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Agricultural Applications of Austempered Iron Components

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ABSTRACT

Farmers, component designers, agricultural equipment manufacturers and after-market agricultural component suppliers have all found unique, cost-effective uses for Austempered components. Austempered Ductile Iron (ADI), Austempered Gray Iron (AGI), and Carbidic ADI (CADI) have all found applications in agricultural equipment and component applications. This paper will give the reader an overview of the processes, the salient properties of those processes, developments in the manufacture of said components, and specific case studies of their application.

INTRODUCTION

In 2002 Hayrynen and Brandenberg published the paper "Agricultural Applications of Austempered Ductile Iron". The paper reviewed the properties exhibited by Austempered Ductile Iron (ADI) and its application agricultural components. That paper has been widely distributed and has lead users to other Austemper-based material/process applications in the agricultural equipment and component industry.

Many developments have occurred in the past few years that merit an updated review of Austempering applications in the agricultural industry. This paper is an overview that includes ADI, Austempered Gray Iron (AGI), and Carbidic ADI (CADI). The authors will attempt to familiarize the readers with each of the processes and the engineering, manufacturing and economic advantages of the aforementioned material/process combinations.

BACKGROUND

Austempering is an isothermal heat treating process that can be applied to ferrous materials to increase their strength and wear resistance without sacrificing toughness. Austempering consists of heating a ferrous material above the critical temperature (red hot), soaking at that temperature for a time sufficient to result in a uniform temperature and microstructure, cooling rapidly enough to avoid the formation of pearlite to a temperature above where Martensite forms (Ms) and then holding (Austempering) for a time sufficient to produce the desired matrix structure. In steel the resultant microstructure is a combination of acicular ferrite and fine, complex carbides. This multi-phased structure, named after its discoverer, Edgar Bain, is called "Bainite". In cast irons, with excessive carbon in the form of graphite, and higher silicon contents, the resultant matrix consists of a mix of acicular ferrite and carbon stabilized austenite, collectively called "Ausferrite". **Figures 1 and 2** show example isothermal transformation diagrams for the Austempering of steel and cast iron respectively.

The strength level in Austempered steels and irons will (largely) be determined by the Austempering temperature. A higher Austempering temperature will produce a material with a lower strength and hardness, but greater toughness and ductility. A lower Austempering temperature will produce a higher strength and hardness material that has somewhat lower toughness and ductility. The "grade" or "hardness" of the material/process combination selected will be determined by the engineering, performance and economic factors defined by the end user and producer.

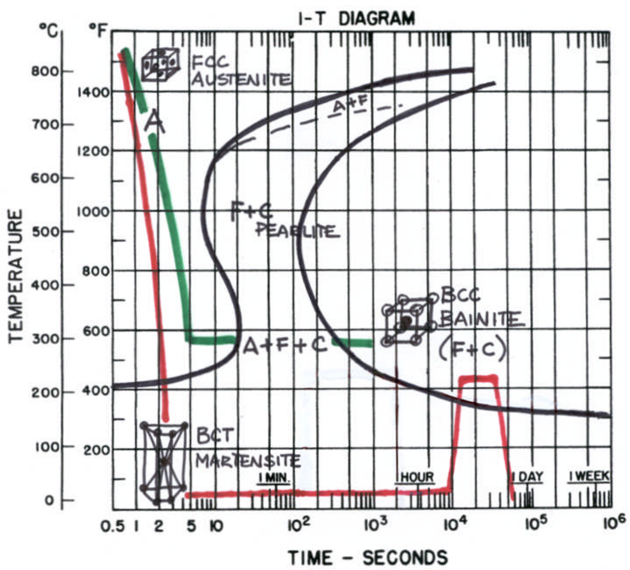

Figure 1 - An isothermal transformation diagram for a medium carbon steel with the austempering and quench and tempering processes indicated.

