

# Carbide Austempered Ductile Iron (CADI)

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## ABSTRACT

Carbide 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.

## INTRODUCTION

Since about 1990 industry has discovered various material/process combinations that exhibit surprisingly good wear resistance but defy classification as either white irons or Austempered Ductile Irons. They combine various thermal and mechanical means for introducing carbides in, and on ductile iron components. They are subsequently heat treated by the Austempering process.

This paper attempts to define this class of Carbide Austempered Ductile Irons and to define for the reader the state of the art to date.

## CARBIDE AUSTEMPERED DUCTILE IRON (CADI)

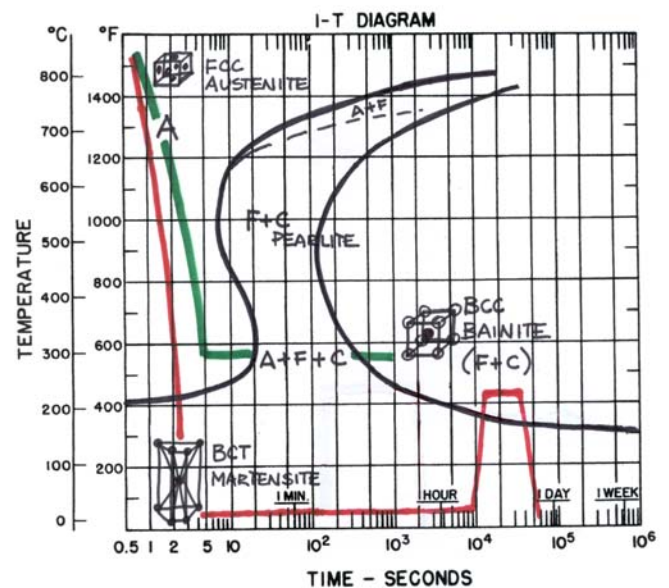
Since the early 1990's several manufacturers have been using various techniques to exploit the advantages of the wear resistance of carbides and the toughness of the Ausferrite matrix produced by the Austempering process.

### What is Austempering?

Austempering is a high performance isothermal heat treatment that imparts superior performance to ferrous metals. The classic definition describes that as an isothermal heat treatment. **Figure 1** compares and contrasts conventional "quench and temper" heat treatment and Austempering in a generic ferrous material.

In conventional quench and tempering (red line) the component is heated to red heat and a fully Austenitic condition. It is then quenched rapidly to a temperature below the Martensite start line. At this point the face

centered cubic Austenite transforms to a taller, body centered tetragonal Martensite. This untempered Martensite is very hard and brittle. This can cause difficulty as the exterior of the part transforms first. Moments later, the inside of the part transforms to Martensite and forces the exterior to "move". This non-uniform transformation can result in severe distortion or cracking. (Cast irons are particularly vulnerable to cracking during quenching). The Martensitic structure is subsequently tempered to produce the desired combination of strength and toughness.



**Figure 1: Compares the quench and temper and austemper processes for a ferrous material.**

The Austempering process (green line) begins similarly with austenitization followed by rapid cooling to avoid the formation of Pearlite. However, there the similarity ends. In the Austempering process the quenching media is held at a temperature above the Martensite start temperature. This results in the FCC austenite cooling to the quench temperature. The quenched material is then held at that temperature for a time necessary to produce the desired acicular structure. In steels, that

structure is bainite, a structure of acicular ferrite and carbide. In cast irons, with their higher silicon content, an intermediate structure called Ausferrite results. Ausferrite consists of acicular ferrite and carbon stabilized Austenite. This isothermal transformation results in uniform transformation of the structure throughout the part. Thus cracking during quench transformation is virtually eliminated.

In Austempered cast iron, this Ausferrite has very good abrasive wear properties because of its tendency to “strain transform” on the abraded surface. Austempered Ductile Iron (ADI) can compete with much harder materials. However, even ADI can be bested by materials containing carbides. But, carbidic irons tend to be very brittle.

**What is Carbidic ADI (CADI)?**

CADI is a ductile cast iron containing carbides, (that are either thermally or mechanically induced), that is subsequently Austempered to produce an Ausferritic matrix with an engineered amount of carbides.

