Research and Application of Carbidic Austempered Ductile Iron

The microstructure of austempered ductile iron (ADI) is composed of needle ferrite and carbon-enriched austenite, called ausferrite. ADI has excellent comprehensive mechanical properties, obtained by changing the chemical composition, austenitizing temperature and holding time, and austempering temperature and holding time. A lot of attention has been paid to the production and application of ADI in various industries, but it is insufficient as a wear-resistant material.

Fig. 1. The as-cast microstructure of CADI features nodular graphite (left) and willemite and carbide (right).

By introducing carbides into the ADI microstructure, its wear resistance can be improved while maintaining sufficient impact toughness.

Fig. 2. CADI has ausferrite, carbide and nodular graphite.

This material is called carbidic austempered ductile iron, or CADI. It has improved abrasion resistance, strength and toughness, increasing CADI’s use in wear-resistant castings in recent years.

Figure 1 shows the as-cast microstructure of CADI. The number of spheroidal graphite is about 300/mm², and the matrix consists of willemite and carbide. After austempering, the microstructure of CADI contains ausferrite, carbides and nodular graphites, as shown in Figure 2.
Fig. 3. This graph depicts the influence of austempering temperature on austenite.

After austempering, the microstructure of CADI contains austenite with high carbon. The proportion of austenite in ausferrite can influence mechanical properties, corrosion resistance and wear resistance. The test results show temperature and holding time greatly affect the amount of carbon-enriched austenite in CADI.

Figure 3 shows the influence of austempering temperature on the amount of carbon-rich austenite. As temperature increases, the austenite content increases gradually.

Fig. 4. This graph depicts the influence of austempering temperature on CADI impact toughness.

Figure 4 shows the influence of temperature on the impact toughness of CADI. When the temperature is below 446°F (230°C), the impact toughness remains steady. After that, the impact toughness increases with austempering temperature up to 554°F (290°C), after which it again flattens out.

Figure 5 shows the influence of austempering temperature on CADI hardness, which decreases as the temperature rises.
Fig. 5. This graph depicts the influence of austempering temperature on CADI hardness.

Figure 6 shows the influence of austenite content on the corrosive speed of CADI in faintly acidic, neutral and alkalescent liquids. The corrosive speed increases with a greater amount of austenite in all kind of media. When the content of austenite was about 22%, the corrosive speed reached its peak. After that, the corrosion speed decreased in faintly acidic and alkalescent liquid, while changing very little in neutral liquid.

Because austenite has a corrosive-resistant microstructure, the corrosive resistance of CADI should increase with the amount austenite. So why does the corrosive resistance decrease with an increase of austenite in range of 16-22%? It is possible the resistance to corrosion is related to a difference between needle ferrite carbon and austenite, but additional research is needed.

Overall, the corrosive speed of CADI is the highest in faintly acidic media, the lowest in weakly basic media and in the middle in neutral media. CADI has lower corrosive resistance in faintly acidic liquid and better corrosive resistance in weakly basic liquid.

Fig. 6. This graph depicts the influence of austenite on the corrosive speed of CADI.

The influence of austenite on the corrosion current density is shown in Figure 7. The corrosion current density of CADI increases with austenite. When the content of austenite reached 22%, the corrosive current density reached its apex. But as the
austenite content of ausferrite increased, the corrosion current density decreased in faintly acidic and basic liquid, and remained steady in neutral liquid. According to a principle of electrochemistry, the corrosive resistance of a material decreases as its corrosive current density increases. CADI that contains 22% austenite was less resistant to corrosion.

With the use of an MLD-10 abrasive wear testing machine, CADI’s corrosive and abrasive resistances were researched with a dynamic load impact power of 1 joule, rotating speed of 200 RPM and impact frequency of 100 cycles per minute in three liquids with different PH values. A low chromium cast iron specimen was the control for the CADI samples.

As shown in Figures 8 and 9, as the content of austenite increased, the CADI specimens lost more weight due to corrosion and their relative abrasive resistance declined. In the weakly acidic and alkaline media, when the austenite content was in the range of 20-22%, the corrosive wearing weight loss was the highest and the relative abrasive resistance the lowest. When the austenite was more than 22%, the weight loss decreased and the relative resistance increased. In a neutral medium, corrosive resistance changed little when the austenite content was more than 22%.

The carbon-enriched austenite contributes to the abrasive resistance of CADI in two aspects. Austenite can transform into martensite under stress, so the surface hardness and abrasive resistance of CADI increases remarkably. Secondly, during the process of transformation from austenite to martensite, the increase of volume is accompanied in the wearing surface layer of specimen, which results in compressive stress on surface that can improve wear resistance.
During powder grinding in metallurgical, mining, cement and thermal power industries, production costs for abrasion materials and energy consumption are a large share of total expenditures. Considering the growth in China’s steel and iron industries, the requirement for iron ore is very large, about 40-50% of worldwide demand. From 2009 to 2011, China increased its production of crude steel from 568 to 680 million metric tons. The domestic iron ore production grew from 880 million metric tons in 2009 to 1.1 billion in 2011. Additionally, in 2012, cement production was about 2.2 billion metric tons, accounting for 60% of global consumption. In 2009, the consumption of abrasion-resistant castings was more than 3.5 million metric tons, with grinding balls used for 1.6 million metric tons. Mineral processing in iron and nonferrous ore accounted for 70% of all grinding ball expenditures.

Currently, grinding balls are made of low chromium cast iron, high chromium cast iron and forged low alloy steel. The characteristics of low chromium cast iron balls are low hardness, poor abrasive resistance, low impact toughness and low breaking points. High
chromium cast iron balls have high hardness, good wear resistance in dry conditions, 
low wear resistance in a corrosive environment, low cost performance and low impact 
toughness. The characteristics of forged low alloy steel balls are low hardenability, low 
volume hardness, low corrosive resistance and poor abrasive resistance. A broken and 
spalling ball can reduce a grinding mill’s efficiency and productivity, while increasing 
energy consumption. In addition, many grinding balls used in China contain different 
amounts of chromium. Because chromium is in short supply in China, 90% of 
ferrochrome is imported. Therefore, the development of a ball with very low or no 
chromium and high abrasive resistance is imperative.

Fig. 10. CADI balls offer benefits in grinding mills.

The application of CADI for a grinding ball is an interesting prospect. Through four 
years of practical application and exploration, a few characteristics of note have been 
discovered in CADI grinding balls:

1. The CADI ball has a low break rate, no deformation and no spalling.

2. The CADI ball has a very high hardenability. The surface hardness of a used CADI 
ball can increase to HRC 64-68 from the original hardness of HRC 56-58.

3. After using CADI balls, grinding ore productivity increased 10-20% and energy 
consumption decreased 10-15%. A company in Hebei Province using five damp mills 
saved 2 million Yuan ($328,300) in a year.

4. Because CADI contains spheroidal graphite and carbon-enriched austenite, it has a 
damping effect that can reduce noise around the ball mill by 10-12 decibels.

5. Because the CADI balls didn’t produce broken fragments, the closed loop system 
experienced decreased wear and an extended working life.

Conclusions
1. Austenite has important effects on mechanical properties, corrosion resistance and abrasion resistance of CADI.

2. As a new kind of abrasive material, CADI can be used for grinding balls in metallurgical, cement and thermal power industries.

3. After application in wet concentrations of iron ore, CADI balls do not spall and increase abrasive resistance by two to three times compared to low chromium cast iron ball, save energy, increase efficiency, decrease environmental noise and improve the working life of slurry pumps and high frequency screens.