



Austempered Ductile Iron Material for the Design of Agricultural Machinery

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ABSTRACT

Agricultural Machinery is mostly used in off road i.e. in the field. In the field these machines perform different field operations like Ploughing, where the parts are subjected to stresses like tensile stress, compressive stress and shear stress thereby high wear due to heavy loads. The critical components in the agriculture machinery are either forged or fabricated out of medium carbon steel by unorganized sectors in India. As a result the users suffer on account of quality and short service life of these components. Recently Austempered Ductile Iron (ADI) has come up which has high strength, high wear resistance and less manufacturing cost. This material is now being widely used in production of critical agricultural machinery components for cost effectiveness uses. The paper described the Mechanical, Tribological properties of Austempered ductile iron and its application areas in agricultural machinery in India and abroad.

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Introduction

The critical components of majority of the agricultural equipments are either forged or fabricated using different cutting or joining techniques. The forging process itself is expensive in view of high set-up cost and therefore its use is limited to medium scale manufacturers. On the other hand fabrication through various processes like forging results in expensive products due to loss of material and high machining cost which directly suffers the farmers. It has been revealed that casting is economical over forging and fabrication for a poor quantity usually marketed by small-scale manufacturer or vender. A schematic cost comparison between fabricated and cast components is shown in fig.1 (Dorazil, 1986).

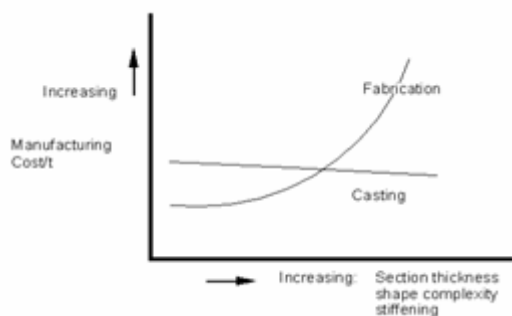


Fig. 1 Schematic cost comparison between fabricated and cast components

History and birth of austempered ductile iron (ADI)

In metallurgy, the form and distribution of carbon in the structure of cast iron is most significant which affects the mechanical properties. The presence of flake like shape of graphite in grey cast iron leads to the brittleness of cast iron i.e. no elastic behavior and fails in tension without significant plastic deformation. The flakes virtually act like cracks in the iron matrix. The magnesium or cerium treatment assured controlled precipitation of carbon in the spheroidal shape of graphite as cast condition. This was the birth (in 1948) of ductile iron (SG Iron) in the world. After 1960, the production of

ductile iron grew annually at 3 to 5% growth rate and estimated to touch 20 million tones per year by 2000 (Design Engineer's Digest, 1983).

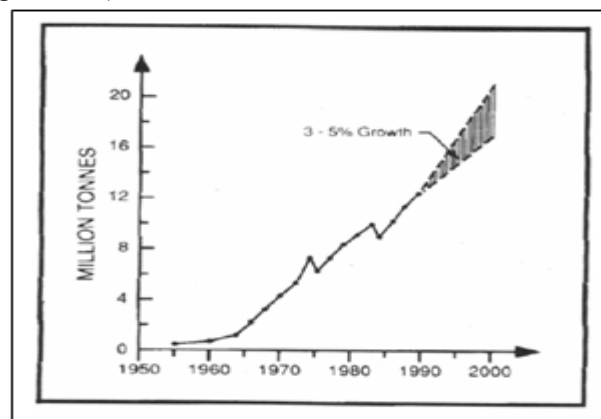


Fig. 2 Worldwide production of ductile iron
 Properties and uses of ADI

Austempered ductile iron is a metal fit for conversions. The material, which is a cast ductile iron, undergoes a specially designed Austempered Heat Treatment process, and offers design engineers an alter-native to steel where high strength and low wear are desired (Blackmore et al., 1986). Also ADI has 3 times the strength and 2.3 times the stiffness of Aluminum and may be a cost effective and weight competitive alternative (Spada, 2003).