Methods of carbide introduction include:

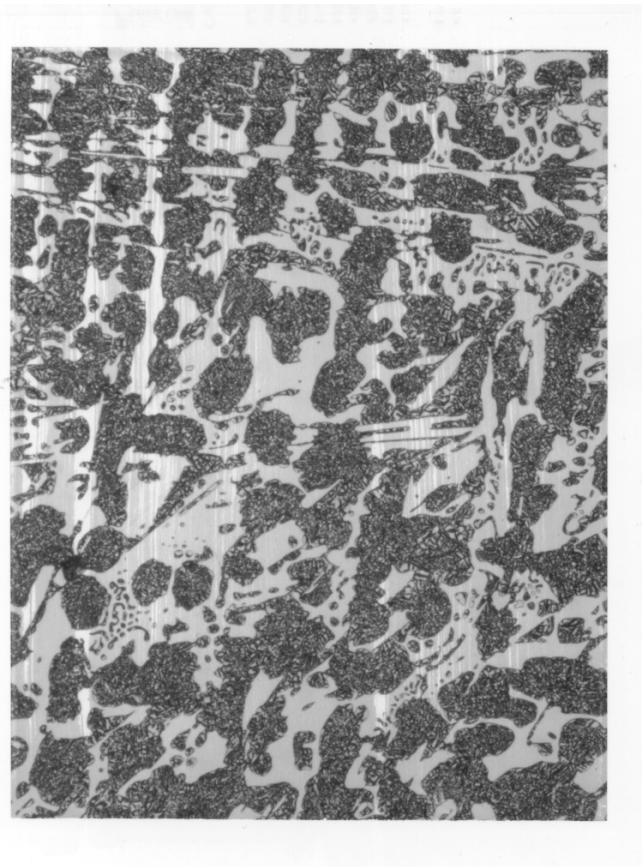
- As-Cast Carbides
  - Internal (chemical or inverse) chill
  - Surface chill (limited depth, directional)
- Mechanically Introduced Carbides
  - Cast-in, crushed  $M_xC_y$  carbides
  - Cast-in, engineered carbides (shapes)
- Welded
  - Hardface weldment
  - Weldment with  $M_xC_y$  grains

**As-Cast Carbides**

**Internal (chemical or inverse) chill**

Iron created as ductile iron and treated with magnesium and/or rare earths to result in spheroidal graphite can be induced to produce a carbidic microstructure by a variety of methods. These include alloying with carbide stabilizers such as chromium, molybdenum, titanium and others, controlling the cooling during shakeout or adjusting the carbon equivalent to produce a hypoeutectic iron chemistry. The carbides produced from this technique can be “dissolved” to a controlled extent by subsequent Austemper heat treatment.

**Figure 2** shows a CADI sample with as-cast carbides that was subsequently Austempered at 500F with 65% carbides remaining.



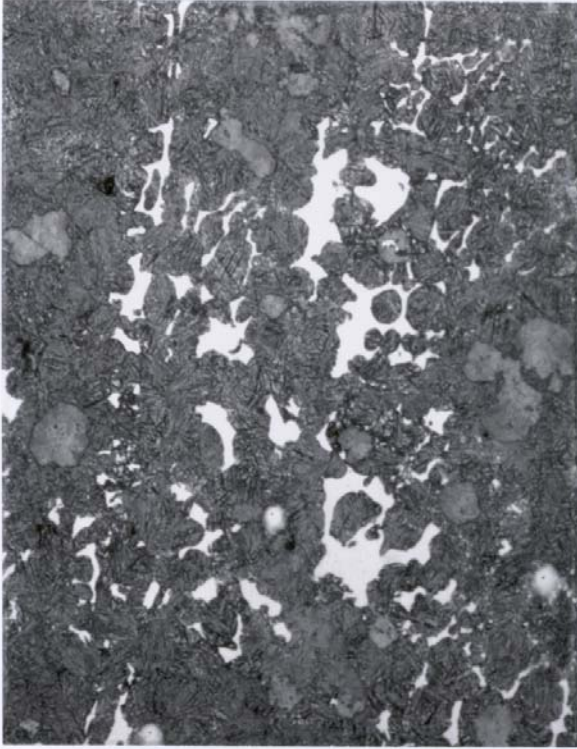
**Figure 2: CADI with 65% carbide and a 500F ADI matrix. (These carbides were produced as-cast).**

This sample has a continuous carbidic matrix that would limit its toughness. **Figure 3** shows a similarly produced iron Austempered at 500F. However, in this sample the carbides were further “dissolved” during austenitization, resulting in 45% carbides and a continuous Ausferrite matrix. This microstructure would be slightly less wear resistant than the iron in **Figure 2** but with greater toughness. **Figure 4** shows a similar iron with carbides further dissolved to 30%. **Figure 5** shows the wear resistance of a typical CADI vs as-cast gray and ductile iron and various grades of ADI. **Table 1** shows a table of typical unnotched Charpy impact values including CADI.

**Directional Surface Chill Carbides**

These carbides are produced by placing media with high thermal conductivity and thermal capacity adjacent to the surface of the solidifying iron. As the molten iron contacts this surface the solidification rate is sufficiently high to create carbides perpendicular to that surface and extending into the body of the part. These components may/or may not be free of carbides in the thermal center of the part. Depth of chill can, and is, controlled by controlling the chill scheme and the chemical analysis of

the iron. These carbides can be “dissolved” to a controlled extent by subsequent Austemper heat treatment.



