASTM 1**
- **Grain Size (μm)**

![Graph showing normalized life or strength vs. grain size](image)