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Influence of Nickel on Abrasion and Erosion Wear Behavior of Thin and Thick Section Permanent Molded Austempered Ductile Iron for Wind Turbine Hubs

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The influence of 2.0% nickel on thin and section permanent molded austempered ductile iron samples were investigated for abrasion and erosion behavior. The section sizes of samples were varied at two levels viz. 25 mm and 50 mm. Wind turbine hubs which were subjected to wear and erosion were made from thin and thick section PMADI castings. The austempering temperature and time were optimized for improved wear behavior and strength at 300^0 C for 60 mins. Nickel additions showed about 7% improvement in the wear resistance of thin section PMADI samples over unalloyed PMADI samples. For the purpose of comparison, sand-cast austempered ductile iron was also evaluated for abrasion, erosion resistance. Thin section (25 mm) PMADI samples subjected to austempering at 300^0 C for 60 mins showed improved abrasion and erosion behavior in addition to higher strength values over thick section (50 mm) PMADI and sand cast ADI samples. Further these data were analyzed with structure property correlation and were well supported by light photomicrographs.

Keywords: *PMADI, Thin/thick section, Abrasion\erosion and Wind turbine hubs.*

1.0 INTRODUCTION

Austempered ductile iron (ADI) is being used increasingly in engineering applications in recent years because higher strength and wear resistances are achievable in these casting without sacrificing toughness and ductility [1, 2]. ADI has found wide applications in the power and mining industries. Several components like turbine blades, Hubs and frames of wind turbines are made of Ductile iron [3]. Components used in coal handling equipments such as chutes and liners in power plant components are made of ADI [4]. While sand molded castings are generally employed to produce ADI, the application of permanent mould process offers several distinct advantages in respect of environmental cleanliness, higher production rate, better surface finish, improved dimensional stability and better mechanical properties. Seetharamu et al. [5] have reported that improved wear resistances are achieved by pouring ductile iron into permanent molds. The wear properties of ADI are dependent on the microstructural changes in the samples. These changes in the structure are influenced by alloying additions, cooling rate and heat treatment variables While sand molded castings are generally employed to produce ADI, the application of permanent mould process offers several distinct advantages in respect of environmental cleanliness, higher production rate, better surface finish, dimensional stability and better mechanical properties. Murthy et al. [6] have reported improved wear and mechanical properties of permanent moulded ADI with Mn as an alloying element.

The information on the effect of section size on abrasion and erosion wear behavior of PMADI is scanty. Since PMADI finds useful applications in thermal power plants, an attempt has been made to study the influence of section thickness

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on abrasion and erosion w.r.t microstructure of PMADI samples.

2.0 EXPERIMENTAL SETUP AND PROCEDURE

The ductile iron samples were prepared using mild steel scrap and low sulfur pig iron in a 15 kg capacity induction furnace. Nickel addition were made to the melt and castings were poured into thin and thick section permanent molds after spherodizing treatment using Ni-mg. Post inoculation was carried out using Ferro-silicon (inoculation grade) and stirred well prior to pouring. The liquid metal was then poured into the permanent gray iron and sand molds having casting dimensions 150 × 125 × 25 mm and 150 × 125 × 50 mm. Table 1 shows the composition of castings poured.

TABLE 1

NOMINAL COMPOSITION (% Wt.) OF PERMANENT MOLDED AND SAND-CAST DUCTILE IRON SAMPLES

Casting designation	C	SI	Ni	S	Mg
Thin section PMADI	3.2	2.8	0.5	0.03	0.04
Thick section PMADI	3.3	2.7	0.5	0.03	0.04
Sand cast ADI	3.6	2.4	–	0.03	0.05

2.1 Austempering heat treatment

The test samples were given an austenitization soak at 9500° C for 2 h followed by austempering in a salt bath held at 3000° C. The austempering time in the salt bath was fixed at 60 min. The austempered samples were then air-cooled followed by removal of decarburized layers.

