TENSILE STRENGTH AND MECHANCAL PROPERTIES EVALUATION OF PERMANENT MOULD DUCTLE IRON SUBJECTED TO NOVEL TWO STEP AUSTEMPERING PROCESS

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ABSTRACT

Austempered ductile iron (ADI) has attracted researchers and manufacturers alike mainly because of its excellent strength and wear properties and also at the same time cheaper to process and produce. With the addition of Mn hardenablity can be improved and it is also reported in the literature that wide range of mechanical properties can be obtained in ADI with varied Mn levels.

In this investigation, ductile iron castings were prepared in permanent moulds and are processed by a novel two-step austempering process. Three batches of samples were prepared. One batch consisted of 0.6%Mn and second batch consisted of 0.8%Mn and third batch with unalloyed DI samples. All the specimens were initially austenitized at 950°C for 2 h .and then the samples were processed by novel two-step austempering process. Test samples were initially quenched for about 5 min. in a salt bath maintained at 250°C. The salt bath temperature was raised to 280°C at a heating rate of 20°C-25°C per hour. Similarly, samples were quenched in the salt bath maintained at temperatures 300°C, 350°C, 400°C and 450°C. The effect of this two-step austempering heat treatment on the microstructure and tensile properties of the samples were examined and compared with the alloyed (0.6% and 0.8%Mn) unalloyed PMADI samples. The results show that this novel process has resulted in moderate improvement in the ultimate tensile strength and substantial improvement in the ductility. The results are analyzed based on the micro structural features.

Key words: **PMADI, Two-step austempering process, Strength, Elongation.**

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1.0 Introduction

Austempered ductile iron (ADI) has attracted researchers and practicing engineers because of its good ductility, high strength, excellent wear resistance and high fracture and fatigue strength [1]. Major applications of ADI include automotive sector, mining, power plants, military and agricultural industries. ADI is conventionally cast in sand moulds. Utilization of permanent moulds for producing ADI have advantages such as fine graphite nodules, improved surface finish, less environmental pollution and better dimensional stability. Seetharamu et al [2] have reported that the permanent moulded austempered ductile iron (PMADI) castings have been found to possess better abrasion and erosion resistance compared to the sand moulded components.

The presence of appreciable amounts of retained austenite in ADI leads to better wear resistance and fatigue strength, due to high work hardening nature of the austenite [3]. Several researchers have studied the effect of alloying additions on the mechanical properties of ADI [4]. It has been reported that ADI possesses higher yield and tensile strength when austempered at lower temperature [5]

ADI has a matrix which consists of a combination of acicular ferrite and stabilized austenite [6]. This structure results in an exceptional combination of strength and ductility [7-8]. Structure and properties of ADI depend on composition and heat treatment parameters. There is a lot scope for researchers to study the effect of variation in heat treatment parameters and resulting changes in the microstructure.

Conventional austempering process consists of austenitizing the castings in the temperature range of 871°C – 982°C for sufficient time to get a fully austenite (γ) matrix and then quenching to an intermediate temperature range of 260°C- 400°C. Mechanical properties of ADI depend on the Bainitic matrix which consists of ferrite and higher volume of retained austenite.

Susil K. Putatunda et al [9] have developed ADI by a novel two step austempering process. They have reported that there is a significant improvement in mechanical properties and fracture toughness of the material as result of the two-step austempering process. Jianghuai Yang and Susil K Putatunda [10] have carried out investigations to examine the influence of novel two step austempering process on yield strength and tensile strength and fracture toughness. The results have indicated significant improvement in yield and tensile strengths and fracture toughness of the material over the conventional single step austempering process. Ravishankar et.al [11] have developed ADI for high tensile strength and fracture toughness by two step austempering process and they reported that it was possible to achieve an exellent combimation of high fracture toughness and high tensile toughness by adopting novel two step austempering process. Ayman et al [12] have studied fracture toughness as well as other mechanical properties of austempered ductile iron produced using both conventional and two-step austempering processes. There has been improvement in fracture toughness of the material, while maintaining the reasonable levels of strength.