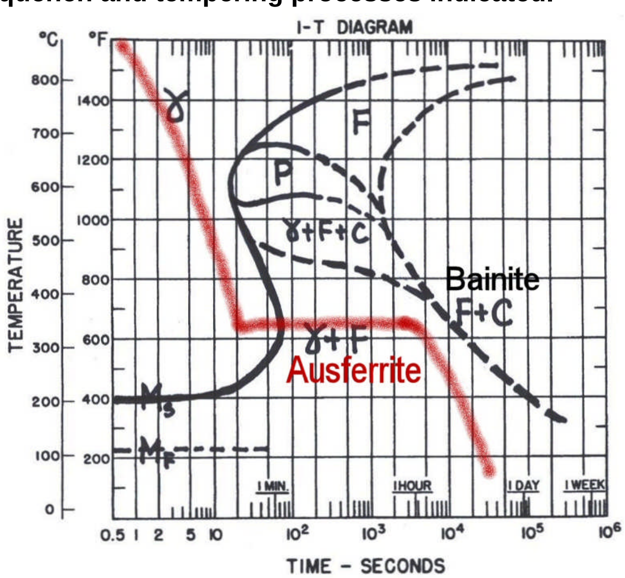

Figure 2 – An isothermal transformation diagram for a typical (3.5%C, 2.5%Si, 0.3%Mn) cast iron with the austempering process indicated.

Because Austempering is an isothermal process, it offers several advantages over conventional quenching and tempering and other methods of martensitic hardening. Martensitic transformation takes place when the local material temperature drops below the Martensite Start (Ms) temperature. Therefore, the transformation (by definition) takes place at different times in sections of differing section modulus. This can result in inconsistent dimensional response, micro-, and even macro-cracking. Since the formation of Bainite and Ausferrite occur uniformly throughout the part, over many minutes or hours, Austempered components exhibit very consistent dimensional response and no cracking (either micro or macro).

ADI, AGI and CADI are generally lower cost replacements for steel and aluminum castings, forgings and weldments.

AUSTEMPERED DUCTILE IRON (ADI)

ADI is produced by austempering a ductile iron (spheroidal graphite iron) material to produce an ausferritic matrix. The spheroidal graphite "nodules" in ductile iron allow us to fully exploit the high strength and toughness of ausferrite as they do not reduce the toughness of the iron as do graphite flakes or large carbides. **Figure 3** shows the properties of the ADI grades specified in ASTM A897/A897M-06. Furthermore, ADI is about 10% less dense than steel due to the presence of these graphite nodules.

Engineers and designers have learned that ductile iron can be easily cast into complex shapes. By subsequently austempering these castings they can exhibit a strength-to-weight ratio comparable to heat treated steel or aluminum. This allows designers to create one-piece designs that were previously assembled from multiple forgings, castings, extrusions, weldments or stampings.

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.

In certain angular and rocky soils, ADI plow points, boots and plow shins have been reported by farmers to out-wear hard-face welded and high-chrome, wear resistant irons. In other, less aggressive soils, ADI does not perform as well. In those applications, CADI is generally chosen and will be discussed later in this paper.

The same "strain transformation" phenomenon that increases surface hardness also induces compressive surface stress which, in turn, increases allowable bending stress. The result is an increase in the fatigue strength of both structural and powertrain components which can benefit greatly from shot peening, grinding or fillet rolling after austempering.

Tensile Strength (MPa / ksi)	Yield Strength (MPa / ksi)	Elongation (%)	Typical Hardness HB_W
750 / 110	500 / 70	11	241 – 302
900 / 130	550 / 90	9	269 – 341
1050 / 150	750 / 110	7	302 – 375
1200 / 175	850 / 125	4	341 – 444
1400 / 200	1100 / 155	2	388 – 477
1600 / 230	1300 / 185	1	402 - 512

Figure 3- Summary of the minimum properties of the six grades of ADI specified in ASTM A897/A897M-06.

There is much more technical information available on ADI's fatigue behavior, machinability and other important design and manufacturing characteristics but the scope of the entire body of information exceeds the scope of this paper. Additional sources can be found within the reference section.

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 **(Figure 4a)** 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 **(Figure 4b).**

The steel fabrication did not hold up to the rigors of the harsh, wilderness terrain in either wear resistance, or strict seed flow-through parameters. The steel weldment wore through after only 500 acres of planting necessitating an expensive and time consuming field replacement. The welded design also lacked the smooth, internal transitions needed for precise seed flow.