2.2 Jet Erosion Test

Erosion tests were conducted as per ASTM G65 standards. The detailed procedure for conducting jet erosion test has been discussed elsewhere [5].

2.3 Rubber Wheel Abrasion Test

Dry sand rubber wheel abrasion tests were conducted as per ASTM-G65 standard [5].

2.4 Tensile Test

The tensile tests were conducted as per ASTM E 8M standards. The test sample was tested in a universal testing machine of 40 MT capacity. The ultimate tensile strength and % elongation of the specimen were determined and reported.

3.0 RESULTS & DISCUSSIONS

3.1 Jet erosion test

The erosion tests were conducted on thin and thick section PMADI and sand cast ADI test samples subjected to austempering treatment for 30 min and 60 min at all impact angles. The erosion data of thin section PMADI, thick section PMADI and sand cast ADI samples austempered for 60 min revealed higher erosion resistance compared to the very same samples austempered for 30 min. Thus the austempering process was optimized for 60 min and further evaluations were carried out for 60 min austempering time only.

Figure 1 shows the erosion volume loss (cc/kg), of thin section PMADI, thick section PMADI and sand cast ADI with impact angle. The following observations are made.

- The erosion resistance is higher at shallow impact angle (i.e. 15^0) but decreases as the impact angle is increased (upto 45^0). At normal impact angles, however, higher erosion resistance is observed.
- The wind turbine hubs made of thin section PMADI samples have superior erosion resistance than thick section PMADI samples.
- There is a marginal increase in erosion resistance of thin section PMADI samples compared to thick section PMADI samples.

- Thin section PMADI samples austempered for 60 min shows upto 10% improvement over thick section PMADI samples austempered for 60 min.

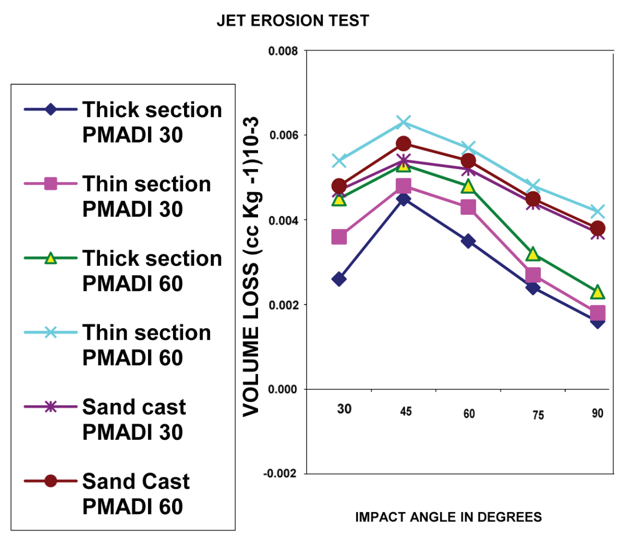

FIG. 1 EROSION VOLUME LOSS OF PMADI SAMPLES.

3.2 Dry sand rubber wheel abrasion test

Table 2 shows the abrasion volume loss (cc/kg) of thin section PMADI, thick section PMADI and sand cast ADI. The following are salient observations.

- The Thin section wind turbine hubs made of PMADI castings showed higher abrasion resistance than thick section PMADI and sand-cast ADI samples.
- Thin section PMADI showed upto 18% improvement over thick section PMADI and upto 26% improvement over sand-cast ADI in abrasion resistance.

TABLE 2

ABRASION VOLUME LOSS OF PMADI CASTINGS AUSTEMPERED AT 300^{0}C FOR 60 MIN.

Casting designation	Abrasion volume loss in cc/kg × 10^{-3}
Thin section PMADI samples	9.26
Thick section PMADI samples	9.87
Sand cast ADI samples	11.5

3.3 Strength and % elongation

Table 3 shows the tensile strength and % elongation values of the samples. The following observations are drawn.

- Thin section PMADI samples showed higher strength and % elongation compared to thick section PMADI and sand-cast ADI samples.

