Near-Net-Shape Manufacturing of Austempered Ductile Iron (ADI) Components

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Near Net Shape (NNS) manufacturing produces the engineering components closer to its final specification in single stage or minimum number of stages. ADI process technology is one of the NNS manufacturing technologies, currently being followed by the industries for manufacturing of engineering components at competitive price. Austempered Ductile Iron is a new class of engineering material which is being manufactured from high quality Ductile Iron through austempering process. ADI castings provide a unique combination of high strength and toughness coupled with superior wear resistance properties.

This paper describes the indigenous development of process technologies for NNS manufacturing of ADI components like Beater Head reversible hammer mill and Swing Hammer for exciter. Results of field trials of these components have also been discussed. Brief description on development of ADI spur gear for exciter has also been highlighted.

Keywords: Austempered Ductile Iron (ADI), Carbidic Austempered Ductile Iron (CADI), Ausferrite.

Introduction

Globalisation has opened up ample scopes for our manufacturing industries to export their products worldwide. The survival however depends upon competitiveness. The manufacturing competitiveness is driven by product and process innovations, quick response, superior quality and competitive price. All of these are technology-driven. New manufacturing methods which produce the engineering components closer to its final specification in single stage or minimum number of stages is known as Near Net Shape (NNS) manufacturing. NNS technologies are now getting wider acceptance all over the world for obvious benefits like maximum utilisation of costly raw material and minimum energy requirement for processing, compared to the conventional manufacturing processes. ADI process technology is one of the NNS manufacturing technologies, currently being followed by the industries for manufacturing of components for wide range of customers.

During last three decades ADI manufacturing technology has gone through an intense phase of worldwide investigation and experimentation. As a result, a new field of applications and market of ADI products have been emerged. ADI exhibits remarkable properties, such as good tensile properties, relatively light-weight and good vibration damping, as well as a high level of ductility, recyclability and wear resistance. In 70's ADI was favourably looked upon by the US automotive industries.[1]

Advantages of ADI process technology are-

- Production of ADI component needs less energy than forged steel components
- Auastempering can impart wide range of mechanical properties in the SG iron to produce ADI which can replace the forged steel and SG iron parts even for critical engineering applications
- Easy to produce complex geometry components in NNS forms
- 10% lighter than steel counterparts
- Higher damping capacity
- 20% cheaper than forged steel parts and aluminium parts.

Meanwhile, ADI applications have evolved from the simple, direct "upgrade" replacement of ductile iron and plain carbon steels to elegant FEA designs that can substantially reduce component weight, minimise (or eliminate) machining and technically compete with steel and aluminium castings, forgings and weldments at a lower price.[2] At the turn of the last century, the world-wide consumption of ADI was estimated at 150,000 tonnes per year, with a forecast of 20% annual growth rate.[3] Due to its attractive properties, ADI material are already being used in the following engineering sectors :

- Automobile Sector
- Mining machinery

- Agricultural machinery and implements
- Rail road components
- Construction equipment.

Keeping in mind the world-wide trend of development of ADI technology and its advantages over the conventional material, one R&D project on ADI technology was initiated at Central Mechanical Engineering Research Institute, Durgapur. During last five years extensive R&D activities were carried out at CMERI, on the important aspects of NNS manufacturing of ADI components. As a result, the comprehensive process technology for manufacturing of different types of industrial components through ADI route has been successfully developed at CMERI. Field trials of some of the components have revealed encouraging results.

This technical paper highlights the salient features of the ADI process technology developed for manufacturing of different types of components, mechanical properties achieved and scope of applications of ADI components in our country. Detailed information on the NNS manufacturing of Beater head and Swing hammers through ADI route and results of field trials have also been discussed .

ADI Manufacturing Technology

Austempered Ductile Iron is a new class of engineering material which is being manufactured from Ductile Iron through austempering process. Austempering is an isothermal heat treatment process applied to ferrous materials to produce a microstructure that is stronger and tougher than the structures resulting typically from conventional hardening and tempering process. Austempering calls for very precise control of process temperatures and times to achieve consistent results. ADI manufacturing process generally consists of following steps:

Component drawing- Solid model – Computerised Methoding-Pattern making- Moulding - Sand Casting – Pre-machining — Austempering Treatment – Final Machining – Inspection & Testing.

For some type of components like beater head and swing hammer, the ADI process technology is capable of producing the components to final dimension without any major machining operation. The indigenous ADI process technology which has been developed through the above route is capable of producing –

- ADI materials which can satisfy the requirements of mechanical properties as per ASTM/ EN standards
- High quality NNS components upto a section thickness of 100 mm.

