Special Projects and Applications

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Special Projects and Applications

Flow Forming (FF) of PM2000 tubes

- Cold FF
- Warm FF
- Grain structures and properties

Selective Laser Melting (SLM) PM2000 powder

- SLM build process
- Build microstructures
- Potential applications
Heat transfer: 12.5 MW
Air flow: 17.5 kg/s
Pressure: 11.3 bar
Air temp: 1013°C
ODS temp: 1090°C
No. of ODS tubes: 80
Three-Roller Flow Forming

‘Graintwist’ - European BRITE project
- Background – ODS tubed heat exchanger
- Tube Flow forming: change GAR in PM2000
- Hoop creep properties
- 3 years / $3.2m

Plansee GmbH / Lechbruck DE
Metall Spezialrohr GmbH DE
Mitsui Babcock Energy Ltd GB
Sydkraft Konsult AB SE
University of Liverpool UK
Risoe National Laboratory DK
University of Cambridge UK
Flow Forming of PM2000\(^1\) tubes

Cold (water cooled) reverse flow formed tubes produced

<table>
<thead>
<tr>
<th>Tube</th>
<th>Total cold deformation</th>
<th>Passes</th>
<th>End. OD x WT (^{(2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>74%</td>
<td>1</td>
<td>46.8 x 1.30</td>
</tr>
<tr>
<td>No. 2</td>
<td>76%</td>
<td>1</td>
<td>46.6 x 1.20</td>
</tr>
<tr>
<td>No. 3</td>
<td>72% (41+62)</td>
<td>2</td>
<td>47.2 x 1.40</td>
</tr>
<tr>
<td>No. 4</td>
<td>74%</td>
<td>1</td>
<td>46.8 x 1.30</td>
</tr>
<tr>
<td>No. 5</td>
<td>73%</td>
<td>1</td>
<td>47.0 x 1.30</td>
</tr>
<tr>
<td>No. 6</td>
<td>47%</td>
<td>1</td>
<td>49.4 x 2.60</td>
</tr>
<tr>
<td>No. 7</td>
<td>92% (43+70+56)</td>
<td>3</td>
<td>45.2 x 0.50</td>
</tr>
<tr>
<td>No. 8</td>
<td>83% (47+72)</td>
<td>2</td>
<td>46.0 x 0.90</td>
</tr>
<tr>
<td>No. 9</td>
<td>81% (43+76)</td>
<td>2</td>
<td>46.2 x 1.00</td>
</tr>
<tr>
<td>No. 10</td>
<td>90% (54+72)</td>
<td>2</td>
<td>45.4 x 0.60</td>
</tr>
</tbody>
</table>

\(^{(1)}\) Fine grained condition

\(^{(2)}\) Start dimensions 53.3mm OD, 4.55mm wall
Flow Forming of PM2000 tubes

PM2000 Tubes Cold Flow formed $^{1,2} + $ Secondary Recrystallised $^3$

Tube 1 (74%)

Tube 9 (81%)

Tube 10 (90%)

$^1$ Water cooled reverse flow forming.

$^2$ PM2000 preforms (53.3mm OD/4.55mm wall).

$^3$ 1320°C / 1.5h
Flow Forming of PM2000 tubes

PM2000 Tubes Warm Flow formed $^1$ + Secondary Recrystallised $^2$

$^1$ Warm flow forming: 600-650$^0$C. Preheated tube / mandrel (gas burners)
$^2$ 1320$^0$C / 1.5h
Flow Forming of PM2000 tubes

Secondary Recrystallisation:

tube – W7 (86%)

warm flow formed + 1h / 1380ºC

Annealing Time @ 1380ºC
Flow Forming of PM2000 tubes

SR Microstructural zones in Warm deformed tube – W7 (86%)

<table>
<thead>
<tr>
<th>Region</th>
<th>Grain Size [μm]</th>
<th>Axial</th>
<th>Radial</th>
<th>Hoop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region A</td>
<td>10 μm</td>
<td>600</td>
<td>10</td>
<td>50000</td>
</tr>
<tr>
<td>Region B</td>
<td>140 μm</td>
<td>650</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>Region C</td>
<td>150 μm</td>
<td>2500</td>
<td>150</td>
<td>1500</td>
</tr>
<tr>
<td>Region D</td>
<td>400 μm</td>
<td>10000</td>
<td>350</td>
<td>7500</td>
</tr>
</tbody>
</table>
1100°C Hoop Creep Test Data

Flow Formed + SR tube Creep Test Data

ODM 751 tube at 1150°C.