TABLE 3

UTS AND % ELONGATION OF THIN SECTION AND THICK SECTION PMADI SAMPLES

Casting designation	UTS N/ mm^2	% Elongation
Thin section PMADI	1326	7.5
Thick section PMADI	1270	5.6
Sand cast ADI	1220	6.0

3.4 Micro-structural analysis

Figures 2 and 3 show the as cast microstructure of Thin section and Thick section and ductile iron samples. The as cast microstructure observed under the microscope shows that the graphite nodules are surrounded by ferrite (white areas), pearlite (dark regions) and, carbides seen at the inter nodular regions. Also, it is noticed that the graphite size was coarser for thick section castings. Table 3 shows the graphite nodule count and graphite nodule size (ave) of all the test samples. Sand-cast ductile iron shows coarser particles and lower nodule count.

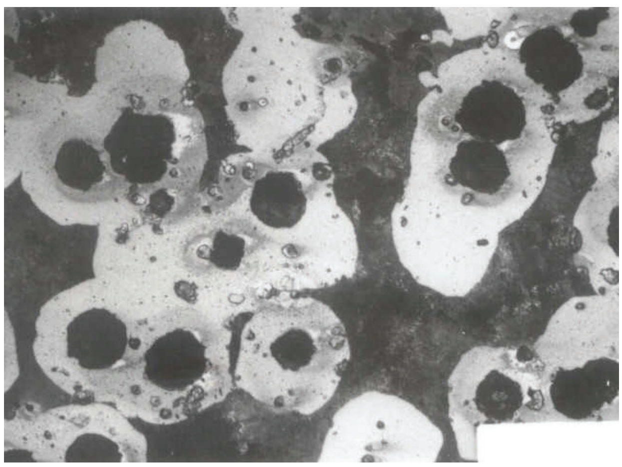

FIG. 2 THIN SECTION AS CAST PMADI SAMPLES 200X.

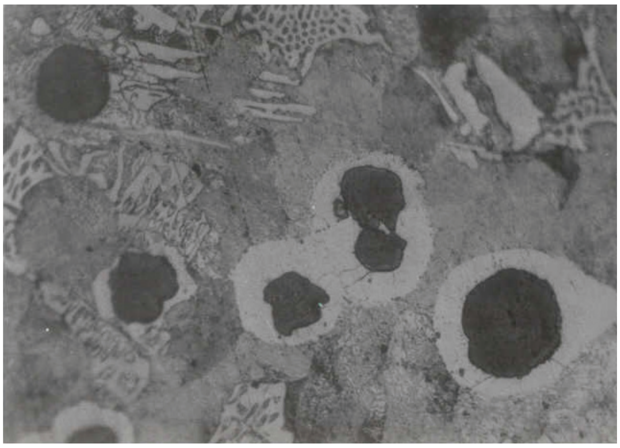

FIG. 3 THICK SECTION PMADI AS CAST 200X.

Figures 4–6 show representative photomicrographs in respect of the samples mentioned above after austempering heat treatment. The matrix microstructure reveals bainitic ferrite (acicular) and retained austenite (non-transformed white regions). Occasional small carbide particles are seen in thick section PMADI samples. The retained austenite was increased from 32–38% with the increase in section thickness from 25–50 mm.

FIG. 4 THIN SECTION PMADI 60 MIN 200X.

It is noticed that thin section PMADI samples shows improvement in abrasion and erosion resistance and strength compared to thick section PMADI and sand cast ADI samples. The erosion resistance of PMADI as judged by jet erosion test results, exhibits marginal variations with section size. A similar trend is seen at all impact angles (Figure 1). The variation in nodule count and size, as well as the retained austenite content in the matrix appears to have influenced the erosion resistance. Thus in summary, it is stated that wind turbine hubs made from thin section PMADI samples subjected to 60 min austempering treatment shows the best results in respect of micro structural features erosion/abrasion resistance, strength and hardness compared to thick section PMADI and sand cast ADI samples.