Mechanical Properties

ADI is ideal for a number of high strength low wear industrial applications. The fatigue properties for ADI are comparable to heat treated steels. All grades of ADI exceed the notched impact resistance and low temperature properties of carburized and hardened ASI 8620 steel (Luyendijk et al., 1983). The wear resistance of ADI for a given hardness level is superior to many conventional materials. In some applications, ADI with 42-46Rc has replaced 60Rc carburized and hardened ASI 8620 steel. Following the heat treatment ADI will have

excellent rolling contact fatigue performance that allow it to function in applications where contact stresses exceeding 250ksi (Luyendijk et al., 1983). ADI's microstructure (Ausferrite) contains carbon stabilized austenite which is thermally stable but, when acted upon by a high, normal force, transforms locally to untempered martensite nested in a ferritic matrix. This dramatically increases the surface microhardness giving ADI an abrasive wear resistance that exceeds that implied by its bulk hardness (John et Al., 2009).

Sector Wise Use

ADI offers the best combination of low cost, design flexibility, good machinability, high strength to weight ratio, good toughness, wear and fatigue resistance. Its application in North America is presented in Fig. 3. It is evident that around 7 percent, out of the total ADI production in North America, is being used in agriculture sector (Saxena et al., 2004). In agriculture, it is widely used to produce plough tips, plough shares, shovels, digger teeth, trash cutters, spring bracket, ammonia knives, gears, sprockets, gears, tractor wheel hubs, disk parts, bell cranks, lifting arms and a great variety of parts of planter, plough, sprayers and harvesters (Saxena et al., 2004).

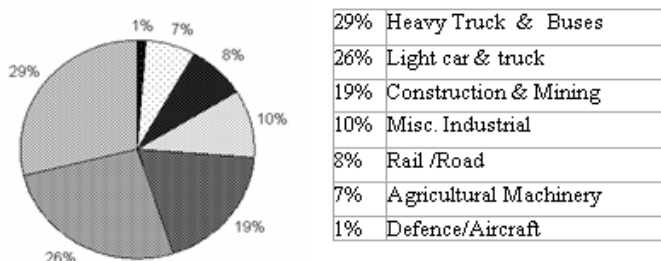


Fig. 3 Estimated distribution market in North America (1998)

With the increased capability in production of reliable high-grade Austempered materials, the demand for ADI made components has increased tremendously (Chang, 1998). The percentage use of ADI made components world over, during the year 2003, has been shown in the Fig. 4 (Hayrynen et al., 2002).

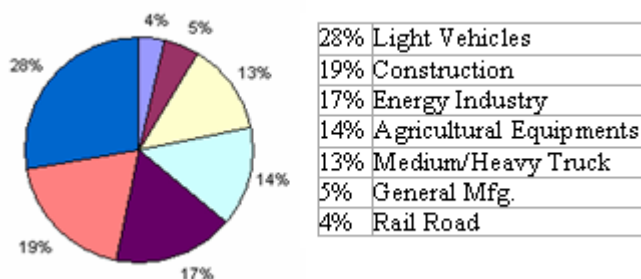


Fig.4 Estimated distribution of ADI market world-wide (2003)

It is evident that around 14% is being used in agriculture equipment. Many companies such as John Deere, Caterpillar and CNH Global are using ADI parts to enhance the performance of their equipments. Some typical examples are plough points, hitches, control arms, digger teeth, draft arms etc.

Comparison Of Properties

Table 1 represents the mechanical property comparison between steel, ductile iron and ADI (Hayrynen et al., 2002). ADI has the advantage over steel in tensile strength, yield strength & hardness.

