Carbidic Austempered Ductile Iron (CADI) – The New Wear Material

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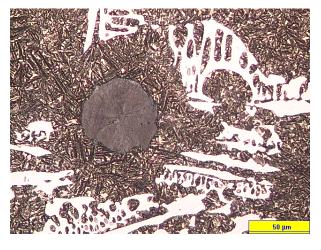Applied Process Technologies Division, Livonia, MI

ABSTRACT

Carbidic Austempered Ductile Iron (CADI) describes a family of ductile cast irons, with given amounts of carbides that are subsequently austempered to exhibit adequate toughness and excellent wear resistance. The abrasion resistance of this new material is improved over that of ADI and increases with increasing carbide content. In a number of wear applications, it can compete favorably with high chromium abrasion resistant (AR) irons in addition to providing improved toughness.
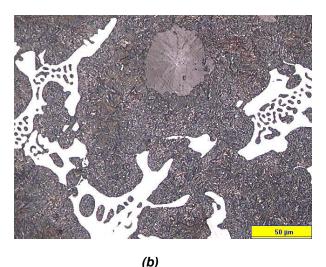
INTRODUCTION

PRODUCTION OF CARBIDIC ADI
Carbidic ADI is produced by austempering ductile cast iron that contains carbides. The resulting microstructure will consist of a given volume of carbides within an ausferrite matrix. The volume fraction of carbide present as well as the microstructural scale of the ausferrite can be controlled to provide a range of properties for this material.

The most common method that is used to introduce carbides is by internal (chemical or inverse) chill. In this method, ductile iron is induced to produce a carbidic microstructure by alloying with carbide stabilizers (i.e. chromium, molybdenum, titanium), by controlled cooling during shakeout or by adjusting the carbon equivalent to produce a hypoeutectoid iron chemistry. Carbides that are produced in this manner are then "dissolved" to a controlled extent by the subsequent austemper heat treatment. **Figures 1 a and b** contain the microstructures of CADI with as-cast carbides that were austempered at both 700°F (371°C) and 500°F (260°C). Note the change in microstructural scale of the ausferrite that is accomplished by controlling the heat treatment parameters.

(a)   (b)

Fig. 1. CADI with as-cast carbides austempered at 700°F(371°C) and 500°F(260°C), respectively. Specimens were etched with 8% Nital.

Extra attention must be paid in the foundry when producing CADI with as-cast carbides. The favorable expansion from the formation of graphite during the solidification process is less for a carbidic ductile iron than for conventional ductile iron. As a result, it feeds more like malleable iron than ductile iron. Shrinkage problems can be encountered if this is not taken into consideration. The presence of shrinkage will have deleterious effects on the final mechanical properties of CADI, particularly the impact performance.

Other methods for carbide introduction include using directional surface chilling, mechanically introducing carbides (either cast-in crushed carbides or engineered shapes) and the use of welding techniques such as hardfacing.

EXPERIMENTAL METHODS

Ductile cast iron alloyed with molybdenum and chromium was produced for this program. This method of as-cast carbide production was chosen because Mo-Cr carbides are very stable and tend to retain their as-cast volume fractions after austenitizing, thus minimizing the number of iterations for heat treat cycle development. The chemical compositions of the materials used in this study are listed in **Table 1**.

Table 1. Chemical compositions of Carbidic Ductile Iron used in this study.

Heat #	C	S	P	Si	Mn	Cr	Ni	Mo	Cu
Low Carbide	3.68	0.014	0.012	2.24	0.23	0.50	0.03	0.42	0.13
High Carbide	3.85	0.016	<0.005	2.09	0.23	1.04	0.03	0.47	0.13

The same austenitizing temperature (1650°F or 899°C) was utilized for all heat treat cycles. Austempering temperatures of 700°F (371°C), 600°F (316°C) and 500°F (260°C) were chosen in order to produce a variety of microstructural scales.

Volume fraction of carbide measurements were made by using image analysis techniques. Specimens were polished and etched with a 10% ammonium persulfate solution in order to reveal the carbides. All volume fraction carbide measurements were made on the actual wear specimens.

Abrasion testing was completed in both high and low stress environments. High stress abrasion testing was done by using the pin abrasion method per ASTM G132-96 while low stress abrasion was conducted using the wet sand/rubber wheel test per ASTM G105-89. All mass loss data from the abrasion tests was converted to a volume loss by dividing by the material density so comparisons of the results could be made to other materials. Density measurements were made per ASTM B311-93.

