RESEARCH ARTICLE

EFFECT OF AUSTEMPERING VARIABLES ON THE MECHANICAL PROPERTIES OF SPHEROIDAL GRAPHITE IRON

Susanta Kumar Swain* and Sudipta Sen

Department of Metallurgical & Materials Engineering, National Institute of Technology, Rourkela-769008, Odisha, India

ARTICLE INFO

ABSTRACT

Austempering variables such as time and temperature have been taken in to consideration for the present investigation with respect to tensile properties and characterization of graphite morphology. Two types of spheroidal graphite (SG) cast iron samples with different weight percentage of copper were austempered at four different temperatures. The austempering temperatures were 250°C, 300°C, 350°C and 400°C. The influence of austempering process on the mechanical properties of spheroidal graphite iron was investigated as a function of austempering time and temperature. The cooling rate and the quenching technique adopted play an important role for the property development of spheroidal graphite iron. The tensile properties have been correlated with the graphite morphology for both the grades of ADI. SEM micrographs have been taken from the fractured surface of the tensile specimens under different austempering conditions. It has been found from the result that ADI having the alloying element (Cu), achieved significant mechanical properties as compared to other grade (M1) throughout the different austempering process adopted in this study.

INTRODUCTION

Austempered ductile iron (ADI) is considered to be an important engineering material because of its attractive properties such as good ductility, high strength, good wear resistance and fatigue strength and fracture toughness. Because of these combinations of properties, ADI is now used extensively in many structural applications in automotive industry, defense and earth moving machineries (Yang and Putatunda, 2004). The optimum mechanical properties of ADI i.e. the adequate combination of strength, toughness, fatigue strength and wear resistance could be achieved if the microstructure consists of retained carbon-enriched stable austenite (enables ductility) together with one of two bainitic morphologies; namely carbide-free bainitic ferrite or bainitic ferrite, in which carbides are distributed in the ferrite (affects strength)(Eric *et al*., 2004). For many years, the ADI has been considered an alternative material, substitute for steels in several mechanical components, because it offers the possibility of obtaining a broad range of mechanical properties starting from a generic spheroidal graphite cast iron melt and applying specific heat treatments (Fierro *et al*., 2003). The austempering process was first developed by Davenport and Bain (Zimba *et al*., 2003) and applied to steels in the 1930s. The austempering process in ductile iron involves austenitising, quenching and isothermally transforming a specimen or component at a temperature in the bainitic region for an appropriate of time. Austenitisation and austempering are often conducted in molten salt baths to avoid surface

oxidation of the specimens or components after which they can either be air or water cooled (Hayrynen, 2002). The structure and mechanical properties of ADI depend strongly on the kinetics of phase transformation and mechanism that occurs during austempering (Desimono *et al*., 1999; Hughes, 1985). In the present investigation, efforts have been made to improve the mechanical properties and effect of processing parameters (austempering time and temperature) on the mechanical properties of ADI has been studied.

EXPERIMENTAL PROCEDURE

Melting & Casting: Two melts (M1and M2) of SG (spheroidal graphite) iron were produced using the tea pot tundish ladle method. For this study charges consists of 100 kg pig iron, 400 kg SG iron returns, 500 kg steel scraps, 35 kg coconut charcoal and 1.3 kg of 75% foundry grade ferrosilicon were melted in 1000 kg capacity of coreless induction furnace as per standard procedure and foundry practices. 2 kg of copper was added in the second melt (M2). Chemical composition of two melts was determined by spectrometer by taking sample from the furnace (as per standard procedure and foundry practices) and final adjustment was carried out in the furnace to get desired composition. The irons were treated in a preheated tea pot ladle containing 12 kg of 4.5% ferrosilicon magnesium and 2.5 kg of 75% foundry grade ferrosilicon (size 2-3 mm). Another 2.5 kg of ferrosilicon was added during tapping. Treament temperature was 1450-1460°C. Argon gas purging was carried out during treatment of the metal for proper mixing. At this time sample was taken for chemical analysis. The treated iron was poured into a dry sand mold

---

Corresponding author: mamuonline@gmail.com

bonded with furan resin and catalyst to cast Y block as per ASTM 897 specification. The iron was properly post inoculated by adding 1.5 kg of 75% foundry grade ferrosilicon (size 0.3-0.4mm) to the stream during pouring. Similar procedure was carried out for other melt and the final chemistry of two heats is given in table 1. For each melt, three molds were poured. The pouring temperature ranges for the first and last molds were 1380^oC-1388^oC and 1360^oC-1366^oC.