Table 1: Mechanical property comparison of Steel, Ductile Iron & ADI

Properties	Steel	Ductile Iron	ADI
Yield Strength (Ksi)	107	78	120
Tensile Strength (Ksi)	132	131	157
Fatigue Strength (Ksi)	58	47	62
Impact Energy (ft-lb)	240	55	104
Elongation (%)	23.2	10.8	13.7
Hardness (BHN)	226-266	262-277	300

This material has become successful in substituting forging process in the following cases:-

1. Forged and carburized ASI 1022 steel timing gear.
2. Snow plough in US and Canada.
3. Chain sprocket in Japan.

The Ford and Chrysler are commercially using ADI for fabrication of car suspension components, crankshaft etc. In many industries, this material is being successfully used for gear production in view of high noise damping capacity (twice to forged steel). The material is also used to resist abrasive wear situation (Brandenberg et al., 2002). The remarkable properties of ADI are developed by a closely controlled heat treatment operation (Austempering), which develops a unique matrix of bainite, ferrite (60%) and retained (high carbon) austenite. The necessary heat treatment is essential to produce ADI in a two-stage operation as shown in Fig. 5 (John, 2000).

Different grades of ADI

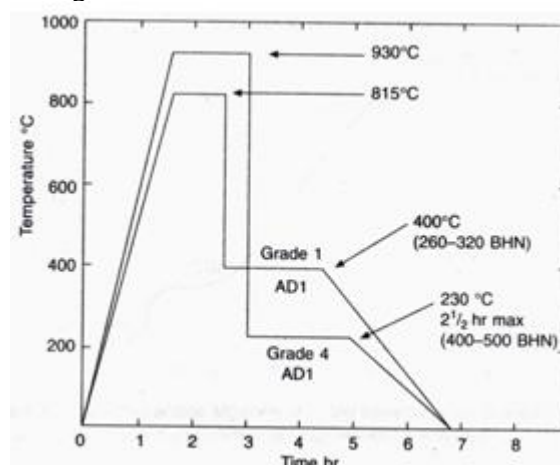


Fig. 5 Typical Heat treatment cycle to produce various ADI grades

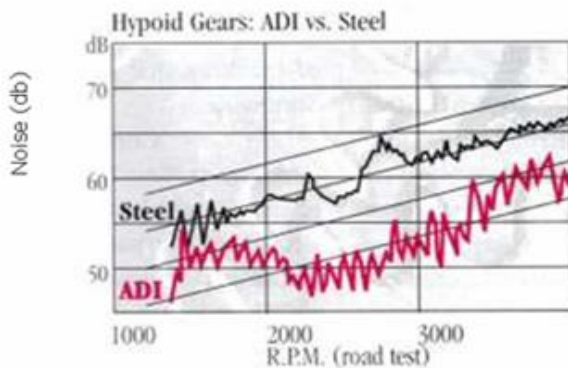
Presently there are five grades of ADI (ASTM 897-90M) being produced for structural and wear resistance application. Out of five grades, three grades are being used mostly for development of Agricultural Machine components. Table 2 represents typical properties of five grades of ADI.

In the ADI standards, the grades are defined only with different strengths, elongation, hardness etc. Microstructure plays a great role in controlling the properties of ADI and proper microstructure gives the optimum properties to the ADI components (Rundman et al., 1988).

The best machining properties is also achievable at the right microstructure of ADI (Voight, 1989). The ADI has high damping properties. The presence of graphite in the ADI matrix improves noise damping, for quieter, smoother running of components. A comparison of noise of hypoid gear made of steel and ADI at different speeds is shown in Fig 6 (Hohansson, 1997).

Table 2: Typical properties of five grades of ADI

Typical Properties	Different grades of ADI				
	Gr.-1	Gr.-2	Gr.-3	Gr.-4	Gr.-5
Static					
Tensile strength (MPa)	850	1050	1200	1400	1600
Offset yield strength (MPa)	550	700	850	1100	1300
Elongation (% in 50mm gauge)	11	10	7	5	3
Hardness Brinell	269-321	302-363	341-444	388-477	444-555
Impact energy (J)	100	80	60	35	N/A
Compressive strength (MPa)	1300	1600	1900	2200	2500
Shear strength (MPa)	870	1025	1180	1370	1490
Modulus of rigidity (GPa)	65.1	64.0	63.2	62.4	62.1
Physical					
Density (gm/cc)	7.09	7.08	7.07	7.06	7.05

**Fig. 6: Comparison of noise of hypoid gear at different speeds**

ADI's abrasion resistance exceeds that of conventionally processed steels and irons at a lower 'bulk' hardness level. Unlike carburized steel, which loses wear resistance when the carburized layer is removed, ADI improves in service.