It has been found that the Mn delays the Bainitic transformation due to Martensite formation as a result of Mn precipitation at the grain boundaries. After prolonged austempering this grain boundary Martensite disappears. The precipitation zone resists the Bainitic transformation and non-transformed grain boundary Austenite is reserved. All these effects of Mn are reflected in mechanical properties. [13]

With the addition of Mn hardenablity can be improved and it is also reported in the literature that wide range of mechanical properties can be obtained in ADI with varied Mn levels. Since mechanical properties of ADI can be enhanced by casting in permananent moulds and also by utilizing two-step austempering process an attempt has been made to study mechanical properties of PMADI developed using two step austempering processes.

2.0 Experimental setup and procedure

2.1 Melting and casting

The ductile iron castings were made using a laboratory induction furnace of 15kg capacity. The charge materials used were clean mild steel scrap, petroleum coke and Ferro-silicon alloy. The melt was super heated to 1500°C and treated with ferro-silicon magnesium alloy and post inoculated using Ferro-silicon (inoculation grade) and stirred well prior to pouring. The melt was poured at 1400°C-1425°C into a pre-heated (200°C) gray cast iron mould. The gray cast iron permanent moulds employed in this work are as shown in Fig.1. The chemical composition of the castings poured is shown in table-1.

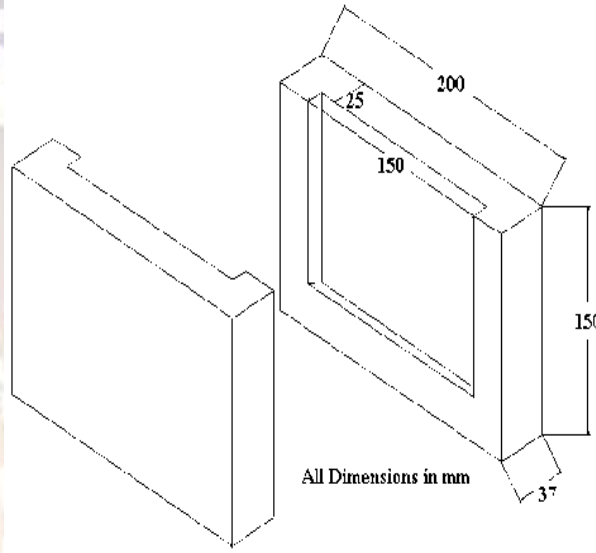

Fig.1 Cast Iron Metal Mould

Table 1: Chemical Composition

Chemical element	Composition of Batch 1	Composition of Batch 2	Composition of Unalloyed sample
Carbon	2.665	2.73	3.3
Silicon	2.879	2.948	2.2
Manganese	0.6	0.8	0.2
phosphorus	0.014	0.014	0.02
chromium	0.112	0.112	0.04
Magnesium	0.035	0.035	0.04

2.1 Austempering heat treatment

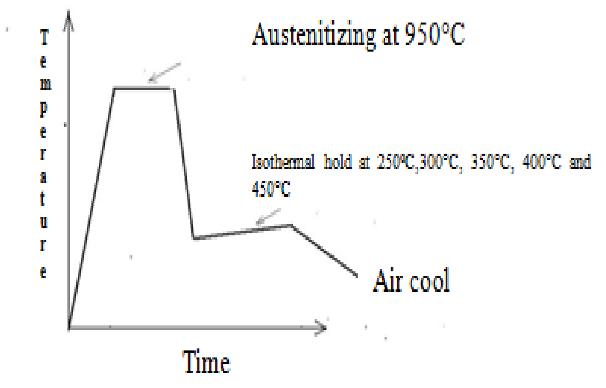

Fig. 2: Two-step Austempering heat treatment cycle

In this investigation, ductile iron castings were prepared in permanent moulds and are processed by a novel two step austempering process. Three batches of samples were prepared. One batch consisted of 0.6%Mn and second batch consisted of 0.8%Mn and third batch with unalloyed DI samples. These samples were initially quenched for about 5 min. in a salt bath maintained at 250°C. The salt bath temperature was raised to 270°C at a heating rate of 20°C-25°C per hour. Similarly, samples were quenched in the salt bath maintained at temperatures 300°C, 350°C, 400°C and 450°C for 60min, 90min, and 120min. A schematic diagram of two step austempering treatment is as shown in Fig.2