The primary object of our R&D project was to develop the ADI process technology for production of specific engineering components in NNS forms. Crankshafts of different engines which are being manufactured through forging and machining route were identified as our target components. ADI Gr.I/Gr.II can be a suitable material for the manufacturing of structural components like crankshafts. Accordingly, it was planned to focus our activities to develop ADI Gr.II material with indigenous resources. Subsequently, other components like Beater head, Swing hammers and Gear for mining machinery were also successfully developed through ADI process. Components development programme was divided into two phases –

a) Development of ADI Gr. II material

b) Development of ADI components

Evaluation of the Mechanical Properties of ADI Material

Based upon the analysis of the technical specifications of the crankshafts, it was decided that ADI grade II material would be the near equivalent material of the existing material of forged and machined crankshaft. Maximum section thickness of this component is 80mm. Therefore, it was decided that ADI test samples would be developed with the target to satisfy the limit of tensile properties of ADI grade II as laid down in ASTM 897M / EN 1564 standard. Mechanical properties as per ASTM and EN standards are given in Table-1.

Table-1 : Mechanical Properties of ADI as per ASTM A897M/EN1564 Standards

Grade	UTS (Mpa)	YS (Mpa)	%EL	Unnotched Impact(J).	Hardness (BHN)	Fracture Toughness K_{IC}(Mpa-$m^{1/2}$)
ASTM -I	850	550	10	100	269-321	—
EN - I	800	500	8	100	260-320	62
ASTM- II	1050	700	7	80	302-363	—
EN - II	1000	700	5	100	300 -360	58
ASTM- III	1200	850	4	60	341-444	—
EN - III	1200	850	2	60	340 -440	54
ASTM- IV	1400	1100	1	35	388-477	—
EN- IV	1400	1100	1	30	380-480	50

The critical factors which influence the final properties of ADI material are –

- Chemical composition
- Treatment of liquid metal
- Heat treatment cycle

ADI normally has the composition 3.6-3.8%C, 2.3-2.5%Si, 0.2- 0.5% Mn and 0.03-0.04% Mg. Other alloying elements like Ni, Cu and Mo are also being added to the melt to increase the hardenability and other properties of the alloy. Carbon and silicon are added for graphitisation purpose. Higher carbon and silicon content increase the graphitisation of the iron as well as castability. For good quality SG iron castings, it is essential to maintain the optimum amount of Si and C. Carbon equivalent (C + 1/3 Si) of SG iron melt is generally maintained between 4.3 to 4.6, based upon the section size of the component.[4] Addition of Ni varies from 0.5 to 2.0wt% whereas Cu content is generally restricted to 0.8 wt%. Manganese can be both a beneficial and a harmful element. It strongly increases the hardenability, but during solidification it segregate in the cell boundaries where it forms carbides and retards the austempering reaction.[5] In case higher section thickness, higher Mn content increases formation of shrinkage, carbides and unstable austenite . Microstructural inhomogeneties are detrimental to ADI components. It adversely affect the mechanical properties of ADI. Austempering process is applied SG iron material to form a unique matrix consisting of acicular ferrite and stable high carbon austenite and the final product is known as Austempered Ductile Iron (ADI). Alloying elements like Ni, Cu and Mo are added to the ductile iron to prevent pearlite formation on cooling to isothermal transformation temperatures.

The sequence of Austempering process is as follows-

- Heating the casting to Austenitising temperature in the range of 815 -930°C for a time sufficient to saturate the austenite with carbon
- Rapid quenching of the part to the Austempering temperature in the range of 230-400°C
- Austempering the parts for a specified duration of 1 - 4hrs
- Air cooling of the parts to room temperature

The critical factors of austempering process are[4]–

- Austenitising temperature and time
- Cooling rate
- Austempering time and temperature.

Higher austenitising temperature increases the carbon content of austenite which in turn increases the hardenability but reduces the mechanical properties after austempering treatment. Lower austempering temperature produces ADI with better mechanical properties depending upon section thickness of castings. Austempering temperature and time had a marked effect on both strength and ductility. Higher austempering temperature (375-415°C) gives lower strength levels. Lower austempering temperature (260 –320°C) gives higher hardness, higher strength but lower impact properties.

Experimental & Discussion

Steel scrap, FeSi, FeNi, and other essential alloying elements were charged in 100 kgs Induction Melting Furnace to prepare liquid iron . The melt was treated in ladle at 1440/1450°C with FeSiMg and NiMg granules by plunging method to achieve Mg content in the range of 0.03 to 0.05 wt% in the melt. Subsequently, fine powder of FeSi was added to the bath as well as in the stream to ensure the high level of nodule count in Y block castings of SG iron. The liquid metal was poured in the sand mould to cast Y block as per the guidelines of ASTM standard. It is very important that the casting should be free from casting defects. Accordingly, the sand mould was prepared to minimise the entry of oxide slag inclusions and erosion of mould wall. Figure 1a shows the end view of Y block showing the locations of tensile and Impact specimens. Fracture toughness (CT) specimens were also prepared from the lower portion of the Y block casting after discarding the top and central portion of the material. Specimens for hardness tests were also selected from the lower portion of the same castings.

