When ductile iron is subjected to an austempering process, the material undergoes a remarkable transformation - ideal for many automotive applications.

Austempered ductile iron (ADI) is stronger per unit weight than aluminium, highly wear resistant and easier to machine than free machining steel - and it has the potential for up to 50% cost savings.

Austempering is a special isothermal heat treatment that can be applied to ferrous materials for increased strength and toughness. Fig. 1 shows a schematic isothermal diagram comparing the austempering (green line) and the quench and tempering (red line) processes. Austempering consists of austenitising followed by rapidly quenching to a temperature range (260-385°C) where the material transforms isothermally to form either ausferrite in cast iron or bainite in steel.

The quench and temper process consists of austenitising and then rapidly quenching below the martensite start line. The martensite formed is a very hard, brittle phase and requires one or more tempering processes to obtain strength and toughness.

As an isothermal process, austempering offers quality advantages versus quench and temper. Formation of ausferrite and bainite occurs over minutes or hours at a single temperature; dimensional tolerances are more readily maintained and cracking avoided. In contrast the formation of martensite occurs with shear at the metal temperature reaches the martensite start line. Since cooling rates vary according to section, the transformation is not homogeneous, significantly increasing the risks of distortion and cracking.

Austempering services are now available from contractors such as ADI Treatments Ltd (West Bromwich, UK). Working with the European foundry industry and castings users, the company operates large scale, specialist furnaces and assists in design and development of ADI components.

**ADI grades, properties and benefits**

ADI materials are versatile; table 1 listing the grades in common use. The designer can select cast composition and heat treatments to provide specific properties required for the application. Fig. 2 illustrates the ausferrite microstructure, a mix of acicular ferrite and carbon stabilised austenite that gives ADI its unique properties.

**Cost advantages**

The price of ADI material is lower per kilo than steel or aluminium, but this accounts for only a fraction of the potential savings as an ADI designed component can save cost at each stage of manufacture. ADI equivalents can then be produced for less than a steel forging or at half the cost of aluminium parts. Several factors favour ADI in value engineering:

- **Excellent castability:** Readily cast into complex shapes, ductile iron has a very high yield rate i.e. the proportion of metal poured versus metal shipped.
- **Lower machining cost:** Well suited to near net shape casting, ADI requires less starting material and less metal removal. Prior to austempering, ductile iron exhibits better machinability than free machining steels.
- **Lower density than steel:** The relative weight per unit of yield strength, ADI is generally the best buy.

**Performance advantages**

Due to superior performance ADI castings are rapidly displacing steel forgings, welded fabrications, carburised steel, and aluminium in key applications:

- **Strength comparable to steel:** Because of its equivalent strength, nearly 80% of all cast and forged steels can be replaced with some grade of ductile iron or ADI.
- **Lower density than steel:** The relative weight per unit of yield strength of ADI allows economy in design without loss of performance. For a given shape, an ADI component will be 10% lighter than steel.
- **‘Lighter’ than aluminium:** ADI is three times stronger than the best cast or forged aluminium and weighs only 2.5 times as much. Because it is twice as stiff, a properly designed ADI part can replace aluminium at a weight saving.
- **Excellent fatigue strength:** ADI’s dynamic

<table>
<thead>
<tr>
<th>Grade</th>
<th>Min tensile stress MPa</th>
<th>Min yield stress MPa</th>
<th>Elongation %</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN-GJS-800-8</td>
<td>800</td>
<td>500</td>
<td>8</td>
<td>260/320</td>
</tr>
<tr>
<td>EN-GJS-1000-5</td>
<td>1000</td>
<td>700</td>
<td>5</td>
<td>300/360</td>
</tr>
<tr>
<td>EN-GJS-1200-2</td>
<td>1200</td>
<td>850</td>
<td>2</td>
<td>340/440</td>
</tr>
<tr>
<td>EN-GJS-1400-1</td>
<td>1400</td>
<td>1100</td>
<td>1</td>
<td>380/480</td>
</tr>
</tbody>
</table>

Table 1. EN1564: 1997 ADI European grades

Both ductile iron and ADI produce dense, discontinuous chips that are easily handled, further reducing cost per kilo.