2.2 Tensile strength test :

The tensile strength of PMADI samples viz. ultimate tensile strength, yield strength and ductility were evaluated using a on universal testing machine. The tests were carried out as per ASTM standard E8M specifications. The machined tensile test samples was held with suitable grips between the cross yoke and the actuator of the machine. Gauge length on the sample was marked. Uniaxial load at a uniform rate was applied the test sample through the actuator until it failed. The variation of applied load vs. the displacement was recorded. The tensile strength, yield strength and percentage of elongation were determined.a schematic diagram of tensile test specimen is as shown in the fig 3.

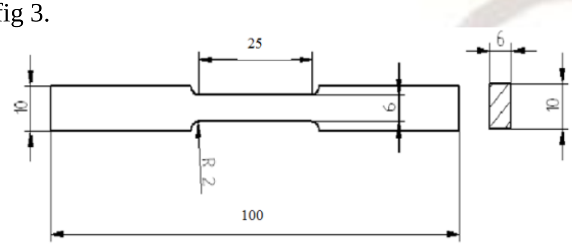

Fig.3: Tensile test specimen

2.3 Microstructure Analysis

The microstructural features of the samples were investigated using an optical microscope. The polished specimens have been etched using 10% Nital (10% Nitric acid with 90% ethanol). The properly etched specimens are observed under optical microscope.

3.0 Results and discussion

3.1 Microstructure

Fig 4 shows the representative photographs of permanent moulded ductile iron samples alloyed with 0.6 and 0.8%Mn. Unalloyed ductile iron samples show very fine graphite nodule with ferrite matrix when compared to alloyed ductile iron samples. Microstructure photographs show good nodule count and size and may be accountable for higher ductility in the alloyed PMADI samples.

3.2 Tensile test

Tensile strength, yield strength and percentage elongation results obtained for alloyed and unalloyed PMADI samples are shown in the table 2, table 3, table 4 and table 5. It is evident from the data presented that the tensile value has decreased when compared to unalloyed PMADI subjected two step austempering heat treatment. The undissolved iron carbide precipitates in the matrix of the alloyed PMADI samples accounts for lower strength.

It is observed from the study that there is an improvement in ductility by 10 to 15% for the alloyed samples, when compared to ununalloyed PMADI samples subjected two step austempering heat treatment. It is observed from the microstructure that probably small addition of Mn has favored pro-bainitic constituent in the matrix. Narasimha Murthy et.al [14] has reported that 3%Mn PMADI samples reveals higher strain and has increased deformation behavior compared to 2% Mn PMADI samples. We also observe the same trend in our study.

The work may be summarized that the alloyed samples showed better ductility with slight decrease in the strength of PMADI samples.

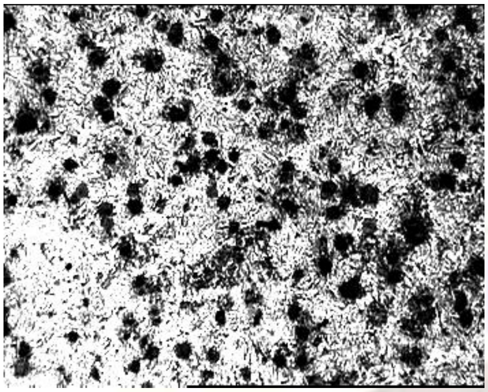

Fig 4-1 (100X-Nital etched): Micro-Structure for 0.8 % Mn Sample Maintained at Temperature: 300°Cfor 120 min.

