Agricultural Applications of Austempered Ductile Iron

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ABSTRACT

Austempering is a high performance heat treat process that, when applied to ferrous materials, produces components that have properties superior to those processed by conventional means. Due to its high strength-to-weight ratio as well as its increased wear resistance, Austempered Ductile Iron and Carbidic Austempered Ductile Iron are well suited for agricultural applications from suspension to ground-engaging components.

INTRODUCTION

Austempering is an isothermal heat treat process that can be applied to ferrous materials to increase strength and wear resistance. Figure 1 shows an isothermal (I-T) diagram for cast iron with both the Austempering (green line) and the quench and tempering (red line) processes outlined. Austempering in cast iron consists of Austenitizing followed by rapidly quenching to a temperature above the Martensite start temperature, where the material is then transformed isothermally to form Ausferrite, (acicular ferrite in carbon stabilized austenite). The quench & temper process consists of Austenitizing and then rapidly quenching below the Martensite start temperature. The Martensite that forms is very hard and brittle; and subsequently must undergo a tempering process to acquire the desired combination of strength and toughness.

Because Austempering is an isothermal process, it offers advantages versus quench & tempering. Since the formation of Ausferrite occurs over minutes or hours at a single temperature, distortion is minimized and cracking does not occur. Meanwhile, the formation of Martensite occurs immediately as the metal temperature drops below the Martensite start temperature. Because cooling is achieved at different rates in various sections, this is a non-uniform transformation, which can result in significant distortion and/or cracking.

Carbidic Austempered Ductile Iron (CADI) is a ductile cast iron containing carbides, (either thermally or mechanically induced) that is subsequently Austempered to produce an Ausferritic matrix with an engineered amount of carbides. This process creates components that have high wear resistance characteristics.

Agricultural equipment demands the same increasing performance measures of other off-highway equipment. Components are driven to be low cost and high performance, to handle high stress applications, and last longer under high wear conditions. With the proven strength and wear resistance of ADI, agricultural components can handle higher loads and tougher wear situations than other competitive materials.

SUSPENSION AND DRIVELINE COMPONENTS
Suspension components are an ideal candidate for agricultural applications, such as the new suspension systems on tractors. The different grades of ADI,
(achieved through a variation in the Austempering temperature and time), can create a range of properties as seen in Table 1. Grades 1 and 2 ADI can withstand the dynamic loading on suspension and driveline components.

Table 1: ASTM A897/897M - 90 Property table for ADI

<table>
<thead>
<tr>
<th>Grade</th>
<th>Tensile Strength (MPa/Ksi)</th>
<th>Yield Strength (MPa/Ksi)</th>
<th>Elong (%)</th>
<th>Impact Energy (J/ft-lb)</th>
<th>Typical Hardness (HBW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>850 / 125</td>
<td>550 / 80</td>
<td>10</td>
<td>100 / 75</td>
<td>269 – 321</td>
</tr>
<tr>
<td>2</td>
<td>1050 / 150</td>
<td>700 / 100</td>
<td>7</td>
<td>80 / 60</td>
<td>302 – 363</td>
</tr>
<tr>
<td>3</td>
<td>1200 / 175</td>
<td>850 / 125</td>
<td>4</td>
<td>60 / 45</td>
<td>341 – 444</td>
</tr>
<tr>
<td>4</td>
<td>1400 / 200</td>
<td>1100 / 155</td>
<td>1</td>
<td>35 / 25</td>
<td>366 – 477</td>
</tr>
<tr>
<td>5</td>
<td>1600 / 230</td>
<td>1300 / 185</td>
<td>N/A</td>
<td>N/A</td>
<td>444 - 555</td>
</tr>
</tbody>
</table>

The tensile and yield strength of ADI increases with increased Brinell hardness as shown in Figure 2.

![Figure 2: Typical Properties of Austempered Ductile Iron as a function of Brinell Hardness.](image)

Wheel hubs are a popular application for ADI across various industries. ADI provides the strength required for the application, and often a weight savings due to its improved strength-to-weight ratio compared to other materials.