EXPERIMENTAL RESULTS AND DISCUSSION

VOLUME FRACTION OF CARBIDE
The image analysis results for carbide volume fraction determination showed some scatter based on location in the casting. All specimens were machined from 10" x 10" x 3/4" plates with the locations randomized. As a result, the best "average" carbide volume fraction was calculated for each heat taking into account a number of specimens. These averages were nominally 5% for the low carbide heat and 17% for the high carbide heat. Because of the inherent scatter from the sample location, the heats will be designated as low and high carbide %, respectively. The averages are probably best referred to as target values.

PIN ABRASION RESULTS
The pin abrasion test results for the high and low carbide heats along with those for ADI are presented in **Figure 2**. The slope of the curve for each material indicates their relative insensitivity to hardness. Previous work has shown that the austenite present in ausferrite will transform to martensite when a high normal force is applied. Since a pin abrasion test is done in a high stress environment, any austenite present on the surface where a force is applied would be expected to transform to martensite. The CADI exhibits improved high stress abrasion resistance compared to ADI. This would be expected due to the presence of carbide in the ausferrite. One might also expect the abrasion resistance of CADI to increase with increasing volume of carbide present. This is also shown in **Figure 2**.

In **Figure 3**, the pin abrasion resistance results for CADI are compared to those for a number of abrasion resistant (AR) irons. Note that high chromium abrasion resistant irons tend to exhibit smaller volume losses at hardness levels above Rockwell C 50. It would appear that CADI can compete competitively with a number of, but not all, AR irons in a high stress environment.

Figure 4 contains a summary of pin abrasion results for cast irons and competitive steels. The cast iron alternatives (ADI, CADI, Ni-Hard, AR irons and Q&T ductile iron) offer better performance in high stress applications than the competitive austempered and Q&T steel.
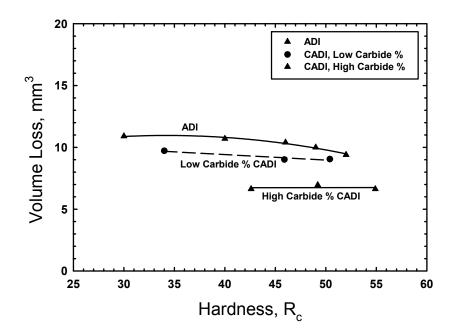
Figure 2: Pin Abrasion test results for ADI and CADI with both high and low carbide levels.
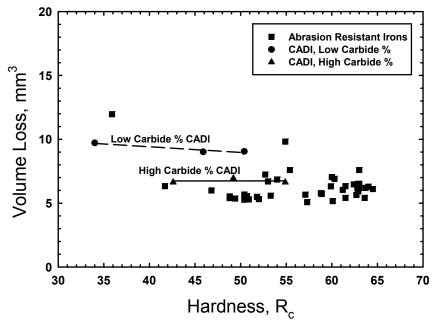

Figure 3: Pin Abrasion test results for both high and low carbide CADI along with results for high chromium Abrasion Resistant irons. Results for AR irons were obtained from the Abrasion-Resistant Cast Iron Handbook.
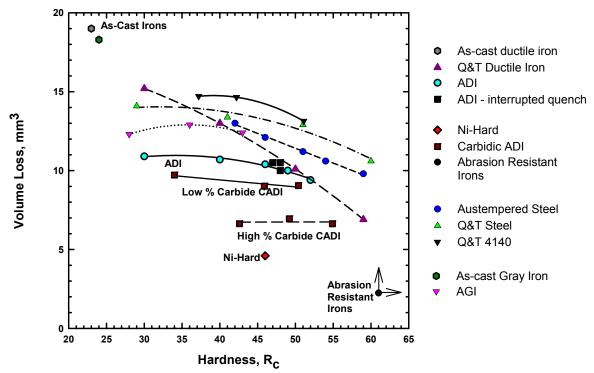
Figure 4: Pin Abrasion test results for various Cast Irons and competitive Steel. The data point for Abrasion Resistant irons represents 1 test for a 27% Cr AR iron. Arrows have been added to reflect the results within Figure 3.

WET SAND/RUBBER WHEEL (WSRW) ABRASION TEST RESULTS

The results for WSRW abrasion testing of ADI and CADI are shown in **Figure 5**. The ADI curve is somewhat linear, while the CADI curves are not. The reason for the deviation in linear behavior for the CADI specimens is most likely due to the scatter in the amount of carbide present. The amount of carbide present for each specimen is reported next to the data point. The level of abrasion resistance of the CADI in WSRW appears to increase with increasing carbide content, like that for pin abrasion testing.

The volume loss for ADI in WSRW testing would be expected to be more than that experienced in a pin abrasion test. This occurs because a WSRW test is a low stress abrasion test. The forces applied are not sufficiently high enough to cause the favorable stress induced transformation of austenite to martensite on the wear surface. As a result, the self-generating wear surface that is produced in ADI during a pin abrasion test does not form during the WSRW or low stress abrasion testing.

