Microalloy Steel for Linkage Forgings

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American Axle & Manufacturing
Schedule of Presentation

• Background
• Metallurgical Properties of Samples
• Testing and Evaluation of Results
  • Component Testing
  • Metallurgical Evaluation
• Discussion
• Conversion of Idler Arm Support
• Conclusions
Background

• Driving force was to eliminate post-forging operations
  • Eliminate heat treat issues and costs
• Ideal material
  • Excellent fatigue & impact properties for varying temperatures
  • Minimal dependency on the forging process
• Generation I, II & II w/Mo were considered
  • Gen I
    • Can achieve desired strength
    • Lower toughness
    • Dependent on cooling rate
  • Gen II
    • Slightly lower strength
    • Better toughness than Gen I
    • Dependent on cooling rate
  • Gen II w/Mo
    • Slightly lower strength
    • Better toughness than Gen I
    • Less dependent on cooling rates
Metallurgical Properties of Samples

- **Alloy I**
  - **1046V – Generation I microalloy**
    - Vanadium is used as the precipitation strengthener
      - Improves toughness by stabilizing the dissolved nitrogen
      - Stabilizes the ferrite formation
      - Raises the impact transition temperature
    - Properties are dependent on the %V & cooling rate from the forging temperature
  - Microstructure of ferrite & pearlite

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.43 – 0.50</td>
<td>0.70 – 1.00</td>
<td>0.040 max.</td>
<td>0.050 max.</td>
<td>0.06 Typical</td>
</tr>
</tbody>
</table>
Metallurgical Properties of Samples

- **Alloy II**
  - **1524V – Generation II microalloy**
    - Vanadium is used as the precipitation strengthener
    - Increased amount of Mn, V, N, and Si
    - Has lower carbon content than Alloy I
      - Helps increase ferrite volume fraction
      - Helps improve the toughness
    - Properties are dependent on the cooling rate
    - Microstructure of ferrite & pearlite

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.19 – 0.25</td>
<td>1.35 – 1.65</td>
<td>0.030 max.</td>
<td>0.050 max.</td>
<td>0.14 Typical</td>
</tr>
</tbody>
</table>
Metallurgical Properties of Samples

- Alloy III
  - 1522VMoTi – Generation II modified microalloy
    - Mo depresses the f/p transformation
      - Large window for the bainitic transformation
      - Less dependent on cooling rate
    - Ti added to control austenitic grain size at forging temp.
      - Makes fine final grain size which improves toughness
    - Microstructure of acicular ferrite & bainite (nontraditional bainite)
# Metallurgical Properties of Samples

## Composition of 1522VMoTi

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.21 – 0.25</td>
<td>1.40 – 1.80</td>
<td>0.03 max.</td>
<td>0.03 – 0.06</td>
<td>0.25 – 0.45</td>
<td>0.40 max</td>
</tr>
<tr>
<td>Ni</td>
<td>0.25 max.</td>
<td>0.20 max</td>
<td>0.18 – 0.25</td>
<td>0.08 – 0.13</td>
<td>0.005 – 0.02</td>
<td>0.010 – 0.016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Metallurgical Properties of Samples

• Process of Samples
  • Alloy 1
    • Hot upset & forced air cooled
  • Alloy II & III
    • Hot upset & air cooled
  • Production samples
    • Hot upset & Q&T
  • All samples were produced to 229 - 269 HB
Engineering Testing and Evaluation

- Testing was performed on all 3 alloy grades and compared to current production
- Impact Toughness
  - Cold and room temperature
- Impact Ductility
- Programmed Fatigue Life
- High-Load Fatigue
Engineering Testing and Evaluation
Cold Impact Testing

• Evaluate the ductility & impact strength
• Expected to withstand impact great enough to deform without signs of fracture
• Pitman arm was soaked for 16 hrs at -70°C
• Arm was assembled into the impact table & impacted when the surface temperature reached -40 °C
Engineering Testing and Evaluation
Impact Twist and Bend Test

- Room temperature impact testing was performed using the same set up as cold impact testing
- Multiple 400 ft/lbs. blows were applied
- Twist and bend were recorded at 4 and 8 blows
Pitman arms were tested at the loads & occurrences established in proving ground vehicle testing.

It is required that the PA lasts 2.5 schedules:
- Each schedule is equivalent to 100,000 miles severe field usage for a passenger car and 125,000 miles for light truck and van.