In order to determine the effect of austempering parameters on the hardness of ADI, 8 Nos of SG iron specimens (25mm x 25mm x 15mm) for carrying out austempering at two different temperatures (345°C and 365°C) for a duration of 1hr and 3hrs. Hardness (BHN) values of ADI samples and their respective process parameters are shown in the Table-2.

Table-2 : Effect of Austempering Temperature and Time on Hardness (BHN) of ADI samples

Austenitising Temp. (°C)	Austempering Temp. (°C)	Austemp. Time (1hr) BHN	Austemp. Time (3hrs) BHN
900	345	400	370
	365	360	348
875	345	395	358
	365	354	360

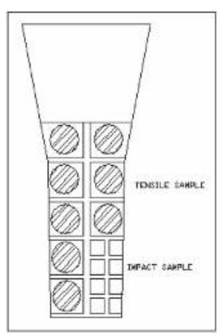

Fig.1a : Drg. of Y block casting (ASTM 897) showing the locations of tensile and impact specimens

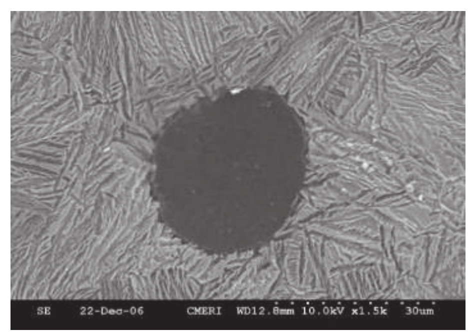

Fig.1b : Scanning electron micrograph of ADI specimen (austempered at 370°C)

The above experiment revealed that in order to achieve the ADI Gr II properties, the specific melt to be austemepered as per the following cycle – Austenitising at 900±5°C, followed by austempering at 365± 5°C, for 1 - 2 hrs . Tensile and Impact test blanks were prepared from specified location of the Y block. All the test blanks were inspected through radiographic tests and the defect-free specimens were heat treated as per the following austempering cycle - Austenitising 900±5°C for 1- 2 hrs, followed be austempering at 365-370°C for 1.5hrs. The ADI test specimens were finally machined to their respective final dimensions as mentioned in the ASTM standards. Tensile tests were carried out with servo hydraulic Instron (UTM) machine at a strain rate of 10^{-4} mm/sec. Results of tensile tests and impact tests are shown in Table-3.

Table-3 : Tensile and Impact Properties of the ADI Samples Developed at CMERI

Specification ADI Gr II	UTS(Mpa)	YS(Mpa)	% El	Unnotched Impact (J)
(A897)	1050	700	7	80
Sample No.1	1186.3	895.6	15	154
Sample No.2	1098.2	818.4	8.8	156
Sample No.3	1108.2	813.5	11.5	156
Sample No.4	1085.9	811.2	9.2	108
Sample No.5	1070.9	814.2	8.5	148
Sample No.6	1108.9	860.7	11.2	155

The examination of microstructures of the ADI revealed that the matrix consisting of fine acicular ferrite, carbon stabilised austenite and graphite nodule. Figure 1b shows scanning electron micrograph of the developed ADI alloy. It was observed that nodule count was 250/275, nodularity was above 85% and carbide content was below 5% .

Fracture toughness- It is a well-established fact that metallic elements sometimes fail by brittle fracture and fatigue especially in presence of a crack like defects particularly when they are exposed to high dynamic stresses. Tensile properties and Fracture toughness (KIC) of a material gives the idea about how it will behave under dynamic environment in presence of sharp small crack type of defects. Although fracture toughness test is mandatory for aerospace material being used for structural applications but for general engineering purpose it is still optional.

