Beta C Spring made from PAM Single Melt Input Stock

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1. RTI International Metals, Inc., Niles, OH
2. Dynamet Incorporated, Washington, PA
3. Renton Coil Spring Co., Renton, WA

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Outline

- Introduction
- Single melt PAM ingot
- Bar rolled from as-cast PAM ingot
- Heat treatment of rolled bar
- Coil making and evaluation
- Summary
Introduction

• Beta C is a high strength titanium alloy widely used for spring and fastener applications

• Input billet for bar rolling is currently made by VAR + Open Die Forging + GFM Forging route

• Use as-cast PAM single melt ingot as input stock for bar rolling provides potential to reduce cost

• Team effort to evaluate single melt Beta C product
  * RMI – make PAM ingot, heat treatment study
  * Dynamet – roll bar, heat treatment study
  * Renton Coil – make coil, product evaluation
Comparison of Mill Processes for Beta C Bar Hot Rolled from VAR and PAM Ingots

**VAR**

- 30-Inch Diameter VAR Ingot
- Press Forge to Intermediate Size (Several Reheats)
- Press Forge to GFM Forged Input Size (Several Reheats)
- GFM Forge to Billet (Rough Turn to Approx. 4-inch Dia.)

**PAM**

- 5-Inch Diameter PAM Ingot

Bar Rolling +
Coil Manufacturing

Beta C Spring made from PAM
Single Melt Input Stock 9-2005
Titanium Melting Processes

Vacuum Arc Remelting (VAR)

Plasma Arc Melting (PAM)

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Plasma Arc Melting (PAM) Ingot
As-Cast Structure of PAM Ingots

Transverse

Longitudinal

Beta C Spring made from PAM
Single Melt Input Stock 9-2005
## Chemistry of Beta C 5” Ø Single Melt PAM Ingot

<table>
<thead>
<tr>
<th>Location</th>
<th>Al</th>
<th>V</th>
<th>Cr</th>
<th>Mo</th>
<th>Zr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>3.3</td>
<td>7.9</td>
<td>6.4</td>
<td>4.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Bottom</td>
<td>3.4</td>
<td>8.4</td>
<td>6.5</td>
<td>4.4</td>
<td>3.4</td>
</tr>
<tr>
<td>AMS 4958</td>
<td>3.0-4.0</td>
<td>7.5-8.5</td>
<td>5.5-6.5</td>
<td>3.5-4.5</td>
<td>3.5-4.5</td>
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</tbody>
</table>

Beta C Spring made from PAM
Single Melt Input Stock 9-2005
Bar Rolling
Rolled 0.6” Ø Bar
Evaluation of 0.6-Inch Diameter Beta C Bar Produced from 5-Inch Diameter PAM Ingot

- Heat Treatment Study
  - Determine effect of heat treatments on aging response and microstructure

- Selection of Heat Treatments for Mechanical Property Evaluation

- Mechanical Property Evaluation
  - Tensile
  - Fatigue
  - Double shear
Heat Treatment Studies

Solution Treatment (ST)

1. Effect of ST temperature

Aging

2. Effect of direct aging temperature
3. Effect of aging temperature after ST
4. Effect of aging time after ST

Different Routes

5. Effect of as-cast PAM vs. forged VAR
Effect of ST Temperature on Macrostructure

ST 1400°F or 1450°F or 1500°F, 30m, AC;
Aging 925°F, 24hr, AC

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Single Melt Input Stock 9-2005
Effect of ST Temperature on Microstructure

ST 1400°F or 1450°F or 1500°F, 30m, AC; Aging 925°F, 24hr, AC

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Single Melt Input Stock 9-2005
Effect of ST Temperature on Tensile Strength

ST 1400°F or 1450°F or 1500°F, 30m, AC; Aging 925°F, 24hr, AC

*Percent of Elongation
Effect of Direct Aging Temperature

Direct Aging at 975°F vs. 925°F, 24 hrs, AC
Effect of Direct Aging Temperature

Direct Aging at 975°F vs. 925°F, 24 hrs, AC

*Percent of Elongation

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Single Melt Input Stock 9-2005
Effect of Aging Temperature after ST on Macrostructure

ST 1400°F, 30m, AC;
Aging 900°F vs. 925°F, 24 hr, AC
Effect of Aging Temperature after ST on Microstructure

ST 1400°F, 30m, AC;
Aging 900°F vs. 925°F, 24 hr, AC

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Single Melt Input Stock 9-2005
Effect of Aging Temperature after ST on Tensile Strength (UTS)

*Percent of Elongation

Beta C Spring made from PAM
Single Melt Input Stock 9-2005
Effect of Aging Time after ST on Macrostructure

ST (1500°F, 30m, AC); Aging at 925°F for 8 or 16 or 24 hrs, AC

- 8 hrs
- 16 hrs
- 24 hrs

Longer aging time leads to more alpha precipitation. The surface and intermediate area have less alpha precipitation.
Effect of Aging Time after ST on Microstructure

ST (1500°F, 30m, AC);
Aging at 925°F for 8 or 16 or 24 hrs, AC

L Direction

8 hrs 16 hrs 24 hrs
Effect of Aging Time after ST on Tensile Strength (UTS)

ST (1500°F, 30m, AC); Aging at 925°F for 8 or 16 or 24 hrs, AC

*Percent of Elongation*
As-Cast PAM vs. Forged VAR

ST (1500°F, 30m, AC); 
Aging at 925°F for 8 or 16 or 24 hrs, AC

T Direction

VAR +

PAM +

8 hrs 16 hrs 24 hrs
As-Cast PAM vs. Forged VAR

ST (1500°F, 30m, AC);
Aging at 925°F for 8 or 16 or 24 hrs, AC

Beta C Spring made from PAM
Single Melt Input Stock 9-2005

*Percent of Elongation
Double Shear Strength of Beta C Bar
Produced from VAR and Single Melt PAM Ingots

Shear Strength, ksi (VAR)
Shear Strength, ksi (PAM)
Linear (Shear Strength, ksi (VAR))

Beta C Spring made from PAM
Single Melt Input Stock 9-2005
Fatigue Data for Beta C Heat Treated Bar Produced from VAR and Single Melt PAM Ingots

<table>
<thead>
<tr>
<th>Maximum Stress, ksi (R=0.1)</th>
<th>Cycles to Failure</th>
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<tbody>
<tr>
<td>176 ksi UTS PAM</td>
<td></td>
</tr>
<tr>
<td>225 ksi UTS PAM</td>
<td></td>
</tr>
<tr>
<td>193/206 ksi UTS VAR</td>
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Beta C Spring made from PAM Single Melt Input Stock 9-2005
Coil Manufacturing

Harsh Coiling Test
mandrel size = wire size x 2
Coil Manufacturing

PAM Beta C bar successfully passed such a test
Coil Manufacturing

• Bars made from single melt PAM ingot have successfully passed the Harsh Coiling Test

• Cycle test of springs is in-progress

• Microstructure and mechanical property evaluations are in-progress
Summary

• Beta C bars produced from as-cast PAM ingot have successfully passed the Harsh Coiling Test

• Tensile properties of single melt bars are comparable to those of VAR processed bars and meet the requirement of AMS 4958 (180 ksi min. UTS and 8% min. elongation)

• Spring cycle test and mechanical property evaluation are in-progress; results will be reported in the future