Figure 6 contains the WSRW testing results for the CADI along with results reported for high chromium Abrasion Resistant irons. Once again, the CADI appears to compete favorably with some of the AR irons. There are a number of AR iron points that are above the CADI curves. These points represent pearlitic white or chilled AR cast irons, which are inferior to the martensitic grades of AR irons in both abrasion resistance and toughness. These grades are typically used in applications that involve modest abrasion and/or low impact.

WHY CADI VERSUS AR IRONS

The results in **Figures 3** and **6** indicate that CADI can compete favorably with AR irons in some, but not all wear applications. While AR irons are known for their superior wear properties, they are typically not known for their toughness. This is where CADI has an advantage over AR irons. Impact testing of CADI is ongoing. However, preliminary results have shown unnotched Charpy impact values ranging from 8 – 20 ft-lbs (11-27 J). Similar unnotched Charpy testing of AR irons (including Ni-Hard Grade 2 and 27% Cr AR Iron) have yielded results of 2 ft-lbs (3 J). CADI is, thus, an ideal material in an application where wear resistance is needed in combination with toughness.
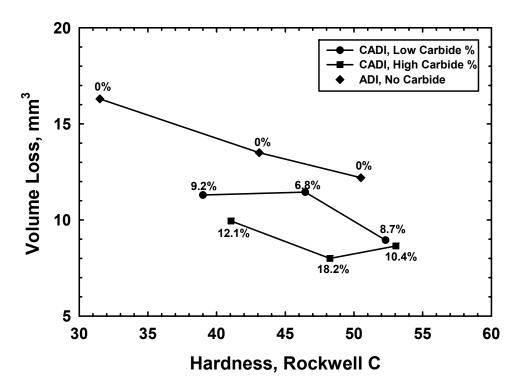
Figure 5 Wet Sand Rubber Wheel (WSRW) Abrasion Test Results for Carbidic ADI and ADI. Carbide levels are indicated next to each point. Points represent an average from 2 test specimens.
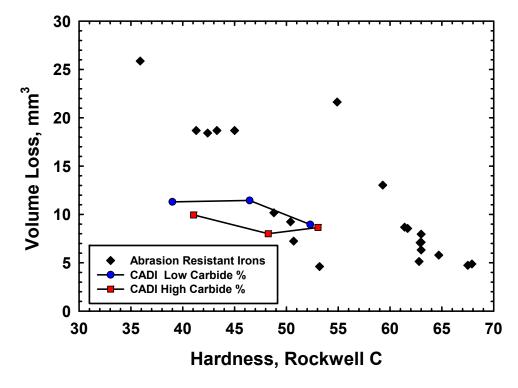

Figure 6: Wet Sand Rubber Wheel (WSRW) Abrasion Test Results for Carbidic ADI and High Chromium Abrasion Resistant Irons. Results for AR irons were obtained from the Abrasion-Resistant Cast Iron Handbook.

The costs to make CADI and AR irons should also be considered. AR irons are heavily alloyed. Nickel and chromium tend to be rather expensive alloy additions. Even though a heat treat process is involved in the production of CADI, the overall costs are often less than those for the heavily alloyed AR iron alternatives.

APPLICATIONS OF CADI

The level of interest in CADI as well as the number of applications continues to grow. In July of 2001, US Patent # 6,258,180 B1 on Wear Resistant Ductile Iron was issued to Wilde, Korpi and Schultz . This patent describes one method of producing CADI.

To date, most CADI applications have been in the agricultural industry where components with as-cast carbides have been produced since the early 1990's. The first application of CADI known to the authors was a small agricultural tip for Carroll Ag that went into production in 1992. In February 2000, John Deere announced the use of CADI elements in its revolutionary new rotary combine. One month later, they publicly announced the use of CADI in their Lazer Rip ripper points. These two events have accelerated ongoing efforts in industry for both production of and research on CADI.

While most interest in CADI has come from the agricultural sector, it does have potential in other areas. Research into chill-carbide CADI camshafts is ongoing. Possible railroad applications include contact suspension components and railcar/hopper 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.

SUMMARY

Carbidic ADI can be made with an optimal amount of carbide in an ausferrite matrix of desirable microstructural scale. Wear results for CADI are improved over those for ADI and in some cases rival those of AR irons. Preliminary results indicate that the toughness of this new material is superior to AR irons, which makes it ideally suited for applications that require wear resistance along with toughness. As more property information becomes available, the applications for CADI are likely to steadily increase.

ACKNOWLEDGMENTS

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