- **Heat treatment savings:** Austempering generally costs less than carburising or induction hardening, and produces a higher degree of uniformity and predictable dimensional changes.
- **Low energy content:** Producing a typical ADI casting consumes 50% less energy than a steel casting, and 80% less energy than a steel forging.
- **Best value:** When comparing relative cost per unit of yield strength, ADI is generally the best buy.

![Fig. 1 Schematic isothermal diagram illustrating the austempering (green line) plus quench and tempering (red line) processes](image1)

![Fig. 6 Ford Mustang Cobra suspension arm wins casting award (courtesy Intermet and Benteler Corporations)](image2)
properties exceed those of forged, cast and microalloyed steels. Unlike aluminium, ADI’s endurance limit remains nearly constant after tens of millions of cycles.

- **Improved noise damping:** The presence of graphite in the ADI matrix improves noise damping, for quieter, smoother running components.
- **Superior wear and abrasion resistance:** ADI’s abrasion resistance exceeds that of conventionally processed steels and irons at a lower ‘bulk’ hardness level. Unlike carburised steel, which loses wear resistance as the carburised layer is removed, ADI improves in service. Wear resistance is superior to steel at any given hardness level, making it ideal for earth moving and other high abrasion applications.

**Case studies in transport**

**TVR crankshaft**

The TVR Tuscan Speed Six (fig. 3) made its debut in 1999 for sale to the UK and Japan as a right hand drive only vehicle. Striking in appearance and power, the Tuscan Six accelerates from 0-96.5km/h (0-60 mph) in 4.2 seconds and reaches a top speed of 289.6km/h (180 mph). To achieve performance, the designers combined aerodynamic styling and a high power to weight ratio. Using composite materials, TVR created curves in the body that could not be accomplished with regular steel stampings. Less visible, the ADI crankshaft is another significant innovation.

Forged steel was originally chosen as the crankshaft material for use in the inline six cylinder engine. Due to high cost of manufacture, steel was later desel ected and TVR turned to 800/2 ductile iron for the design prototype. Tests were carried out on a bench dynamometer and in vehicles; however the parts failed, in some cases with a fatigue crack at a fillet radius on the flywheel end.

ADI (fig. 4) became the next choice. TVR was already using the material in V8 engines but had initial reservations about distortion in the manufacture of the new crank. To compensate for distortion in the design phase, the crankshaft was rough machined, heat treated and then finish machined. This significantly reduced the concern, while final machining actually increased the strength of the component.

The ADI crank out performed the ductile iron version, showing no signs of fatigue cracking during bench testing. ADI’s internal damping characteristics also gave the engine superior noise properties compared to engines with steel or ductile iron crankshafts. Mechanical results performed on all three materials are shown in table 2.

**Independent truck stabiliser arm**

Trucking in the Australian Outback is a challenging experience. The terrain is rough and isolated and distances may be exceptionally long between service stops. When making the 3,500km trip from Sydney to Perth, the priority is to complete the journey safely while utilising the effective space in the trailer.

Originally, the independent suspension design was a fabrication made from low carbon steel. The first iteration was a 50mm thick, V-shaped swing arm. It was to be road tested over the route the truck would take in service - from Sydney to Perth and back. However, at the first trial of these components, the wheels splayed under the truck during loading; the fully loaded trailer weighing 22.5 tonnes. The test was run as planned but the welded components failed after approximately 1,200km. One of the suspension brackets began to crack at its weld points; concern was also raised because these brackets would flex so heavily that the negative camber induced uneven tyre wear. A second set of welded steel brackets was tested, travelling approximately 4,000km before failure.