Strength To Weight Ratio

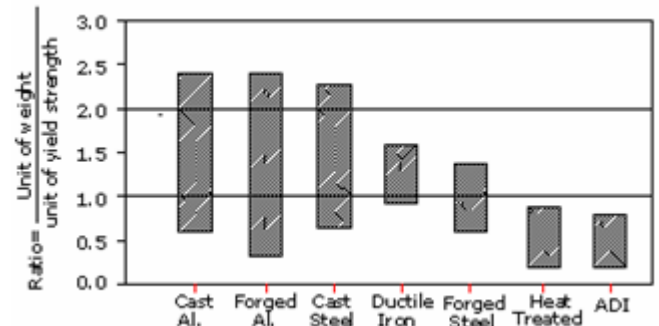
The static strength of ADI is very near to quenched and tempered steels. Also contact fatigue strength can be compared, in some applications, with surface hardened steels (Shiokawa, 1978).

Wear resistance is superior to steel at any given hardness level and this is due to presence of Graphite. Hence wear of any mating parts and other high abrasion parts, made out of ADI, will be less. Due to these reasons one of the most applications of ADI is as gear material, which replaces forged steel with major cost savings (Hohansson, 1997). Other ideal applications areas are tractor and earth moving machinery components.

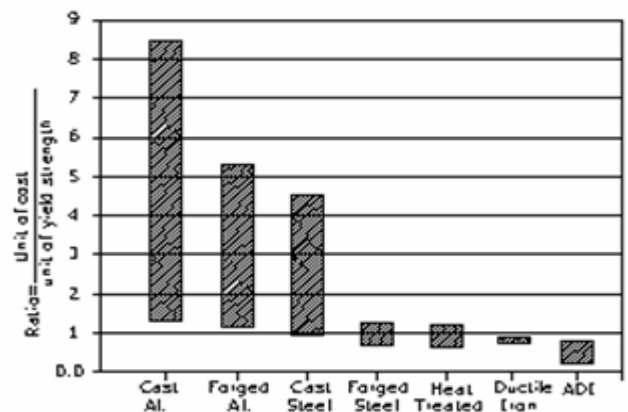
The relative weight per unit of strength of ADI allows economy in design without loss of performance. For a given shape, an ADI component will be 10% lighter than steel. ADI is also three times stronger than the best cast or forged aluminum and weighs only 2.5 times as much (Moore et al., 1984). Because it is twice as stiff, a properly designed ADI part can replace aluminum at a weight saving. Therefore during comparison of relative weight per unit of yield strength of ADI

with that of various aluminums and steels, it is easy to see the engineering and design advantages inherent in ADI.

Fig.7 represents the relative weight per unit of yield strength (Saxena et al., 2004).

**Fig. 7 Relative weight per unit of yield strength of ADI material**

For a typical components ADI costs 20% less per unit weight than steel and half that of aluminum. When analyzing the cost-per-unit-strength of ADI vs. various materials, the economic advantages of ADI become apparent. Fig. 8 represents relative cost per unit yield strength in case of ADI material (Saxena et al., 2004).

**Fig. 8 Relative cost per unit of yield strength of ADI material**

Uses of ADI in industry

Automobile industry

From the above discussion it has been revealed that ADI is having excellent properties for use in Automobile industry as well as for Agriculture Machinery.

These are some of the example which are mostly relevant to automobile industry are given below.