![Figure 3: ADI Control Arm for AWD Tractor (courtesy of John Deere)](image)

Axles can also be converted from a steel assembly to a one-piece ADI casting for use in agricultural equipment.
WEAR APPLICATIONS
Austempered Ductile Iron has increased contact fatigue strength and wear resistance than comparable materials. Figure 6 compares the allowable contact stress behavior of ASTM Grades 2 and 5 ADI, (ASTM 1050-700-07 and 1600-1300-00).

Figure 7 demonstrates that the contact fatigue properties of various grades of ADI are comparable to gas nitrided steels and can be competitive with carburized and hardened steel.

Figure 8 illustrates that ADI has improved abrasion resistance when compared to other materials. ADI experiences less volume loss at similar hardness levels, resulting in a component with improved wear characteristics in a high stress environment.

Ground engaging applications withstand heavy wear, thus, ADI is a suitable material for these applications. Figures 9 and 10 show ripper points and plow points that have been successful applications of ADI. Other wear applications include tillage points, seed boots, and sway limiters. The higher wear resistance of ADI increases the life of these components. In addition, they are less expensive than Abrasion Resistant White Irons.
GEARS
Increased contact and bending fatigue strengths, as well as noise reduction make ADI well suited for gear and sprocket applications. Figure 11 shows a comparison of tooth root bending fatigue of several ferrous materials. This data shows that ADI is very competitive with cast and through-hardened steels. When shot peening is utilized, the increase in compressive stresses on the surface can make ADI comparable to gas nitrided and case carburized steels in tooth root bending fatigue.

ADI is used for gear and gear housing applications in many industries, including agricultural equipment. Often times the ADI casting can be cast to near-net shape. Austempered gears are used in diesel engine applications across many industries, for their strength, noise reduction and ease of manufacture.

Noise is becoming an important design consideration for many applications, including agricultural equipment. Ductile Iron is intrinsically quieter than aluminums and steels due to the presence of graphite. However, when ductile iron is Austempered, there is an even greater reduction in noise. Figure 13 shows the decrease in
decibel level (dB) in a hypoid gear and pinion application when the components were made from ADI instead of steel.

Support brackets, gears, PTO components and many other parts can benefit from the noise reduction in Austempered Ductile Iron. ADI engine mounting brackets can help dampen the vibrations in the engine compartment.

![Graph showing decibel readings of a steel hypoid gear and pinion set compared to an ADI hypoid gear and pinion set.](image)

**Figure 13: Decibel readings of a steel hypoid gear and pinion set compared to an ADI hypoid gear and pinion set.**

**UNIQUE SOLUTIONS**
As a cast product, ADI can offer other unique design solutions for various applications. In the case of Figure 14, this knotter gear was designed, cast, Austempered and put into service with minimal machining required prior to heat treatment.

In the case of Figure 15, this anhydrous ammonia knife was made more cost effectively with ADI, but required the insertion of a steel tube for application of anhydrous ammonia. The steel tube was set into the green sand mold and the iron was cast around the tube, which eliminated a costly machining attachment and/or welding procedure as well as protected the tube from wear.

![ADI Hay Baler Knotter Gear](image)

**Figure 14: ADI Hay Baler Knotter Gear**

**MANUFACTURABILITY** – ADI offers an opportunity for increased manufacturability since rough machining can be done prior to heat treatment. In the as-cast condition, the material is much easier to machine, resulting in a cost reduction. Though many applications can be heat treated after final machining, finish machining after heat treatment increases the strength characteristics of ADI, giving it superior bending fatigue strength when compared to parts austempered after machining. **Figure 16** compares the relative machinability of several ferrous materials. Note that ductile iron in a ferritic or pearlitic condition is easier to machine than 30 Rc 4140 steel or Grade 1 ADI. If ductile iron is machined prior to heat treatment, one can gain the advantage of better machinability. Furthermore, machining of ductile iron and ADI results in a compact, discontinuous chip that is easily handled and is fully recyclable.

![Graph comparing the relative machinability of several ferrous materials.](image)

**Figure 16: Relative Machinability of Several Ferrous Materials**
LOW TEMPERATURE CONSIDERATIONS –
ADI exhibits un-notched Charpy impact values that are up to three times higher than those reported for conventional ductile iron, but lower than those of forged steel. Because of the notch sensitivity of cast iron, it is difficult to directly compare ADI to steel. Fracture toughness is perhaps a better means of comparison. It has been found that when valid comparisons like fracture toughness are made, the toughness of ADI is much greater than conventional ductile iron and equivalent or superior to competitive cast and forged steels.