Table 1. Chemical composition of the melts (wt %)

| Melt	C	Si	Mn	S	P	Cr	Ni	Cu	Mg
M 1	3.62	2.21	0.16	0.009	0.022	0.02	0.05	0.04	0.039
M 2	3.64	2.23	0.17	0.011	0.024	0.02	0.05	0.48	0.041

Austempering Process

After 48 hours of pouring, the test blocks were cut and machined for preparing tensile test specimens as per EN1563 standard. In order to determine the austempering parameters of ADI, 12 nos. of SG iron specimens $(25 \times 25 \times 15 mm)$ of each melt were taken for carrying out austempering at four different temperatures (250^oC, 300^oC, 350^oC and 400^oC) for duration of 0.5 hour, 1 hour and 1.5 hour. Hardness values (R_A) of ADI samples and their respective parameters are shown in figure 1. Samples were heated to 900^0C for one hour (austenitising) and then transferred quickly to a salt bath (four numbers) containing (50 wt% $NaNO_3$ + 50 wt% KNO_3) maintained at four austempering temperatures as mentioned for 0.5 hour,1 hour and 1.5 hour. Similarly another 12 nos. of specimens of each melt were made for tensile test. These specimens were inspected through radiographic test and the defect free specimens were subjected to heat treatment. The ADI test specimens were finally machined to their respective dimension as per EN1563 standard. Tensile tests were carried out with servo hydraulic UTM machine having 1000KN capacity. Results of tensile tests are shown in figure 2 and figure 3 respectively.

RESULTS

### Effect of Austempering time on hardness

Figure 1 lists the hardness values of ADI specimens at different temperatures. Hardness values of the specimens from the melt M2 gets more increased as compared to the specimens from the melt M1 by 3 to 9 Rockwell hardness unit in A scale for different austempering conditions. This may be due to the large amount of pearlite present in the matrix of M 2 specimens. Hardness is increasing from half an hour to one our and then decreasing.
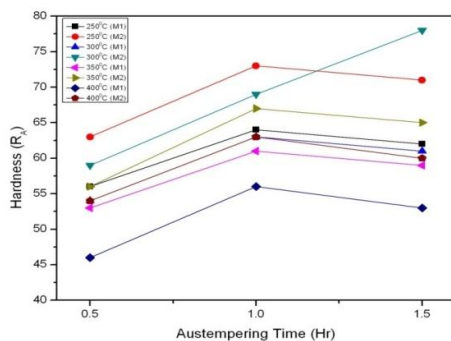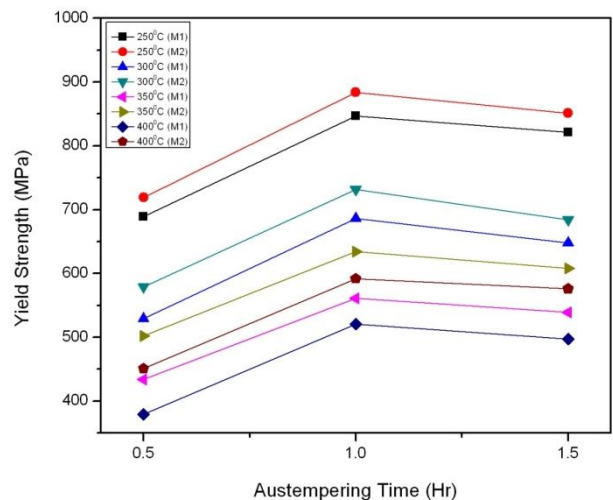

Fig. 1 Variation of Hardness with different austempering time of the melts M1 and M2 austempered at four austempering temperatures.