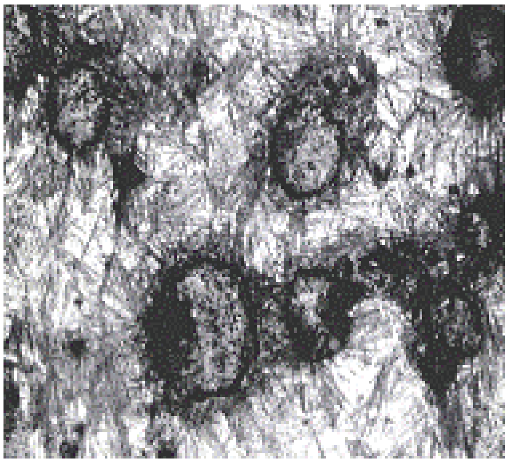

FIG. 5 THICK SECTION PMADI 60 MIN 200X.

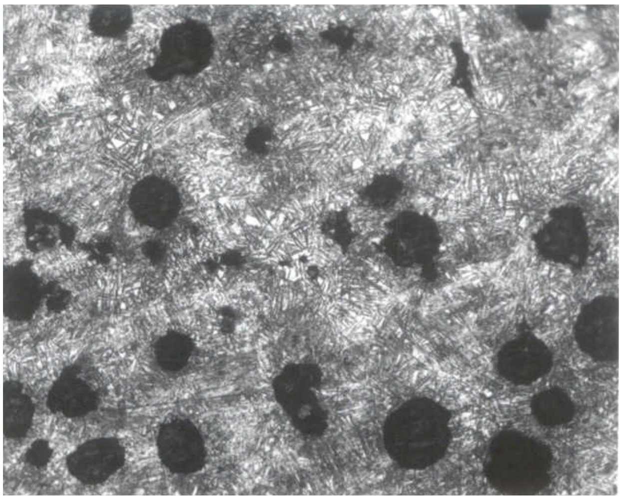

FIG. 6 SAND CAST ADI 60 MIN 200X.

4.0 CONCLUSIONS

- Nickel additions showed about 7% improvement in the wear resistance of thin section PMADI samples over unalloyed

PMADI samples PMADI samples austempered for 60 min show optimum properties in erosion resistance compared to 30 min of austempering.

- Thin section PMADI samples were reported to possess superior abrasion and erosion properties which could provide additional advantages in the manufacture of wind turbine hubs for power plant applications.
- The thin section casting is found to be beneficial from the point of improving the strength and contributing to better wear characteristics compared to thick section PMADI as well as sand cast ADI samples. The reason is attributed to the finer bainitic structure with higher nodule size and count as seen from the optical microphotographs.
- Thin section PMADI samples show up to 12% improvement over thick section PMADI and upto about 28% improvement over sand cast ADI in erosion resistance.

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REFERENCES

[1] Shepperson S and Allen C. "The abrasive wear behavior of austempered spheroidal cast irons", *Wear*, Vol. 121, pp. 271–287, 1988.

[2] Rundman K B. "Austempered ductile iron: Striving for continuous improvement, *World conference on austempered ductile iron, Bloomingdale, IL,* pp. 1–21, 1991.

[3] Bontorabi S M A, Young I M and Kondic V. "Structure and impact properties of spheroidal graphite unalloyed aluminium cast iron", *World Conf. on ADI, Bloomingdale, IL,* pp. 516–548, March 1991.

[4] Vuorinen J. "Strain hardening mechanism and characteristics of austempered ductile iron", *2nd International Conference on ADI, University of Michigan, Ann Arbor, MI,* pp. 179–186, 1986.

[5] Seetharamu S, Sampathkumaran P, Kumar R K, Narasimha Murthy K, Martin Jebaraj P. "Abrasion and Erosion resistance of permanent molded austempered ductile Iron", *Wear*, Vol. 163, pp. 1–8, 1993.

[6] Narasimha Murthy K, Sampathkumaran and Seetharamu S. "Abrasion and erosion behavior of manganese alloyed permanent moulded austempered ductile iron", Wear 267, pp. 1393–1398, 2009.