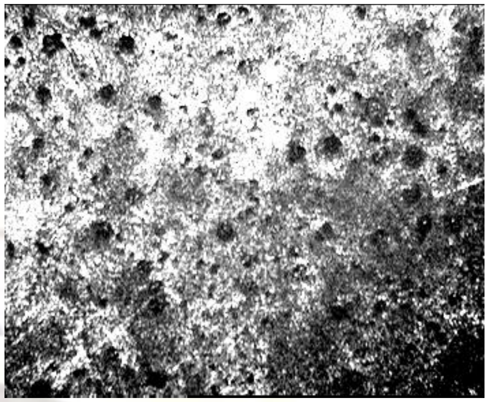

Fig 4-2 (100X-Nital etched): Micro-Structure for 0.6 % Mn Sample Maintained at Temperature: 300°Cfor 120 min.

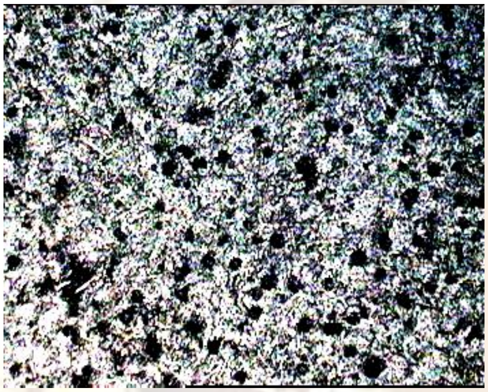

Fig 4-3 (100X-Nital etched): Micro-Structure for 0.8 % Mn Sample Maintained at Temperature: 350°Cfor 120 min.

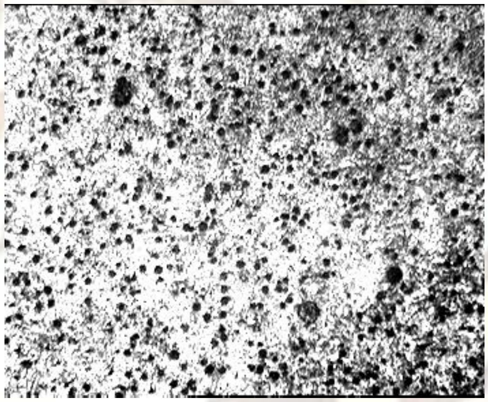

Fig 4-4 (100X-Nital etched): Micro-Structure for 0.6 % Mn Sample Maintained at Temperature: 350°Cfor 120 min.

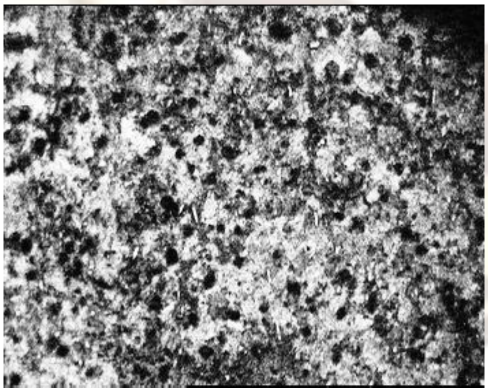

Fig 4-5 (100X-Nital etched): Micro-Structure for 0.8 % Mn Sample Maintained at Temperature: 400°Cfor 120 min.

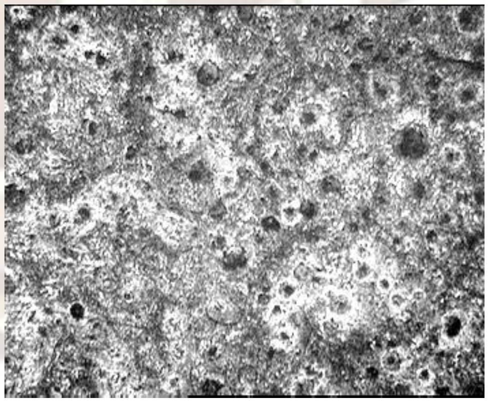

Fig 4-6 (100X-Nital etched): Micro-Structure for 0.6 % Mn Sample Maintained at Temperature: 400°Cfor 120 min.