At lower temperatures, ADI maintains a rather high percentage of its room temperature toughness. Figure 17 shows that ADI retains nearly 70-80% of its room temperature toughness at –40°C. Figure 18 further illustrates how the fracture toughness of ADI does not significantly vary in low temperature applications.

CARBIDIC AUSTEMPERED DUCTILE IRON
Carbidic ADI or CADI consists of an ausferritic microstructure that contains a controlled volume fraction of carbides. It is produced by austempering ductile iron that contains carbides. These carbides can be introduced by using several methods which include:

-As-Cast Carbides
  -Internal (chemical or inverse) chill
  -Surface chill (limited depth, directional)
-Mechanically Introduced Carbides
  -Cast-in, crushed \( M_xC_y \) carbides
  -Cast-in, engineered carbides (shapes)
-Welded
  -Hardface weldment
  -Weldment with \( M_xC_y \) grains

Figure 19 shows a CADI microstructure with as-cast carbides that was Austempered at 700°F. The volume fraction of carbide in the matrix after austempering was 18%. Figure 20 shows the same base iron as Figure 19 except that the material has now been austempered at 500°F. Note the change in the microstructural scale of the ausferrite. The heat treatment parameters for making CADI can be controlled in order to produce Ausferrite with different ferrite/austenite ratios and microstructural fineness.
The Ausferrite/Carbide mix of CADI offers improved wear resistance versus ADI. Figure 21 shows pin abrasion results for CADI, ADI and other competitive materials. The Abrasion Resistant Iron results are represented by one point, but in reality encompass a family of materials which exhibit pin volume losses of up to 0.008 cm³. [6] Figure 21 shows that CADI can compete competitively with some of the AR irons within this range.

Table 2 shows typical unnotched Charpy impact values for various materials including CADI. The impact strength of CADI is similar to Carburized 8620 steel and pearlitic malleable iron. Note the improvement over AR irons.

Table 2: Typical un-notched Charpy impact values (ft-lbs). Tested at 72F (22C).

<table>
<thead>
<tr>
<th>Material</th>
<th>Charpy Impact Value (ft-lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A532 Abrasion Resistant Iron</td>
<td>2</td>
</tr>
<tr>
<td>30 - 45% Carbide 500 CADI</td>
<td>10</td>
</tr>
<tr>
<td>Carburized 8620 Steel</td>
<td>13</td>
</tr>
<tr>
<td>Pearlitic Malleable Iron</td>
<td>13</td>
</tr>
<tr>
<td>7003 Ductile Iron</td>
<td>38</td>
</tr>
<tr>
<td>Grade 5 ADI</td>
<td>40</td>
</tr>
<tr>
<td>5506 Ductile Iron</td>
<td>45</td>
</tr>
<tr>
<td>Grade 3 ADI</td>
<td>70</td>
</tr>
<tr>
<td>Grade 1 ADI</td>
<td>90</td>
</tr>
<tr>
<td>4512 Ductile Iron</td>
<td>95</td>
</tr>
</tbody>
</table>
POTENTIAL APPLICATIONS FOR CADI

Agricultural components have been produced in CADI with as-cast carbides since the early 1990s. Limited production quantities of CADI parts with cast-in, crushed carbides have been produced as well. Research into chill-carbide CADI camshafts is ongoing. However, the visibility of CADI has been greatly increased of late with the public launch of CADI in programs at John Deere.

SUMMARY

Austempered Ductile Iron (ADI) has an exceptionally high strength-to-weight ratio with good wear resistance and fracture toughness. ADI is suitable for many agricultural applications in drivetrains, suspensions, hitches and wear components.

Carbidic Austempered Ductile Iron (CADI) is a family of ductile cast irons produced with carbides, (both thermally and mechanically introduced), that are subsequently Austempered to exhibit adequate toughness and excellent wear resistance. CADI is suitable for heavy wear applications, such as ground engaging components.

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- ADI Treatments Ltd. Pty.
- Carroll Ag
- Case New Holland
- Dana Corporation
- Gothic Millhouse
- Hay and Forage
- John Deere Corporation

REFERENCES

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