Effect of Austempering time on Tensile strength and yield strength

Figure 2 and figure 3 lists the tensile strength values of ADI specimens at different austempering temperatures. From the results, it is observed that both tensile strength and yield strength is increasing from 0.5 hour austempering time to one hour and decreasing from one hour to 1.5 hour. ADI of M 2 showing higher tensile strength as compared to ADI of M 1.
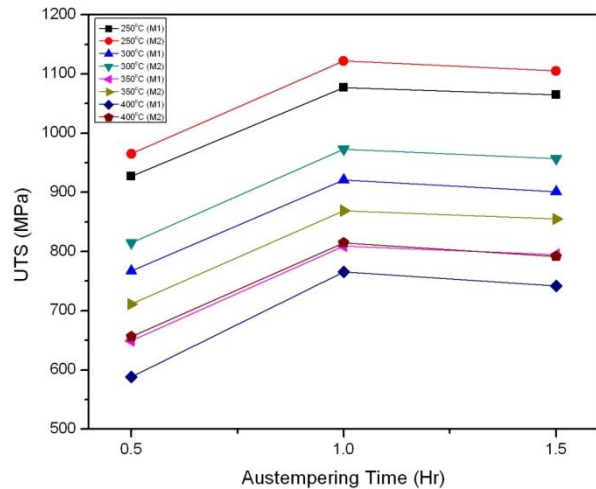
Fig. 2 Variation of Tensile Strength with different austempering time of the melts M1 and M2, austempered at four austempering temperatures.

Fig. 3 Variation of Yield Strength with different austempering time of the melts M1 and M2, austempered at four austempering temperatures.

Effect of Austempering time on Elongation

Figure 4 lists the elongation values of ADI specimens at four different austempering temperature and time for both grades (M1 and M2). Elongation is increasing from half an hour austempering time to one hour, form one hour to one half hour it is increasing for all austempering temperatures (250^0C, 300^0C and 350^0C) but decreasing at 400^0C. ADI specimens of M 2 are showing lower elongation than ADI specimens of melt M 1.
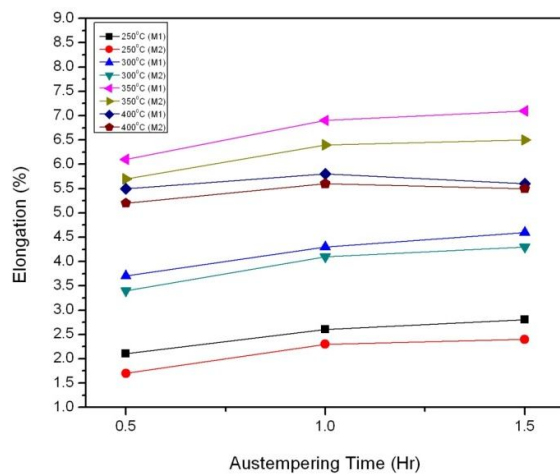
Fig. 4 Variation of Elongation with different austempering time of the melts M1 and M2, austempered at four austempering temperatures.

DISCUSSION

The hardness, tensile strength and yield strength of the specimens of M2 gets more increased as compared to the specimens of M1(Fig 1, 2 and 3) but the Cu decreases ductility in ADI (Fig 4) by some nominal value. For smaller austempering time, during the initial stage, stage I reaction proceeds and the amount of bainitic ferrite and high carbon austenite gradually increases. The bainitic transformation in the austempered ductile iron can be described as a two stage phase transformation reaction. The initial transformation is of primary austenite (γ) decomposing to ferrite (α) and high carbon-enriched stable austenite (γ_{HC}). This transformation is commonly known as the stage I reaction (Eric *et al*., 2004; Gazda, 2010); i.e. $\gamma \rightarrow \alpha + \gamma_{HC}$. But carbon enrichment in retained austenite is too less to make the entire retained austenite stable at room temperature and some transformation to martensite is involved. With the increase in austempering time, the amount of retained austenite and bainitic ferrite increases until completion of bainitic transformation resulting in increase in hardness, tensile strength and yield strength. After completion of bainitic transformation, if austempering is continued for still longer duration, stage II reaction (Eric *et al*., 2004; Gazda, 2010) sets in and retained austenite decomposes to bainitic ferrite and carbide; i.e. $\gamma_{HC} \rightarrow \alpha + $ carbide. Stage II reaction is undesirable since it causes the embrittlement of structures and degrades the mechanical properties. This results in decrease of hardness, tensile strength and yield strength after achieving a peak value (Eric *et al*., 2006). This may be formation of lower bainite and small volume fraction of austenite (Fig 5) which is present in the bainitic ferritic needles. Shallow dimples are observed and may be due to the presence of lower bainite and lower quantity of retained austenite in the microstructure. The low ductility for shorter austempering times (Fig 7 and 8) can be attributed to some brittle fracture taking place due to the presence of martensite in the microstructure (Jung *et al*., 2005, Batra *et al*., 2004). But with increasing austempering time, the amount of retained austenite increases resulting in increase of elongation (Fig 6). This reaches maximum at the completion of stage I reaction and with the onset of stage II reaction. The ductility decreases owing to the decrease in retained austenite. Moreover the amount of retained austenite at low temperature is less resulting in lesser elongation.
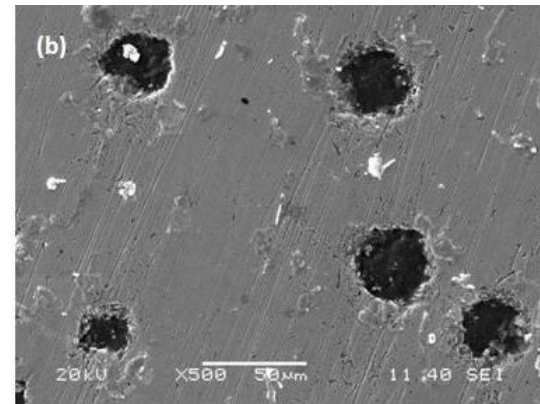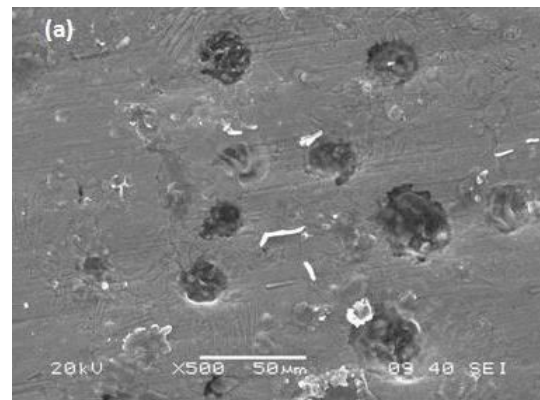