Table 2: variation of UTS for the various austempering temperatures and times

Austempering temperature	UTS of 0.6% Mn (N/mm^2) with austempering Time(min)			UTS of 0.8% Mn (N/mm^2) with austempering Time(min)		
	60	90	120	60	90	120
250°C	1232	1235	1289	1179	1119	1189
300°C	1307	1311	1311	1265	1291	1297
350°C	1194	1286	1306	1131	1247	1222
400°C	1174	1239	1244	1118	1215	1217
450°C	1156	1200	1141	1115	1181	1102

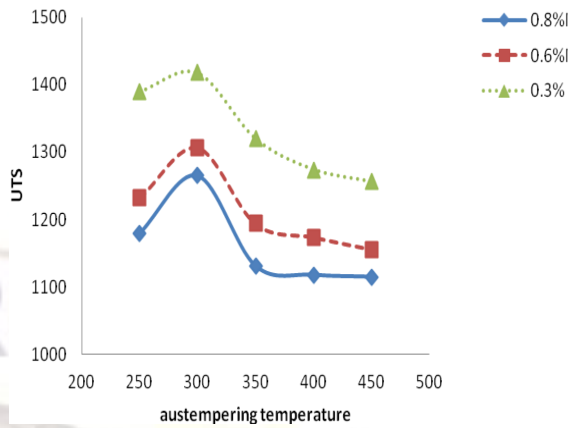

Fig 5-1: Effect of austempering temperature on tensile strength soaked for 60 min.

Table 2: variation of yield strength for the various austempering temperatures and times

Austempering temperature	YS of 0.6% Mn (N/mm^2) with austempering Time(min)			YS of 0.8% Mn (N/mm^2) with austempering Time(min)		
	60	90	120	60	90	120
250°C	436	414	414	414	414	404
300°C	415	407	408	419	408	407
350°C	404	406	403	400	397	400
400°C	429	406	408	399	415	408
450°C	396	399	412	410	399	430

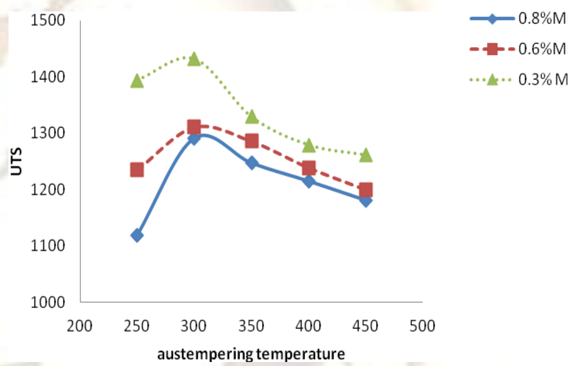

Fig 5-2: Effect of austempering temperature on tensile strength soaked for 90 min.

Table 3: variation of % elongation for the various austempering temperatures and times

Austempering temperature	% elongation of 0.6% Mn with austempering Time(min)			% elongation of 0.8% Mn with austempering Time(min)		
	60	90	120	60	90	120
250°C	8.82	8.68	8.96	7.68	7.82	7.2
300°C	8.85	8.95	9.13	7.95	7.85	7.62
350°C	9.93	10.12	10.07	9.12	8.93	8.14
400°C	11.54	10.56	12.49	9.56	10.54	8.63
450°C	11.6	11.6	13.4	10.	10.6	12.

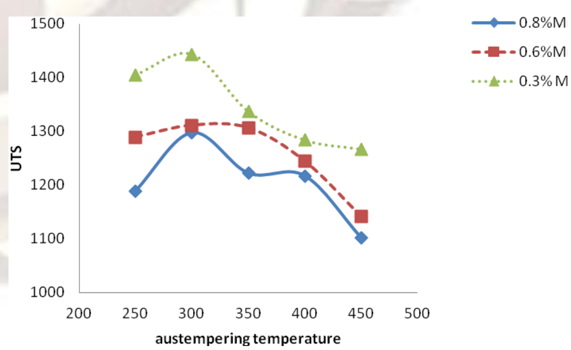

Fig 5-3: Effect of austempering temperature on tensile strength soaked for 120 min

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Table 4: variation of UTS and % elongation of 0.3% Mn for the various austempering temperatures and times