Crankshaft

The crankshaft for any automobile is one of the very important component. It is generally manufactured by steel forging process. But since the development of ADI, research was going on to find a suitable material to replace steel forging with ADI. Now various leading automobile manufacturer have replaced their crankshaft with ADI for better strength to weight ratio.

The crankshaft for TUSKAN six speeds TVR sports car engine was forged steel (Brandenberg et al., 2001). It was substituted by ductile iron (800/2 grade) but it failed on a bench dynamometer test. Finally, ADI grade 1 substituted the forged steel crankshaft with cost and weight saving.

The crankshaft of FORD turbo charged engine was initially made by forging. This is substituted by ADI because of superior strength and less machining, thereby material saving and lower cost. The crankshaft is shown in Fig.9 (Saxena et al., 2004).

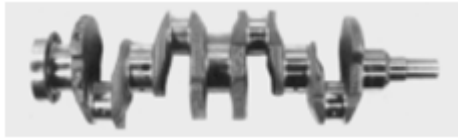


Fig. 9 ADI Crankshaft for FORD turbo charged engine

Both the steel and ADI made crankshaft perform better than ductile iron component. But ADI crankshaft exhibits the best fatigue strength over steel and ductile iron component (Hayrynen et al., 2002).



Fig. 10 ADI Crankshaft for TVR sports car

Uses Of ADI In Argicultural Machinery
Design of agricultural machinery is one of the difficult task for a designer as their are so many factors that affect the performance as a whole. The factors include like strength, weight, material wear, soil reaction, costs etc. These are generally considered while designing an agri machinery. Here are some of the examples with part designing is discussed.

Ground Engaging Parts

Ground engaging applications are considered by many to be some of the most difficult to engineer due to the abrasiveness of environments on the equipment. The Truax Company's Rangeland Planter Boot is one where exceptional wear resistance, coupled with a detailed casting design, was required for a very specific and tough application; the replanting of arid, wilderness grasslands. The incumbent steel weldment (Fig. 11a) used for the application was not holding up to the environmental and functional design needs of their seed planter. They teamed up with Smith Foundry Company and Applied Process for an exceptional material solution in ADI (Fig. 11b) (John et al., 2009).



a



b

Fig. 11a A seed boot constructed of welded steel

Fig. 11b ADI casting that replaced it as a cost and weight reduction (Courtesy of Smith Foundry)

The redesigned ADI casting (shown installed on the planter in Figure 5) meets Truax's difficult requirements while posting a

15% reduction in part weight, cutting the manufacturing lead time in half (from six weeks to three weeks), better than doubling the life of the boot, and reducing the part cost by more than 65%. This conversion won Smith Foundry and Truax the 2007 Engineered Casting Solutions / American Foundry Society Casting of the Year Award (John et al., 2009).



Fig. 12 Truax Rangeland Planter Boot installed on the planter

Agriculture Pump Crankshaft

In India the Central Mechanical Engineering Research Institute, Durgapur has also developed crankshaft for 5 HP single cylinder agriculture pump engine and transport car. The components are now under rigorous testing (Jas et al., 2003).



Fig.13 ADI Crankshaft for 5 HP single cylinder agriculture pump engine

Threshing Application

M/s John Deere announced inclusion of carbide ADI in threshing element in new high performance rotary combine in Feb 2000. There are several examples of the use of this material to tackle structural and abrasive wear problem in agricultural sector. The material is lighter (10%) and cost competitive, and could substitute complex process and high cost fabrication techniques.

Mould Board Plough

M/s Fedmech Holdings Limited produces mounting bracket on a mould board plow. The reason for switching to a grade 500 MPa ductile iron casting was the many field failures of the heavily welded steel part. Repeated attempts to improve the fabricated design resulted in too many components, which led to warping and dimensional accuracy problems during welding (Hayrynen et al., 2002).