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.


a


b

Figure 4a shows a seed boot constructed of welded steel. Figure 4b shows the ADI casting that replaced it as a cost and weight reduction. (Courtesy of Smith Foundry).

Figure 5 shows the Truax Rangeland Planter Boot installed on the planter.

Sometimes ADI is simply chosen for its low cost to manufacture. That is the case with the small ADI lever arm shown in **Figure 6.** 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.

Figure 6- 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 **(Figure 7b)**, 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 (**Figure 7**) 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 variabilities in cutting, stamping, drilling, bolting and welding the components together.

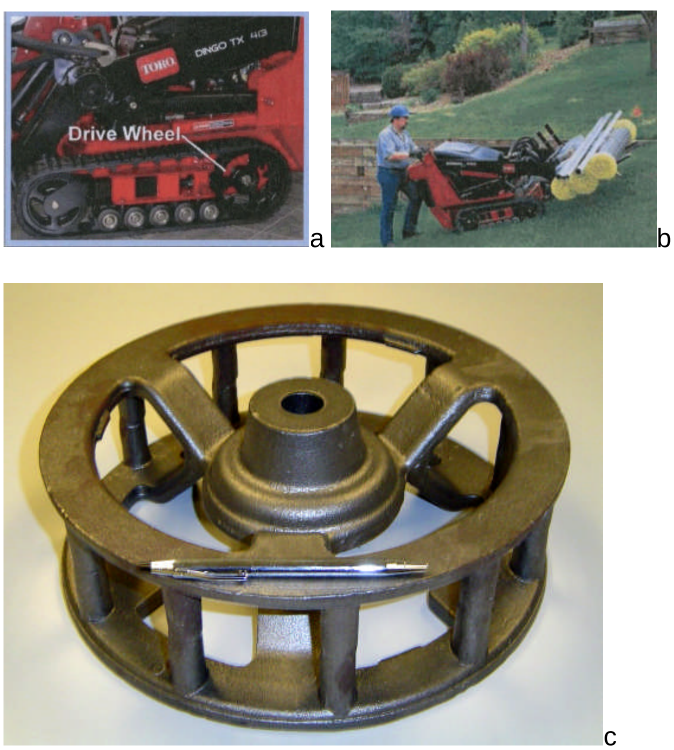

Figure 7 – a) Toro Dingo TX drive system, b) Toro Dingo TX c)The one-piece ADI main drive wheel replaced an 82-piece steel welded and assembled component. (Courtesy of Toro and Smith Foundry).

Of course, the earliest agricultural applications of ADI were simple aftermarket plow points and wear shins. **Figure 8** shows a typical ADI plow point that has been in production for more than 15 years. These through-hardened ADI ground engaging parts replace hardened and hard-faced welded steel components at a competitive price.

Figure 8 shows a typical ADI plow point.

Australian farmers have utilized the prize-winning MitchTip design since the 1990's (**Figure 9**). This clever, proprietary ADI design utilizes impacted soil to extend the life of the tip. An "engineered CADI" version with a brazed on carbide tip and a durable ADI body is also available. MitchTips have proven equal to the task of ripping abrasive Australian soils.

Figure 9- 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 and CADI. **Figure 10** 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.

Figure 10- 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 **(Figure 11)** 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.

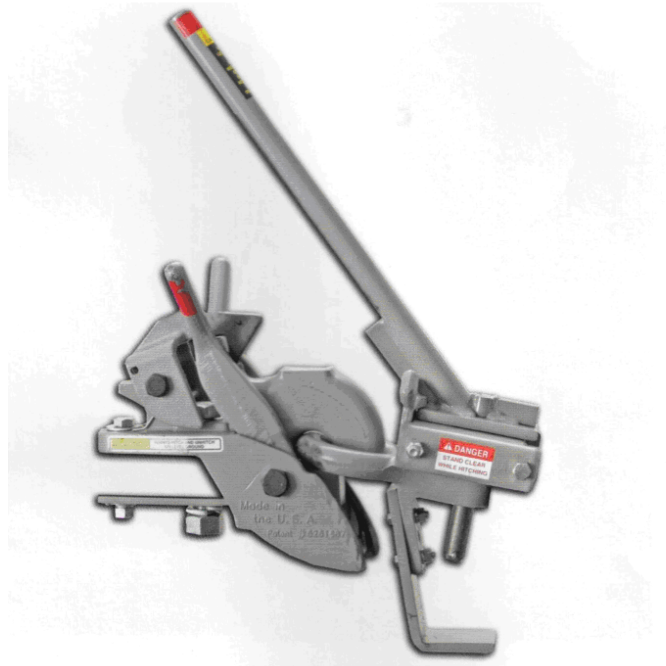

Figure 11- The Agri-Speed hitch uses four ADI components.