K_{IC} values of the material gives idea about intrinsic resistance of the material to crack propagation. It has been observed that sometimes small casting defects may exist in the subsurface of a finished products cleared for dynamic applications. Therefore, it was decided to evaluate the K_{IC} values of the same ADI material . Accordingly, CT specimens (shown in Fig. 2) were prepared from austempered blank. Fracture toughness test was carried out at NML, Jamshedpur as per the guidelines of ASTM E 399. Table-4 shows the values of YS and K_{IC} of three types of ADI material. It can be observed that the K_{IC} results of ADI material developed at CMERI is well above the limit specified in EN standard and are comparable with the values reported for similar type of ADI material developed at US. The table also shows the ratio of K_{IC} to yield strength of these material. This ratio indicates the size of flaw that can be tolerated when the materials are subjected to constant fraction of their yield strength. It has been reported that ADI has equal or greater flaw tolerance than pearlitic ductile iron and quenched and tempered steels.[5]

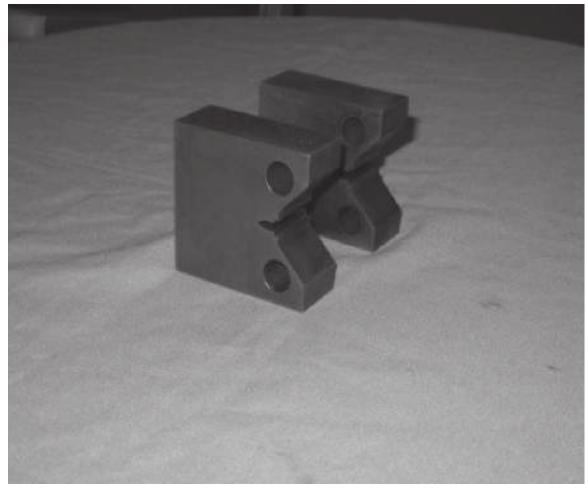

Fig. 2 : Photograph of CT Specimens Prepared from ADI 4 Alloy.

Table-4 : YS, Fracture Toughness and Flaw Tolerance of ADI Samples

Alloy	Y. S(Mpa)	K_{IC}(MPa $m^{1/2}$)	$[K_{IC}/YS]^2$ (mm)
EN 1564(Gr.I)	700	58	–
ADI-I*	989	72	5.3
ADI-II*	793	74	8.6
ADI-4**	860	70	6.6

ADI-4**- material developed at CMERI, Durgapur and Fracture Toughness tests were carried out at NML, Jamshedpur. ADI- I* and ADI II*- Source - Ductile Iron Data for designer–Section 4 htm (1998).

Manufacturing of a Few Engineering Components with ADI

Beater head and Swing hammer are being used in the mining machinery for processing of different types of hard ores. Chrome nickel steel hammers are currently being used for manufacturing of these components. M/s. McNally Bharat, Kumardubi, manufacturer of mining machinery, was interested to improve the wear resistant properties, thereby to increase the effective life of these parts. M/s McNally Bharat requested CMERI to develop Beater head and Swing hammer from the wear resistant ADI alloys to achieve the desired objectives.

Beater Head

Beater heads are assembled in the reversible hammer mill which crushes the lump of ore like limestone and pyroxnite for continuous supply of material to the blast furnace. Four numbers of Beater heads mounted on the shaft of the hammer mill which rotates at 700 rpm (tip speed 55m/sec) to crush silica bearing abrasive ores. In every rotation of the shaft each beater head experiences higher level of centrifugal load, impact load as well as high magnitude of abrasion. Therefore, the challenges was to develop the ADI beater head samples which should withstand the environment as well as should also show improved life. Manufacturing process of ADI Beater head consists of–

Component drawing – Solid model – Computerised Methoding-Pattern making – Moulding – Sand Casting – Fettling – Austempering Treatment – Inspection – Testing.

Considering end application of this component, composition of the melt, process parameter of casting and austempering process were appropriately designed. Sand mould was prepared after taking the data from computerised methoding of beater head. Finally, the components were cast from SG iron melt. Two types of composition and two types of austempering temperatures were selected for this developmental trial. The components were cast in NNS form. Figure 3 shows the SG iron beater head with side riser and Fig. 4 shows the beater head after fettling. No machining was carried out on the ADI beater head samples before assembly. After fettling operation, the components were austempered for 2hrs and hardness values were between 380 – 430 Bhn. After inspection for dimension, hardness and weight, the components were released for field trials. Figure 5 shows the 4 Nos. of beater head samples released for field trials. Two ADI beater heads and two Steel beater heads were assembled in four arms located in a single plane of the crusher. Therefore, two pairs of ADI beater heads were fitted with steel samples in 5th and 13th planes of the crusher which was operated for crushing of raw material (limestone and pyroxnite) for 430 hrs. Steel and ADI beater heads were exposed in the same environment for 430 hrs. Both the steel and ADI samples were removed from the crusher and were inspected for loss in weight. It is to be noted that all the ADI samples had survived the test. Figure 6 shows the ADI beater head samples after completion of above field trial. Percentage loss of material of all the samples are shown in Table-5. It can be seen from the values of the ADI beater head samples Sl. No. 3 and 5 minimum weight loss compared to other steel and ADI samples.