Fig. 14 Mould board plough

Other Agricultural Applications

Sometimes ADI is simply chosen for its low cost to manufacture. That is the case with the small ADI lever arm shown in Fig.15. This arm is an alternative to forged steel. It is cast in ferritic/pearlitic ductile iron, machined completely and then Austempered giving the end user the low product cost and durability that they need.



Fig. 15 Small ADI actuating lever for a European agricultural application

Many types of wheeled agricultural and construction equipment are being converted to rubber tracks for increased versatility, lower weight, cost and soil compaction. In one application, the Toro Dingo® TX 413 (Fig. 16b), the main drive wheel consisted of an 84 piece welded and bolted steel assembly. Engineers at Toro and Smith Foundry collaborated to create a one piece ADI design (Fig. 16) that proved to be lower in cost and more durable. Because 84 pieces of steel were replaced with one, green sand, ADI casting, the wheel reliability was improved by eliminating the inherent variability in cutting, stamping, drilling, bolting and welding the components together (Brandenberg et al.,2002).



Fig.16. a) Toro Dingo TX drive system, b) Toro Dingo TX c)The one-piece ADI main drive wheel replaced an 82-piece steel welded and assembled component (Courtesy of Toro and Smith Foundry)

Australian farmers have utilized the prize-winning Mitch Tip design since the 1990's (Fig. 17). This clever, proprietary ADI design utilizes impacted soil to extend the life of the tip. MitchTips have proven equal to the task of ripping abrasive Australian soils (John et al., 2009).



Fig. 17- ADI Mitch Tips from Australia

Harvesting machines present their own set of challenges to the designer. The advent of the highly efficient rotary designs has created new opportunities for castings. Many grain rasps, deflectors and other parts used to separate and convey the grain within the harvester have been converted to ADI. Fig. 18 shows

an ADI grain deflector for a harvester. This complex shape would be nearly impossible to produce by any other method than casting. The wear resistance offered by ADI allows it to stand up to abrasive grain flow (John et al., 2009).



Fig. 18- An ADI Grain Deflector for a harvesting combine

A small, Iowa manufacturing company named Bergman Manufacturing has patented the rugged, simple to use, Agri-Speed Hitch (Fig. 19) that consists of two main components with five ductile iron sub-components, of which, four are ADI. It allows the operator of a tractor to safely back up and hook, or unhook a wagon without leaving the tractor. Ductile iron and ADI replaced steel in this application to reduce the cost and improve the durability of the hitch. This device was awarded a "Best in Class" in the 2008 Engineered Casting Solutions / American Foundry Society casting competition.



Fig. 19- The Agri-Speed hitch uses four ADI components

ADI is also used in power train and sprocket driven applications. Fig. 20 shows an ADI adjuster sprocket on a John Deere harvester. The ADI casting is a cost effective alternative to a steel sprocket machined from bar stock.



Fig. 20- This ADI adjuster sprocket is a durable alternative to steel

Agricultural components must often withstand impact loading and the abrasive wear characteristics of sandy and/or wet grass, stalks and organic material. The ADI flail shown in Fig. 21 is an elegant, cost effective design that puts the rotating mass where it is needed (Brandenberg et al.,2002).



Fig. 21- ADI rotating flail for an agricultural mower-conditioner (Courtesy of Buck Foundry)

Conclusions

ADI has opened up new scopes to use nodular iron in many engineering application in lieu of steel. The static strength of ADI is very near to quenched and tempered steels. Contact fatigue strength can be compared with surface hardened steel product. The abrasive wear resistance of ADI is also superior than steel. ADI is a cost effective, durable alternative to steel and aluminum castings, forgings, weldments and assemblies.

The experimental study revealed that ADI is ideal for a number of high strength low wear industrial applications. At present around 14% is being used in Agriculture machinery equipment. The ADI grades 1, 2, & 3 (Table 2) are being used for critical components of agricultural machinery and earthmoving machinery for weight reduction purpose applications. However grades 4 & 5 are used in critical components, which are subjected to abrasive wear. It is also being used in components where high damping properties are required.

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