**Figure 3: CADI with 45% carbide and a 500F Ausferrite matrix (These carbides were produced as-cast).**

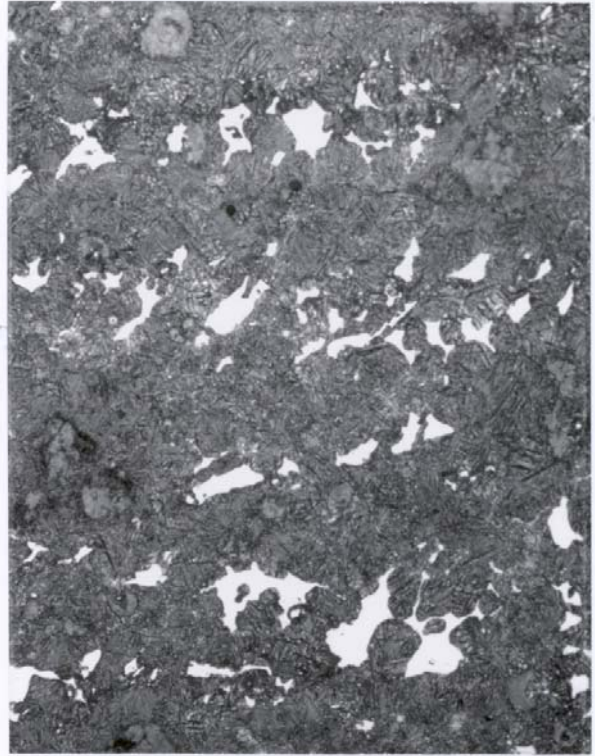
### Mechanically Introduced Carbides

#### **Cast-in, crushed $M_xC_y$ carbides**

This process, to the authors’ knowledge is only practiced by license to Sadvik Corporation. In this process, crushed  $M_xC_y$  carbides are strategically placed in the mold cavity at the desired location. The metal then fills in around the carbides resulting in a continuous iron matrix with discrete carbides mechanically trapped in it. The specific method used to contain the carbides “in place” during mold filling is not known to the authors. This method allows the engineer the option of placing carbides only where needed resulting in a traditional ductile iron matrix throughout the rest of the casting. These particular carbides are essentially unaffected by subsequent Austemper heat treatment.

#### **Cast-in, engineered carbides (shapes)**

This process requires the setting of engineered carbides into the mold with special core prints or other techniques. These engineered carbides may have back drafts or keyed features that allow them to be mechanically locked into the metal once it solidifies. These carbides are then unaffected by subsequent Austemper heat treatment.



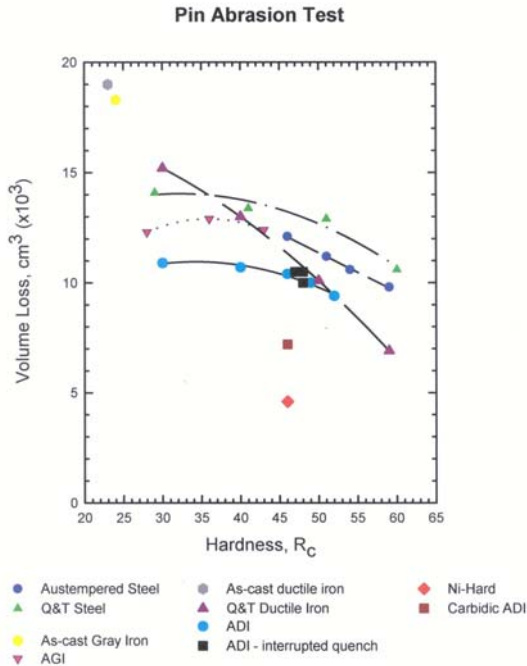
**Figure 4: CADI with 30% carbide and a 500F Ausferrite matrix. (These carbides were produced as-cast).**

### Carbide Weldments

#### **Hardface Weldment**

This process starts with a conventional ductile iron casting, typically with a fully, or mostly ferritic matrix. The casting is then hard-face welded in the area of greatest wear. This results in a carbide weld and a heat affected area at the weld/casting interface as shown in **Figure 6**. Subsequent Austemper heat treatment has little or no effect on the weld structure (depending on the chemical analysis of the weld material chosen) but the heat affected zone is eliminated and a fully Ausferritic matrix results in all areas other than the weld itself as shown in **Figure 7**. In some weld applications powdered

metal carbides can be purged into the molten weld to provide additional wear resistance.