ADI is also used in powertrain and sprocket driven applications. **Figure 12** 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.

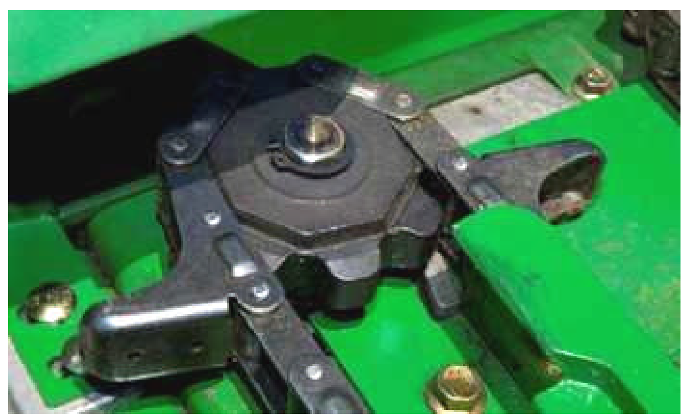

Figure 12- This ADI adjuster sprocket is a durable alternative to steel.

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 **Figure 13** is an elegant, cost effective design that puts the rotating mass where it is needed

Figure 13- ADI rotating flail for an agricultural mower-conditioner (Courtesy of Buck Foundry)

AUSTEMPERED GRAY IRON (AGI)

AGI provides the same excellent wear resistance as it's ausferritic cousin, ADI. AGI exhibits much higher strength than as-cast gray iron. **Figure 14** shows the tensile strength array of Class 20, 30, and 40 gray iron as-cast and austempered at 371°C (700°F), 316°C (600°F) and 260°C (500°F). Its most salient feature is its ability to damp noise due to the combination of an ausferritic matrix and large graphite flakes. Note that **Figure 15** shows that as the austempering temperature is decreased, the strength of the AGI increases, as does the damping coefficient. Those graphite flakes also limit the strength of AGI, acting as angular voids in the metal matrix and allowing maximum strengths no higher than around 450 MPa.

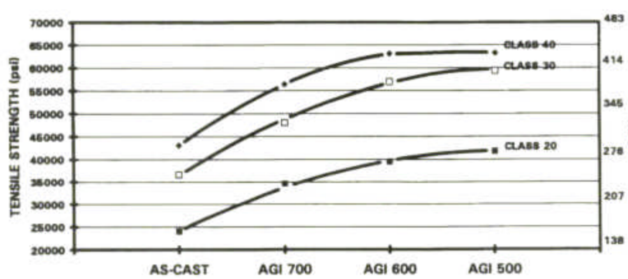

Figure 14- Tensile strength of gray iron Classes 20, 30 and 40 as-cast and austempered at 371°C (700°F), 316°C (600°F) and 260°C (500°F)

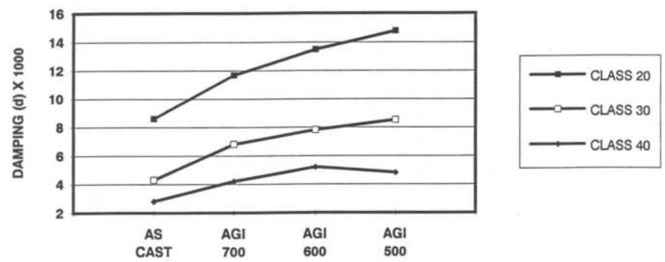

Figure 15-shows the damping coefficient of three classes of gray iron as-cast gray iron and austempered at three different austempering temperatures.

The advantages of AGI are its low cost and excellent castability. This makes it a good candidate material/process combination for applications that require low cost, a complex shape, good strength and wear resistance where impact and cyclic stresses are not significant.