The pitman arms were tested on a hydraulic testing machine with envelopes of different loads and peak loads of 5,175 lbs.
Engineering Testing and Evaluation
High Load Fatigue Testing Parameters

• Alloy II & Alloy III pitman arms were subjected to this fatigue test
• The maximum loads were recorded during vehicle curb push-away tests
• The minimum expected life is 3,000 cycles.
• Test speed is 60 CPM
Discussion of Test Results

• Alloy III meets all durability requirements for this application
• Alloy I samples showed erratic life during program fatigue testing and low impact ductility
• Alloy II and III had similar properties as production for program fatigue testing, impact ductility and cold impact testing
Discussion of Test Results (Continued)

- Alloy II & III passed the high load fatigue test requirements
Metallurgical Evaluation

- Microstructure evaluation was performed on all of the tested alloys

<table>
<thead>
<tr>
<th>Grade</th>
<th>Microstructure</th>
<th>Apparent Grain Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>Tempered martensite</td>
<td>7 - 8</td>
</tr>
<tr>
<td>Alloy I</td>
<td>Ferrite and pearlite</td>
<td>NA</td>
</tr>
<tr>
<td>Alloy II</td>
<td>Ferrite and pearlite</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Alloy III</td>
<td>Acicular ferrite – bainite</td>
<td>6 – 8</td>
</tr>
</tbody>
</table>
Metallurgical Evaluation
Variation of Alloy III (1522VMoTi)

• Microstructure & hardness variation evaluation was performed on alloy III

<table>
<thead>
<tr>
<th>Sample</th>
<th>BID (mm)</th>
<th>BHN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning of Run</td>
<td>3.90</td>
<td>241</td>
</tr>
<tr>
<td>Middle of Run</td>
<td>3.95</td>
<td>235</td>
</tr>
<tr>
<td>End of Run</td>
<td>3.90</td>
<td>241</td>
</tr>
<tr>
<td>Top of Bin</td>
<td>4.00</td>
<td>229</td>
</tr>
<tr>
<td>Middle of Bin</td>
<td>3.90</td>
<td>241</td>
</tr>
<tr>
<td>Bottom of Bin</td>
<td>3.80</td>
<td>255</td>
</tr>
<tr>
<td>Specification</td>
<td>3.70 – 4.00</td>
<td>229 - 269</td>
</tr>
</tbody>
</table>
## Microstructure Variation

**Test Data for Alloy III (1522VMoTi)**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Microstructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top of Bin</td>
<td>Bainite w/15 – 20% acicular ferrite</td>
</tr>
<tr>
<td></td>
<td>Some alloy segregation</td>
</tr>
<tr>
<td>Middle of Bin</td>
<td>Bainite w/10 – 20% acicular ferrite</td>
</tr>
<tr>
<td></td>
<td>Some alloy segregation</td>
</tr>
<tr>
<td>Bottom of Bin</td>
<td>Bainite w/10 – 20% acicular ferrite</td>
</tr>
<tr>
<td></td>
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</table>
Microstructure Variation
Alloy III (1522VMoTi)

Top of Bin
Middle of Bin
Bottom of Bin
Discussion

- The microstructure & hardness evaluation showed that the alloy III was less dependent on cooling rate
Discussion continued…

- The engineering properties for this application were found to be satisfactory due to the following:
  - The addition of at least 0.10% Mo suppresses the pearlite transformation (alloying bainite to form over a large range of cooling rates)
  - The addition of Ti produces a finer grain size, which improves the toughness over alloy I
  - The acicular ferrite & bainite microstructure improves the toughness over alloy I
  - V was used as a precipitation strengthener
Conversion of Idler Arm Support

- The development work done on the PA was applied to a production idler arm support
  - 1524M carburized quench and tempered steel
- Object was to remove post forging processing
- Durability testing was performed on the idler arm supports comparing alloy III to the customer requirements
  - Alloy III conformed to all the customers requirements
Conclusion

• Alloy III (Gen II Mo treated microalloy) can be used in these specific applications to replace:
  • conventional medium carbon quench & temper steel
  • high manganese carbon carburized quench and tempered steel
• Alloy III (Gen II Mo treated microalloy) showed nearly identical hardness & microstructure for varying cooling rates from the hot forging temperature