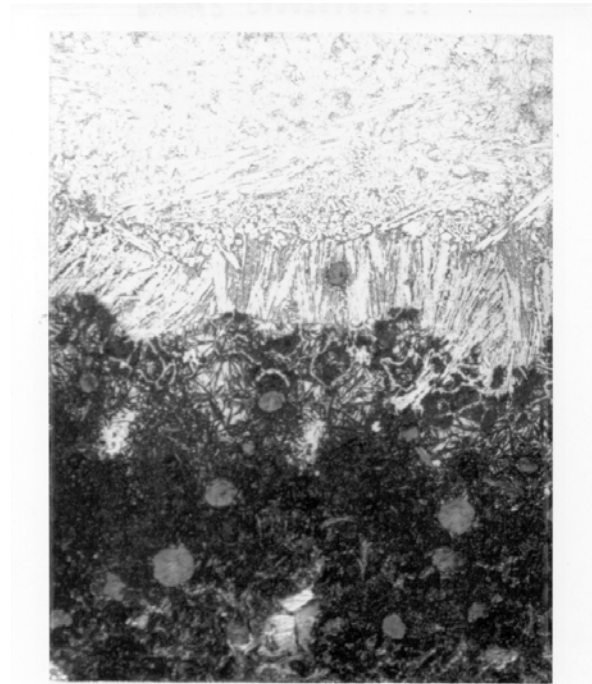
**Figure 5: Abrasive wear resistance of CADI vs. steels, as-cast, and heat treated gray and ductile irons and Ni-hard.**

**Table 1**

30-45% Carbide 500 CADI	10
Carburized 8620 Steel	13
Pearlitic Malleable Iron	13
7003 Ductile Iron	38
Grade 5 AD I	40
5506 Ductile Iron	45
Grade 3 AD I	70
Grade 1 AD I	90
4512 Ductile Iron	95

**Table 1: Typical un-notched Charpy impact values (ft-lbs). Tested at 72F (22C).**

**Figure 7: (Right) Microstructure of hard-face welded ductile iron that has been subsequently Austempered at 700F showing the Carbide weld (light) and the Ausferrite matrix (dark). ( Right →**



**Figure 6: Microstructure of hard-face welded ductile iron showing the Carbide weld (light) and the pearlitic heat affected zone (dark).**



### POTENTIAL APPLICATIONS FOR CADI

The current applications for CADI are limited, but growing. Agricultural components have been produced

in CADI with as-cast carbides since the early 1990s. A Sandvik licensee has produced limited production quantities of CADI parts with cast-in, crushed carbides 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.

In the February 2000 issue of SAE Off Highway Magazine John Deere announced the use of CADI elements in its revolutionary new rotary combine (**Figure 8**).



**Figure 8: John Deere's new, high performance, rotary combine uses CADI in its critical threshing elements. (Courtesy of SAE Off Highway Magazine)**

Then, in John Deere's Owners Circle Magazine (March 2000) they publicly announced the use of CADI in their Lazer Rip ripper points. These two events accelerated ongoing efforts in the industry in both research and production.

CADI presents some intriguing product possibilities. Potential applications in vehicles include camshafts and cam followers. Agricultural applications may include rippers, teeth, plow points, wear plates and harvester, picker and baler components. Possible railroad applications include contact suspension components and railcar/hopper car wear plates. In construction and mining potential applications include digger teeth and scarifiers, cutters, mill hammers, flails, guards, covers, chutes, plates, housings, transport tubes and elbows, rollers and crusher rollers. General industrial applications could include pump components, wear housings and plates, conveyor wear parts, skids and skid rails, rollers and blast parts.

#### **WHAT ARE THE RISKS / DISADVANTAGES OF CADI?**

- CADI exhibits only limited machinability (possibly grinding only)
- If alloying is used the returns must be segregated
- Additional operations and costs may be incurred if carbides are welded on or cast-in

#### **WHAT ARE THE ADVANTAGES OF CADI?**

- CADI is more wear resistant than Grade 5 ADI with acceptable toughness.
- CADI is less expensive and tougher than 18% chrome white iron.
- No capital investment is required for the metal caster to add this new product line.

#### **WHAT MARKET OPPORTUNITIES DOES CADI PRESENT TO THE DUCTILE IRON PRODUCER?**

- Replaces Mn steel at equal or lower cost
- Replaces 18% Cr white iron at lower cost
- Sells as a premium, engineered iron with longer life
- Creates new markets for ductile iron

#### **SUMMARY**

CADI is a relatively new engineering material. This paper attempted to summarize the state of knowledge at the time of this writing. Ongoing research and market developments will be reviewed in subsequent reports.

#### **ACKNOWLEDGMENTS**

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- Terry Lusk
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#### **ADDITIONAL RESOURCES**

- +SAE Off Highway Magazine February 2000
- +John Deere Owners Circle Magazine March 2000
- + Applied Process Inc. internal research
- +[www.appliedprocess.com](http://www.appliedprocess.com)
- +[www.ductile.org](http://www.ductile.org) / associated links / DIMG / Ductile Iron Data for Design Engineers, Chapter 4, ADI