PM2000 sheet at 1100°C

PM2000 tube (pilgered) at 1100°C

MA956 tube at 1100°C
Flow forming of PM2000 tube: outcomes

- Flow Formed (FF) tube can exhibit large hoop creep strength increment c.f. Pilger tube

- FF deformation > 80% required to achieve useful (coarse) SR grain structures

- ‘Warm’ FF may offer certain advantages over ‘cold’ FF

- Commercial FF produce complex deformation patterns in tube:
  - axially periodic (reflect roller positions)
  - vary significantly through tube wall thickness
  - influenced by number of passes/roller geometry

- FF produces a wide range of SR microstructures in tube:
  - grain size
  - GAR (and orientation)
  - $T_{\text{Rex}}$
  - texture type/strength

  vary through wall thickness

- grain size varied with total level of FF deformation (50-90%)
Metal Spinning for Combustor Cans

Schematic showing a CNC metal spinning process.

Example of a conventional combustor can (Typhoon DLE). Courtesy of Siemens

Metal spinning imparts tangential material flow: influences circumferential grain structures after SR.

Different grain morphologies can be produced depending on the combination of forming parameters.

Figures show plan views of grain structures in different PM2000 spun cans.

Grain morphology relative to the component varies from almost fully axial (a) to fully circumferential (b).
Selective Laser Melting (SLM) PM2000 powder

PM 2000 Thermocouple Sleeves
Application: e.g. in Gas Turbines; temperature measurement close to combustion chamber

PM 2000 low NO<sub>x</sub> burner nozzles

Micro-heat exchanger by SLM (20mm cube)
Selective Laser Melting (SLM) PM2000 powder

PM2000 Particle size analysis

- The PM2000 MA powder exhibited a bi-modal particle size distribution.
- Powders were sieved to remove large particles that would impede flow/disturb the powder bed.
Increasing scan speed \( \rightarrow \) (m/s)

Increasing laser power \( \uparrow \) (W)

Selective Laser Melting (SLM) PM2000 powder

50W, 0.1m/s wall

PM2000 SLM wall, side view, 50w, 0.1m/s.
Electron channelling contrast images.

- Walls ≤ 200μm thickness
- Columnar grain structure
- Some porosity; sensitive to build parameters
Selective Laser Melting (SLM) PM2000 powder

TEM revealed nano-particles present in all SLM PM2000 builds
c.f. \( r_m = 15.0\pm 4.5\)nm for ODS particles in PM2000 tube annealed 1h/1380\(^{\circ}\)C
Selective Laser Melting (SLM) PM2000 powder

SLM build in progress 50W/0.2ms⁻¹

SLM array of 1cm³ PM2000 mesh cubes

PM2000 SLM 1cm³ mesh 0.6mm octahedral cell

SLM used to fabricate:
- walls and mesh arrays using as-MA PM2000 ODS alloy feed powders.
- demonstrator, fabricated with a CoCr alloy, to show how SLM can direct build enclosed, mesh filled parts.
SLM deposition of PM2000 surface layer (~150μm) on IN939 (Co-Cr Ni-base superalloy) substrate
Selective Laser Melting (SLM) PM2000 powder

PM2000: 25mm OD, 15mm height, 3mm ‘wall’, 0.25mm thick uniform shell.
Selective Laser Melting (SLM) PM2000 powder

Design for honeycombe within honeycombe SLM PM2000 Build

Sulzer Neomet products: typical honeycombs – labyrinth air seals for aero gas turbines.
Selective Laser Melting (SLM) PM2000 powder

Small hexagon side | 2 mm
Large hexagon side | 8 mm
Wall thickness      | 0.2 mm
Hexagon build height| 15 mm
Height rebate (centre to edge) | 4 mm
SLM of PM2000 powder: outcomes

SLM:
Direct build from PM2000 powders feasible
Retention of ODS particulate
Possible applications include:
  Complex shapes
  Self canning
  coatings