Fig. 5 SEM micrographs of the fractured surface under tensile condition austempered at 250^{0}C for 1 hr (a) melt M1 and (b) melt M2
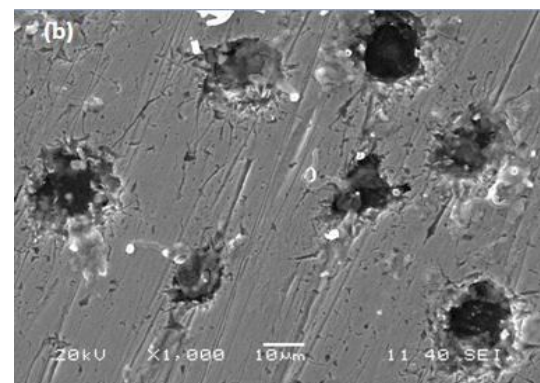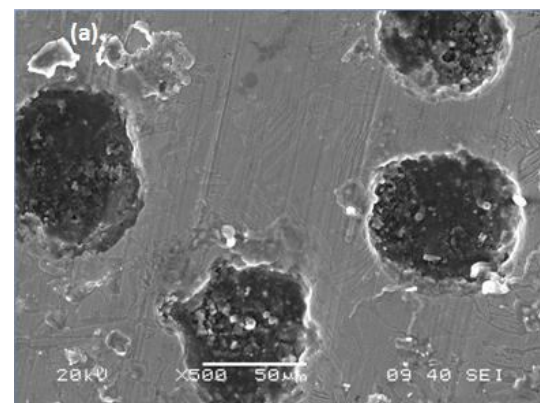

Fig. 6 SEM micrographs of the fractured surface under tensile condition austempered at 300^{0}C for 1 hr (a) melt M1 and (b) melt M2

With the increasing austempering temperature, the amount of retained austenite increases and the ductility decreases. But

