ADI -THE MATERIAL REVOLUTION AND ITS APPLICATIONS AT CMRDI

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In the last three decades, the revolutionary material; the austempered ductile iron (ADI) with its unique combination of mechanical properties, has been offering the design engineer alternatives to conventional material/process combinations. The excellent properties of this material have opened new horizons for cast iron to replace steel castings and forgings in many engineering applications with considerable cost benefits. Moreover, the sustained efforts worldwide of the automotive industry to use lightweight materials have eroded the market for the heavier iron castings. Currently, ADI with its super strength can successfully compete with the lightweight alloys, a point which has yet to be fully understood by many design engineers.

This review is an attempt to compile the results of the worldwide explosion of research and development that followed the announcement of the first production of this material, meanwhile, reference is made to the work carried out at Central Metallurgical R&D Institute (CMRDI) over the past decade. It is not intended to provide an in-depth investigation of any specific technique, but to present a macro-analysis of the current state of metallurgy, processing and applications of ADI.

Better understanding of the strengthening mechanisms of ADI has led to the development of new techniques that contribute to enhance strength and toughness of the alloy, some examples will be discussed in details such as:-

- Ausformed ADI; where mechanical processing component was added to the conventional heat treatment as a driving force to accelerate the rate of stage I austempering.
- Squeeze cast ADI; where superior quality ADI castings were produced through squeeze casting of molten iron in a permanent mold, followed by in-situ heat treatment of the hot knocked-out castings in the austenite range followed by normal austempering in a salt bath.
- Two step austempering to achieve finer ausferrite at higher undercooling during austempering treatment followed by austempering at higher temperature where higher austenitic carbon is promoted due to the enhanced diffusion rate of carbon into austenite.
- A recently published patent shows that the combination of a very high yield strength, fatigue strength and fracture toughness, that cannot be achieved in structural materials could be obtained in nano-structured ADI. The exceptional combination of mechanical and physical obtained is comparable to Maraging Steel without excessive alloying and costly processing.

The excellent abrasion resistance of ADI could still be remarkably increased through the development of:

- Carbidic ADI-ductile iron containing carbides subsequently austempered to form ausferritic matrix with an engineered amounts of carbides. Methods used to introduce carbides in the microstructure of A include alloying with carbide stabilizers, higher cooling rate during solidification, using ductile iron with lower CE as well as surface chilling. Carbides may also be mechanically introduced, where crushed $M_x C_y$ carbides are strategically placed in the mold cavity at desired locations.
- Bainitic/martensitic (B/M) ADI containing less expensive alloying elements such as Si and Mn in the range of 2.5 - 3.0%.
- Selective surface treatment, where parts of the casting subjected to excessive wear may be locally hardened, either by induction heating and then austempered or by surface laser processing.

The review analyses the key features of important processing techniques of ADI such as:

- Cold rolling, where as thin as 3 mm sheets have been successfully produced at CMRDI with enhanced strength and hardness properties.
- Welding, whether used as repair welding for the parent ductile iron castings before austempering or to weld already austempered parts to each other or to other materials such as steel and ductile iron.
- Some of the machining difficulties, that appeared with the first use of ADI as engineering material still persist today, which are mainly related to the work hardening and deformation induced martensitic formation from retained austenite. Recent work at CMRDI clearly indicates that cutting force during machining of ADI is closely related to martensitic transformation, which in turn, is a function of cutting depth and speed of cutting.
- A novel development of ADI is the intercritically austempered ductile iron; an exciting engineering material with a favorable combination of good strength and ductility, excellent fatigue strength and good machinability resulting from a microstructure containing colonies of proeutectoid ferrite together with isolated islands of austenite. In contrast to the conventionally austempered ADI, where the austempering temperature and time play the dominant role in determining the material properties, the austenitizing time and temperature strongly affect the mechanical properties since this determines the α & γ ratio and how much carbon and alloying elements are put into solid solution in γ before quenching to the austempering temperature.
- The performance of different ADI types under very high strain rate dynamic deformation were jointly assessed by CMRDI and Fraunhofer Institute in Germany using a servo hydraulic testing machine at crash-like strain rate of 50 sec-1. Higher deformations are recommended for suspensions parts, such as automotive steering knuckles, in particular for legal reasons in context of accidents. Different ADI grades proved to be candidate materials for steering knuckles production.

Different applications of ADI cover automotive e.g. gears, crankshafts, connecting rods, camshafts transmission as well as suspension components and steering knuckles as well as earthmoving, defense and agricultural consumables such as plough blades. Case studies will be shown with emphasis on the experience of CMRDI in production of gears of different types and agricultural parts in its experimental foundry. ADI and steel properties related to gear performance will be compared such as structural integrity, abrasion resistance, bending fatigue, teeth conformation, noise and vibration reduction, manufacturing cost, weight reduction and gear power loss, the comparison seems to be in favor of ADI. The CMRDI experience with the use of ADI in agricultural applications will be discussed. Production of thin wall ADI components may offer potentials for new applications. Thin wall ADI castings are capable to build complex thin wall parts of high strength.