The most ubiquitous application of AGI is in cylinder liners for diesel engines. In that application the cylinder liners offer good wear resistance and noise damping as well as improved burst strength over as-cast gray iron liners.

The complex harvester machine cam in **Figure 16** demonstrates the excellent manufacturability of AGI components. The gray iron has good castability and is easily machined. The critical shape of the cam is maintained during the austempering process. The ausferrite matrix provides good wear resistance for cam durability and good noise damping.

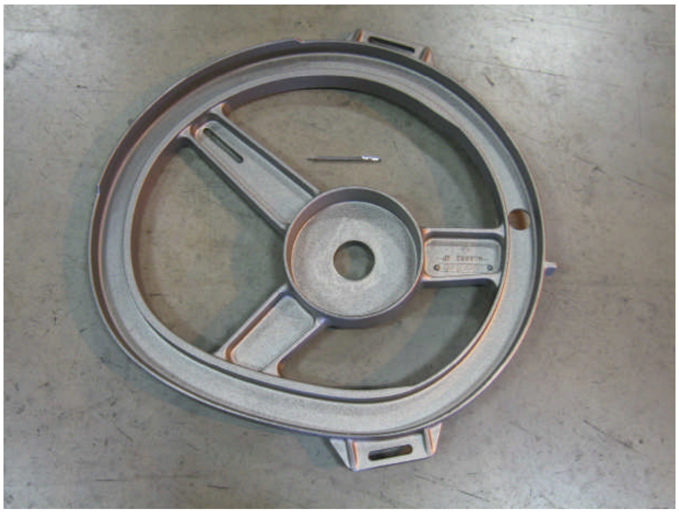

Figure 16- a large, AGI cam wheel for a harvesting machine.

CARBIDIC AUSTEMPERED DUCTILE IRON (CADI)

CADI is produced by the introduction of carbides into the cast iron matrix during the casting process. The iron is subsequently Austempered in a manner that produces a controlled percentage of carbides in an ausferritic matrix. CADI was introduced in 1991 to produce components with better wear resistance than ADI at a price (and performance) competitive with abrasion resistant irons, but with a modicum of impact strength. **Figure 17** shows the abrasive wear resistance of CADI vs. an array of other engineering materials.

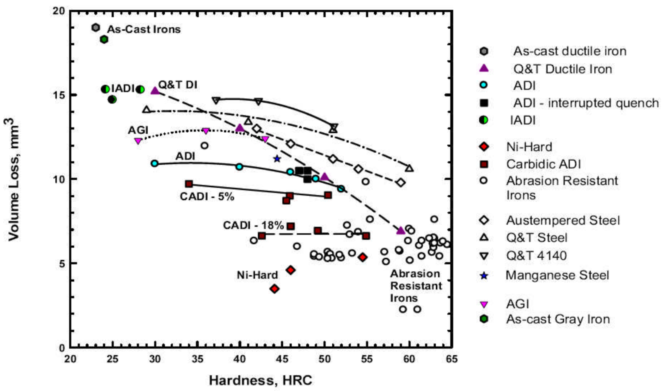

Figure 17- Pin abrasion performance of 5% and 18% carbide CADI vs. other engineering materials.

CADI may also be produced by mechanically introducing carbides into a casting cavity prior to the introduction of molten metal. The subsequent austempering of the component does not affect the cast-in carbides. Another version of CADI can be produced by casting a part as ductile iron, hard-face welding a locality on the part and then subsequently austempering it, leaving the carbidic hard-face weld unaltered, while producing a base matrix of Ausferrite.

The first commercial application of CADI occurred in 1991. A small, agricultural implement manufacturer then using ADI needed “a little more wear resistance” on a certain fully-supported plow point (**Figure 18**). Keough and Kovacs worked with the manufacturer, Carroll Agricultural, and G&C Foundry to develop a casting process to produce an as-cast iron matrix containing mixed spheroidal graphite and carbides. The carbides were subsequently partially dissolved during austenitizing. The material was then austempered. The resulting wear resistance was suitable for the customer’s application and the parts exhibited adequate toughness to survive initial dropping of the plow and impacts with stones.