after reaching some maximum elongation, at still higher austempering temperature the stage II reaction is more pronounced and proceeds at a faster rate than that at lower austempering temperature. Thus, this leads to some decrease in ductility. The hardness, tensile strength and yield strength of ADI specimen decreases with increase in temperature but the ductility initially increases with temperature and then after reaching a peak value it starts decreasing. At lower austempering time, the high strength and high hardness value can be attributed to the presence of acicular bainite, some martensite and retained austenite (Ali *et al.*, 2000; Hsu and Lin, 2011). The fine structure of the bainite plates and low amount of retained austenite results in high strength at low austempering temperature. At higher austempering temperatures (at 350^0C and 400^0C), it is observed that the dimples become deeper and more numerous. It may be due to the presence of upper bainite and large volume fraction of austenite (Fig 6, 7 and 8).Deep dimples and river like features in a few places are found and this may be attributed to martensite at the centre of the retained austenite (Shelton and Bonner, 2006; Putatunda, 2001).
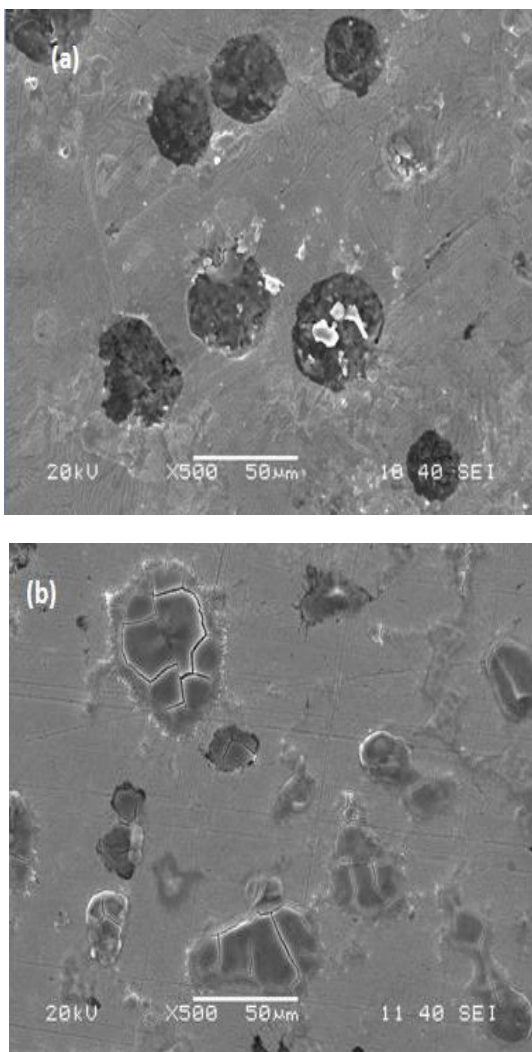

Fig. 7 SEM micrographs of the fractured surface under tensile condition austempered at 350^{0}C for 1 hr (a) melt M1 and (b) melt M2
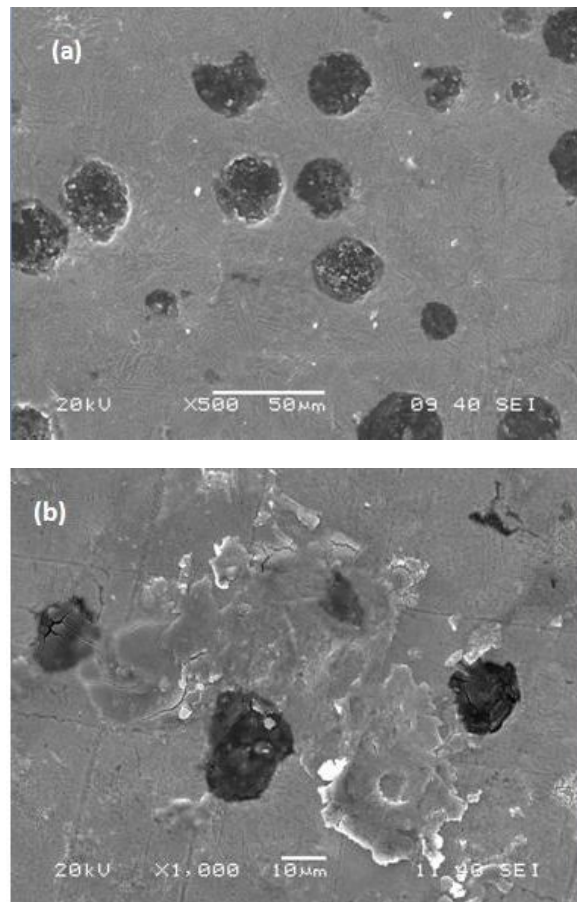

Fig. 8 SEM micrographs of the fractured surface under tensile condition austempered at 400^{0}C for 1 hr (a) melt M1 and (b) melt M2

Moreover, other factors such as dispersed carbides, high dislocation density and lattice distortion of the ferrite contribute to the mechanical properties. With the increase in austempering temperature, the amount of retained austenite increases and martensite disappears from the microstructure resulting in decrease in strength and hardness (Batra *et al.*, 2000, 2003). At higher austempering temperature, bainitic ferrite produced is coarser but in lesser volume, leading to decrease in strength.