Fig. 3 : As-cast beater head (SG iron).

Fig. 4 : ADI Beater head (no shrinkage defect).

Fig. 5 : Four ADI beater heads having hardness range 370 –440 BHN.

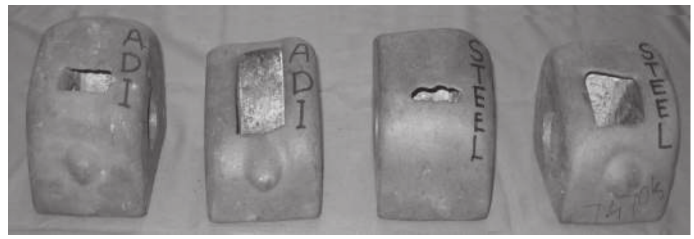

Fig. 6 : ADI beater heads and steel beater heads after 430 hrs of field trials.

Table-5 : Result of Weight Loss of Beater Head Samples : (ADI and Steel) after 430 hrs of Field Trial

Sl. No.	Initial Weight of Beater Head	Plane of Assembly (position)	Final Weight of Beater Head	Loss of Material
1	20 Kg (ADI)	5th	6.410 Kg	67.95%
2*	22 Kg (Steel)	Do	7.600 Kg	64.45%
3*	20 Kg (ADI)	Do	8.540 Kg	57.3%
4	22 Kg (Steel)	Do	7.470 Kg	66.04%
5	20 Kg (ADI)	13th	7.800 Kg	61.0%
6	22 Kg (Steel)	Do	6.560 Kg	70.18%
7	20 Kg (ADI)	Do	7.520 Kg	62.4%
8	22 Kg (Steel)	Do	8.020 Kg	63.54%

In order to assess the morphology of worn out surfaces, the small samples were carefully taken out of beater head samples Sl. No. 2 and 3 and subsequently examined under SEM. Figure 7 and Fig. 8 show the SEM photographs (150x) of the worn out surfaces of ADI and steel samples respectively. Field trial of beater head samples revealed that ADI beater heads can be a cost-effective alternative for steel beater head samples. Since no machining was involved to reach final dimension, the manufacturing cost of ADI beater heads would be 15-20% less than the steel counterparts.

Swing Hammer

M/s McNally Bharat Ltd. was interested to replace the steel hammer with a superior wear resistant which would ensure higher

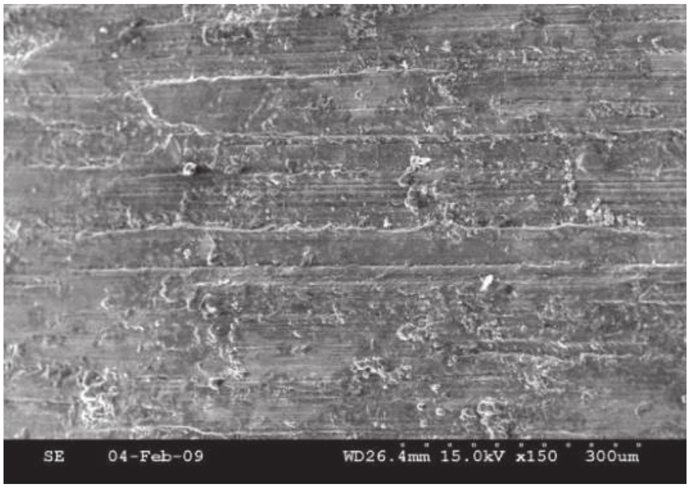

Fig. 7 : SEM photograph of working surface of ADI beater head (sample No. 3) showing fine scratches on work hardened surface.

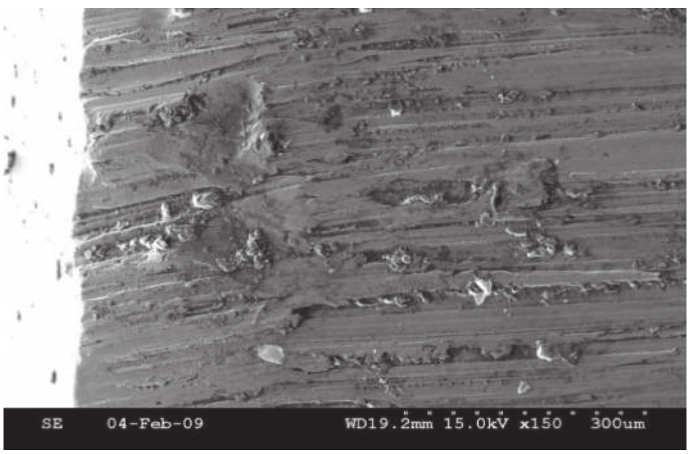

Fig. 8 : SEM photograph of working surface of steel beater head (sample no 2) showingdeep scratches with cavitation damage.