The suspension was re-designed as a single-piece ductile iron casting; trial batches were cast and then austempered to achieve Grade 2 ADI (fig. 5). These parts were subjected to the same Perth to Sydney trip as the fabricated steel brackets. At the time of writing the ADI brackets had completed over 322,000km without problems. As well as providing an additional 20m³ storage space inside the truck, tyre life has been extended by over 80,000km.

**Duralite truck hub**

Walther EMC has developed an ADI truck trailer hub that is 2% lighter than its aluminium counterpart and over 30% lower in cost. This is a rather high visibility example of ADI replacing aluminium ‘kilo for kilo’, possibly because of ADI’s superior strength to weight ratio.

**Ford Mustang control arm**

GM has demonstrated the feasibility of ADI suspension control arms on Cadillac limousines since 1995. More recently Bentler Corporation was contracted by Ford to produce a lightweight, cost effective, independent suspension system for its high performance Mustang Cobra sports car. ADI was chosen for the upper control arms (fig. 6) for its combination of low weight (approximately 3 kg), noise damping and low manufacturing cost.

The components were FEA modelled to take full advantage of the strength and stiffness of ADI. An aluminium design was considered but it was impossible to fit the much larger and thicker component in the given space. ADI allowed the manufacturers to meet their space, weight, safety critical, and cost objectives. The success of this application was recognised by the 2003 AFS Casting Congress - at its annual Castings Contest, five of the top awards were

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**Fig. 2 The ADI austemrite micro-structure - a mix of acicular ferrite and carbon stabilised austenite**

**Fig. 3 Tuscan Speed Six (courtesy TVR Engineering Ltd)**

**Fig. 4 ADI crankshaft for the Tuscan Speed Six - 295kg**

**Fig. 5 Duralite truck hub**

**Fig. 6 Ford Mustang control arm**
Transport

Table 2. Test results for the steel, ductile iron, and ADI crankshafts, and ASTM 897/90 Standard ADI Grade 1 specifications

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel Yield strength MPa</th>
<th>Ductile iron Tensile strength Mpa</th>
<th>ADI Fatigue strength Mpa</th>
<th>ASTM ADI Grade 1 Tensile strength Mpa</th>
<th>Impact energy Joules</th>
<th>Elong (%)</th>
<th>Hardness BHN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>738</td>
<td>538</td>
<td>827</td>
<td>550</td>
<td>400</td>
<td>324</td>
<td>226-266</td>
</tr>
<tr>
<td>Ductile iron</td>
<td>910</td>
<td>903</td>
<td>1083</td>
<td>850</td>
<td>275</td>
<td>75</td>
<td>262-277</td>
</tr>
<tr>
<td>ADI</td>
<td>400</td>
<td>324</td>
<td>427</td>
<td>N/A</td>
<td>141</td>
<td>10</td>
<td>300</td>
</tr>
<tr>
<td>ASTM ADI Grade 1</td>
<td>910</td>
<td>903</td>
<td>1083</td>
<td>850</td>
<td>275</td>
<td>75</td>
<td>260-321</td>
</tr>
</tbody>
</table>

Another Best in Class was awarded for a drive wheel, part of a construction and landscape utility loader. Originally an 84 piece steel assembly, the redesigned component is a one piece casting at a 15% weight reduction, 55% lower in cost. Thirty minutes of assembly time have been eliminated while the part exhibits superior wear, durability and appearance compared to the original.

Looking ahead

ADI is being applied increasingly by the automotive industries as the cost and performance benefits are recognised. Following historical growth rates, annual world production of the material is expected to reach 300,000 tonnes by 2010, with approximately two thirds in North America. Carbidic ADI grades have recently been introduced and are adding to the interest worldwide.

Companies like ADI Treatments Ltd actively help to develop the markets and technology in partnership with foundries and their customers. Some of the case studies illustrated have been the result of such co-operations, frequently starting with workshops organised on the customer’s site. European manufacturers, often stimulated by USA connections, are now implementing their own volume applications: Contract austempering services are set to expand to meet the demand. The future for ADI is limited only by an ability to fully exploit this unique material.

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