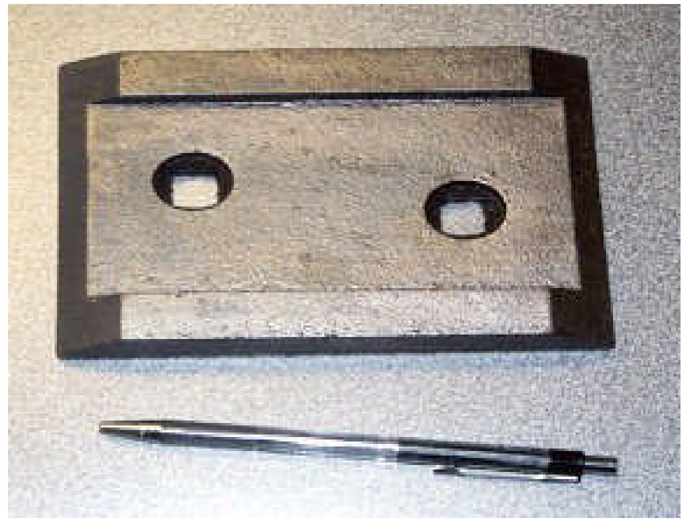

Figure 18- The first, commercial CADI application (circa 1991) was this small plow point for Carroll Agricultural.

Figure 19 shows the John Deere LaserRip™ ripper points that utilize CADI for good wear resistance and toughness highly abrasive, rocky soil. They provide better wear resistance than standard steel points and better impact resistance than high-chrome, abrasion resistant steels and irons. Many of the John Deere CADI components are produced using a special, patented method for the production of CADI developed by ThyssenKrupp Waupaca specifically for John Deere components.

Figure 19- John Deere LaserRip™ CADI ripper points. (Courtesy of John Deere and ThyssenKrupp Waupaca)

Harvesting machines pose interesting challenges to design engineers. If the handling and thrashing components are too soft, they will wear out, causing downtime at critical harvest times. If those same components are too brittle, they may break, causing the machine to be off-line at a critical time. Engineers have found that CADI rasps, thrashing tines, flights and buckets can withstand the impacts sustained in grain harvesting and provide sufficient wear for a full season and more. **Figure 20** shows several CADI components used in harvesting machine applications.

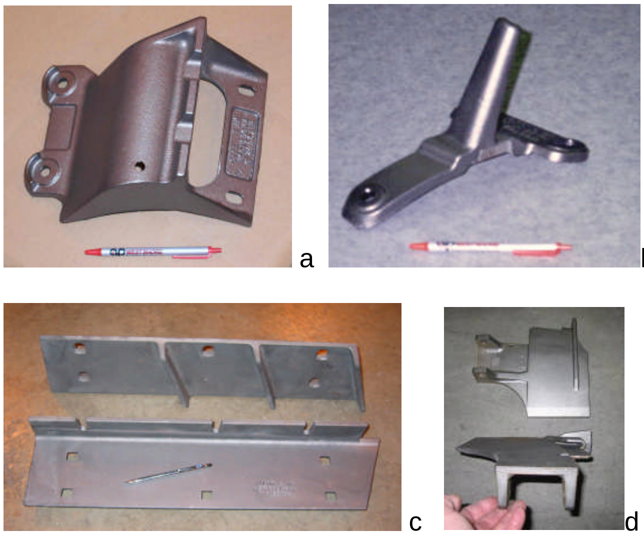

Figure 20 shows several CADI harvester applications. a) bucket, b) thrashing tine, c) flight, d) scraper blade.

SUMMARY

Austempering offers manufacturers numerous opportunities to make their iron components tougher, stronger, lighter, quieter and more wear resistant.

ADI is a cost effective, durable alternative to steel and aluminum castings, forgings, weldments and assemblies.

AGI combines good wear resistance and noise damping at a total manufacturing cost less than ADI, steel or aluminum.

CADI offers extreme wear resistance with a modicum of toughness that gives it performance and cost advantages over conventional abrasion resistant iron components.

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ADDITIONAL RESOURCES

Here the authors list additional sources of information that the reader may choose to review.

+ Applied Process Inc. internal research
+www.appliedprocess.com
+www.metalcastingdesign.com
+www.mitchtip.com