productivity of mining machinery being used for crushing of high silica containing iron ore. Considering the advantages of ADI, M/s McNally Bharat Ltd. requested CMERI to develop the Swing hammer from ADI material for above application. Fifteen or 9 Nos. of Swing hammers are fitted to the Reversible Impactor which crushes the lump of iron ore. Three Nos. of hammers are mounted in a single plane on the shaft of the Impactor which rotates at 650 rpm to crush silica bearing iron ores. In every rotation each hammer experiences higher level of impact load as well as high magnitude of abrasion. Therefore, the challenges were not only to develop the ADI hammers to withstand the critical environmental load but to ensure higher life and productivity also. It has been reported that wear resistant properties of carbidic ADI is superior than ADI Gr.V material. Therefore, efforts were made to develop one set of CADI Swing hammer with minor addition of carbide forming element like Cr/Mo. Weight of one Swing hammer is 35 kg. As per the norms of assembly, the weight difference between any two hammers should be within ±50gms to achieve the criteria of dynamic balancing of the system. The main objective of the process technology was to produce the cast hammers without any major shrinkage defect at neck portion (section thickness -100mm) and to minimise the dimensional differences between the hammers. Computer simulation plays an important role in eliminating the shop-floor trial and error method thus providing optimised process parameters leads to shorter time as well as better yield.

The solid model of the Swing hammer was created using AutoCAD as shown in Fig. 9 and the initial solidification simulation was carried out without gating and risering system to locate the position of riser placement as shown in Fig. 10. Risering and gating systems were designed using risering and gating wizard of the software and anumber of simulations were carried out to standardise the casting process parameters including optimised risering system. Fig. 11 shows the optimum casting module without any defect and Table 6 shows the standardised process parameters for casting of Swing hammer.

Based on the results obtained from the computerised methoding, the wooden patterns were made for casting of the same. Three types of compositions were designed to prepare alloyed ductile iron and components were cast using medium frequency induction furnace. Integral test specimens were also cast along with the components. Various austempering heat treatment cycles were then imparted on the cast components as well as to the test specimen to prepare ADI and CADI material. Microstructural analysis and hardness measurement were carried out on the heat-treated test specimen. Hardness measurement was also carried out on all heat-treated hammers. The developed swing hammers were fitted in the reversible crushing mill located at Vagus Beneficiation Plant, Goa for field trial to evaluate the performance of the developed components.

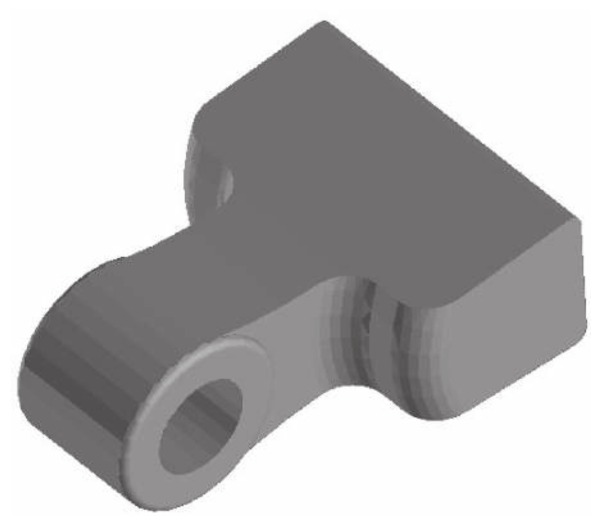

Fig. 9 : Solid Model of Swing Hammer.

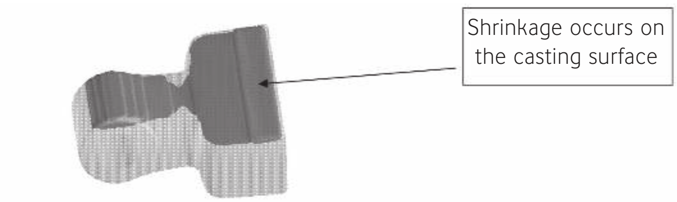

Fig. 10 : Simulated Result of Cast Hammer without Gating and Risering System, Showing the Shape and Size of Shrinkage.