Austempering temperature	UTS of 0.3% Mn with austempering Time(min)			% elongation of 0.3% Mn with austempering Time(min)		
	60	90	120	60	90	120
250°C	1390	1394	1405	1.5	1.7	2.1
300°C	1418	1432	1443	2.3	2.5	3.1
350°C	1320	1329	1337	5.6	5.9	6.2
400°C	1274	1279	1284	8.8	9.1	9.3
450°C	1256	1261	1267	10.7	10.1	10.7

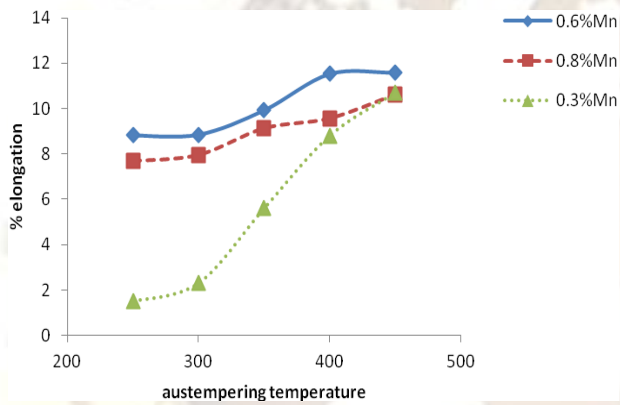

Fig 6-1: Effect of austempering temperature on % elongation soaked for 60 min.

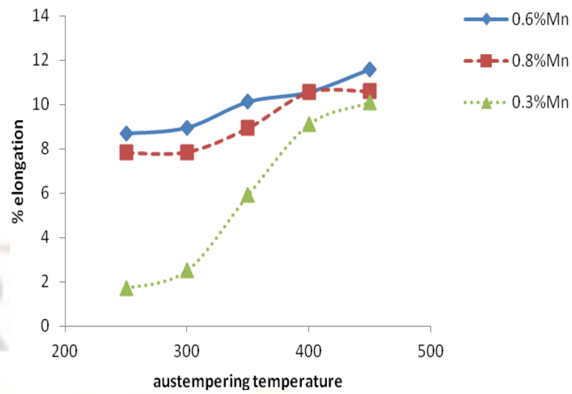

Fig 6-2: Effect of austempering temperature on % elongation soaked for 90 min.

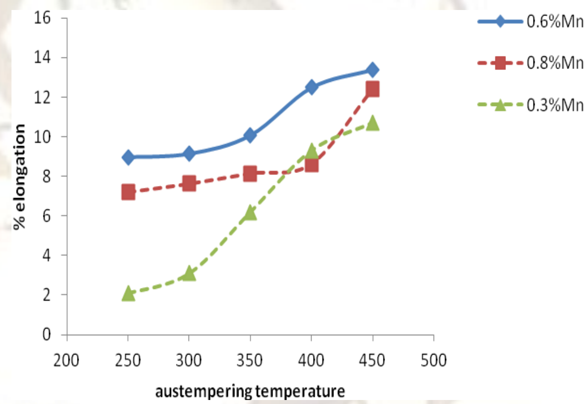

Fig 6-3: Effect of austempering temperature on % elongation soaked for 120 min.

4.0 Conclusions:

Based on results of the study, the following conclusions can be made:

a. The tensile strength of alloyed PMADI samples subjected to novel two-step heat treatment is decreased by 3 to 6 %, when compared to tensile strength of unalloyed ADI.

b. It is found from the study that the ductility of alloyed PMADI is increased by 10 to 15% when compared to the ductility of unalloyed PMADI samples subjected to two step austempering heat treatment.

c. It was also found that the tensile strength increased with increasing austempering time andhe ductility decreased with austempering time (60, 90 and120 min).

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d. The tensile strength of PMADI subjected to novel two-step heat treatment was maximum at 300°C (austempering temperature) and ductility was found maximum at 400⁰C.

e. Microstructure photographs show good nodule count and size and may be accountable for higher ductility in the alloyed PMADI samples.

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