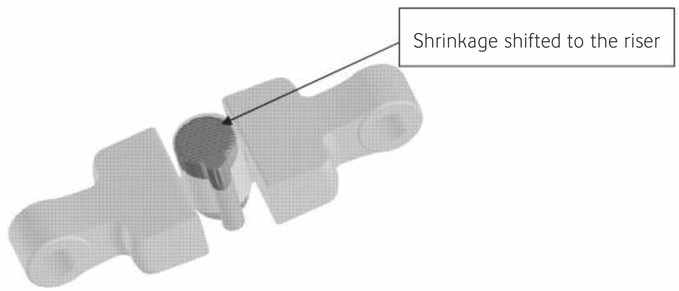

Fig.11 : Simulated Result with Gating and Risering System.

Table-6 : Standardised Process Parameters

Sl. No.	Parameters	Values
1.	Pouring Temperature, ^{0}C	1280
2.	Mould Temperature,^{0}C	30
3.	Mould filling time, Sec	10
4.	Riser Dimension (Diameter X Height), mm	110X140
5.	Yield, %	83

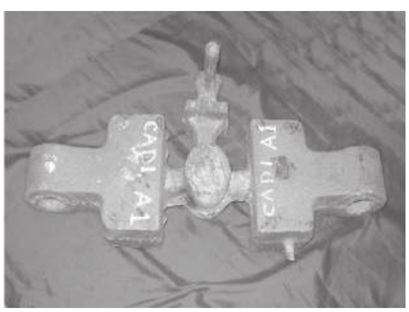

Fig. 12 : As-Cast Hammers with Risers and Runner.

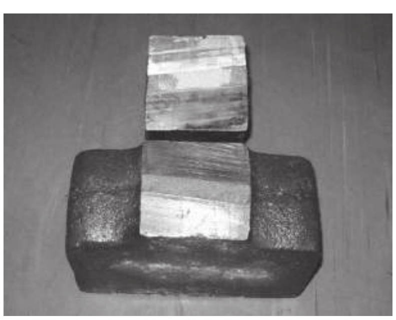

Fig. 13 : Sectional View of Cast Swing Hammer Showing no Shrinkage Defects at Neck Area.

Fig . 14 : Nine Hammers (ADI&CADI) Before Assembly.

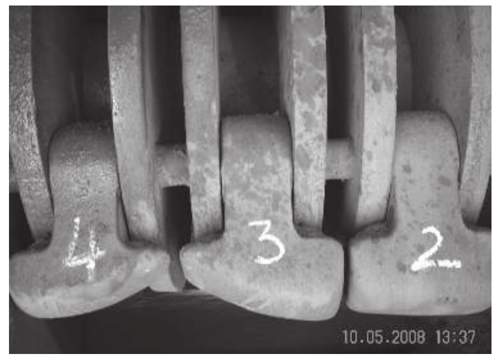

Fig. 15 : Worn out Hammers After 158 Hrs of Operation.

Table-7 : Average hardness values of three batches of hammers after austempering at different temperatures

Alloy	Average Hardness (bhn)
A1	376
A2	399
A3	341

Three types of alloys were designed for the present investigation and they were designated as A1, A2 and A3. From each alloy, three components were developed. Figure 12 shows the as-cast sample of hammer along with side-riser and runner. After fettling the cast components were austempered at 300-320^{0}C to achieve the specified level of hardness. Hardness test of the components were carried out with a Drop Hardness Tester and average hardness values are given in Table-7. In order to assess the quality of the casting, one was destroyed at location of neck of the hammer, no shrinkage defect was noticed. Figure 13 shows the photograph of the cut sample. Weight of all the hammers were measured and difference of weight in complete set of hammers (9 Nos.) were well within the limit. Figure 14 shows the 9 swing hammers before dispatch to Goa. The ADI hammers were fitted in an Impactor located in an iron ore crushing plant. The performance evaluation result shows that machine fitted with the developed components crushed around 10,000 MT of material during 158 hours of operation compared to 6000-7000 MT by the existing machine fitted with steel hammer. Figure 15 shows the worn-out hammer inside the 'Impactor' after 150 hrs. of operation. Normally, the impactor fitted with steel hammers can process 6500/7000 tonnes of iron ore. It was observed that the ADI components were not only able to withstand the complex state of stresses but also showed higher level of productivity.

Work in Progress - Development of Gear

M/s McNally Bharat also requested CMERI to undertake the development of ADI Spur gear for Exciter. It has already been observed that increased contact and bending fatigue strengths, as well as noise reduction make ADI well-suited for gear and sprocket applications.[6] Considering technical requirements of this gear CMERI initiated the project for development spur gear through ADI route with the aim to improve the life of the component. The forged and machined gear is being manufactured from EN 19 steel having the hardness level 260/290 Bhn. Analysis of drawing revealed that there is a scope to reduce the weight of the gear. After discussing with the designer, the geometry of the cast gear has been modified by introducing a groove in between the internal and external surfaces. As a result, the weight of the gear has been reduced from 50kg to 35 kg. The gear blank was cast in NNS shape from SG iron melt having Mn level less than 0.30%.

Manufacturing process of the gear consists of following steps :

Drawing – Solid model – Computerised Methoding – Pattern making - Moulding – Melting and Casting of blank – Pre-machining – Austempering Treatment – Dimensional Inspection – Final Machining – Assembly – Testing. Each stage of the above process plays important role to reach the final objectives.

The challenges of development of this gear are :

- To produce defect-free and smooth surface on 94 gear teeth (surface area 4700sq cm)
- To maintain the hardness within the drawing limit after austemepering treatment
- Developed material should be easy machinable with HHS tools.
- To restrict the distortion within a narrow limit.

With the help of computerised methoding the mould cavity including the runner and riser were prepared. Finally, it was possible to produce the SG iron cast blanks without any detectable defects. The pre-machined cast blanks were inspected by ultrasonic method and no defects were noticed. Figure 16 shows the cleaned surface of pre-machined blank. Subsequently, the helical gear teeth were formed by hobbing process which was carried out by M/s McNally Bharat, Kumardubi. The gear was austemperd with special care to achieve the hardness 265 –290 Bhn with minimum distortion. CMM measurement of the gear (Fig. 17), before and after the austempering treatment, revealed that the diametrical growth (OD) of the gear at different planes were less than 0.4% (average) and ovality was 0.5mm (average).

Fig. 16 : Premachined SG Iron Gear Blank Showing Cleaned Machined Surface.

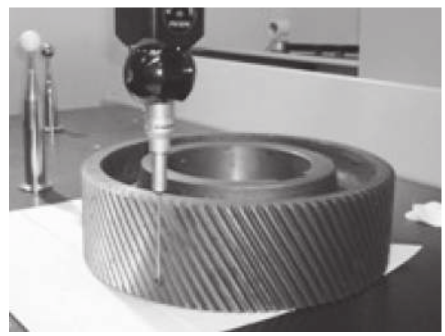

Fig. 17 : CMM Measurement of the Spur Gear Showing the Profile of Helical Teeth.

Then the ADI gear has been supplied to McNally Bharat, Kumardubi for finishing operation, assembly and field trial. During the development of this ADI gear, extensive R&D work was carried out on machining of ADI material with HSS tools.

Conclusion

It has been observed that ADI material can be easily developed with the help of indigenous resources and the developed material can satisfy the acceptance criteria of international specifications (EN/ASTM) including fracture toughness properties, applicable for ADI material.

The critical factors of the ADI process technology are as follows:

- Identification of correct grade of raw material to maintain consistent chemical composition
- Designing of in-gate system to ensure non-turbulent flow of liquid metal inside the mould cavities
- Optimisation of riser geometry and its position to make defect-free casting

- Optimisation of tapping and pouring temperature of the melt
- Appropriate melt treatment technique to ensure high nodule count (above 100) and nodularity above 85% in SG iron castings
- Optimisation of the Austempering parameters for the particular alloy composition, viz
  - i) Austenising temperature and soaking time
  - ii) Austempering temperature and time
  - iii) Contolling of salt bath temperature within the narrow limits
  - iv) Faster rate of cooling of the components to prevent pearlite formation

The following conclusions can be drawn from the above field trials:

- Presence of ausferrite matrix increases toughness which allows the hammer to absorb the impact energy during crushing. Presence of fine complex carbide within ausferrite matrix increases hardness as well as wear resistance properties
- Based upon the output of field trials, it can be concluded that wear resistant ADI and carbidic ADI hammers can improve the output of the crushing machine in the tune of 1.5 to 2 times than the machine fitted with conventional steel hammers. However, few more field trials and laboratory experiments are required to establish the other parameters essential for production technology.

This development programme has demonstrated that austempered ductile iron is a suitable contender for manufacturing of hammers for mining applications. It has been observed that with good control of process parameters of casting and austempering, it is possible to produce the ADI components for mining application with indigenous resources. As far as manufacturing of ADI gear is concerned, it is preferable to complete the major machining operation in SG state and minimum material to be removed after austempering treatment. Consistency of composition and hardness of the ADI products are important factors to be considered for getting good result during machining.

Acknowledgement

The authors acknowledge with thanks to the technical support provided by members of Foundry Group and NDT & Metallurgy Group of CMERI for their whole-hearted technical support to successfully complete this research work. The authors also acknowledge the active support provided by M/s McNally Bharat Engg. Co. Ltd, Kumardubi for carrying out the field trial of the developed components and sponsoring the research work. The authors would like to acknowledge thank to Director, CMERI for support and encouragement to carry out this research work.

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