Conclusions

The effect of alloying element (Cu) on the mechanical properties of SG iron austempered at four different temperatures with varying austempering time has been investigated in the present investigation. The following conclusions are made:

1. Alloying element (Cu) improves the mechanical properties of spheroidal graphite iron after austempering.The increasing is constant with austempering time but with increasing austempering temperature it initially increases and then gradually becomes constant.
2. The ductility of ADI also initially increases with austempering time up to a certain value and then it starts decreasing with further increase in time.Hardness,tensile strength and yield strength of ADI decreases continuously with austempering temperature.

3. The ductility of ADI initially increases with austempering temperature and then after reaching some maximum value at around 350°C, it starts decreasing with further rise in temperature.

REFERENCES

Ali M. Rashidi and Moshrefi-Torbati, M. 2000. Effect of tempering conditions on the mechanical properties of ductile cast iron with dual matrix structure (DMS). *Mat.Lett*.45 (3-4): 203-207.

Batra, U. Ray, S. and Prabhakar, S. R. 2003. Effect of austenitisation on austempering of copper alloyed ductile iron, *JMEPEG*, 12 (5): 597-601.

Batra, U. Ray, S. and Prabhakar, S.R. 2004. The influence of nickel and copper on austempering of ductile iron. *JMEPEG*,13 (1): 64-68.

Batra, U. Tandon, P. and Kaur. K. 2000. A study of austenitisation of SG iron, *Bull.Mat.Sci*.23(5): 393-398.

Desimoni, J. Gregorutti, R. Laneri, K. Sarutti, J.L. and Mercader, R.C.1999. Influence of the Mn Content on the Kinetics of Austempering Transformation in Compacted Graphite Cast Iron, *Meta. Mat. Trans.* A, 30(8): 2745-2752.

Eric, O. Jovanovic, M. Sidjanin, L. Rajnovic, D. and Zec, S. 2006. The Austempering study of alloyed ductile iron, *Mater. Des*. 27 (7): 617-622.

Eric, O. Sidjanin, L. Miskovic, Z. Zec, S. and Jovanovic. M.T.2004. Microstructure and toughness of Cu, Ni, Mo austempered ductile iron. *Mater. Lett.* 58 (22-23): 2707-2711.

Fierro, V.E. Sikora, J. A. Ansaldi, A.F. Ratto, P.J.J. Aguera, F.R. and Alvarez, H. N. 2003 Mechanical Behavior of spheriodal graphite cast iron in the temperature range between -100°C and +100°C, *Lat. Am. Appl. Res*. V.33 n.1 Bahia Blanca ene./mar. 2003.

Gazda, A. 2010. Analysis of decomposition process of ausferrite in copper-nickel austempered ductile iron, *J.Therm.Anal.Calorim.* 102(3): 923-930.

Hayrynen Kathy L., The Production of Austempered Ductile Iron (ADI), 2002 World Conference on ADI.

Hsu, C. and Lin, K. 2011. A study on microstructure and toughness of copper alloyed and austempered ductile irons. *Mat.Sci.Eng*.A528 (18): 5706-5712.

Hughes, I.C.H. 1985. Austempered ductile irons-their properties and significance. *Mat. & Desi*. 6 (3): 124-126.

Jung, S. Ishikawa, T. Sekizuka, S. and Nakae, H. 2005. Effects of sulphur on interfacial energy between Fe-C melt and graphite. *J.Mater.Sci*.40 (9-10): 2227-2231.

Putatunda, S. K. 2001. Development of austempered ductile cast iron (ADI) with simultaneous high yield strength and fracture toughness by a novel two-step austempering process. *Mater. Sci. Eng.*, A 315 (1-2): 70 – 80.

Shelton, P.W. and Bonner, A.A. 2006. The effect of copper additions to the mechanical properties of austempered ductile iron. *J.mat.proces.tech*.173 (3): 269-274.

Yang, J. and Putatunda, S. K. 2004. Improvement in strength and toughness of austempered ductile cast iron by a novel two- step austempering process. *Mater. Des*.25 (3): 219-230.

Zimba, J. Simbi, D.J. and Navara, E.2003. Austempered ductile iron: an alternative material for earth moving components. *Cement & Concrete Composites* 25 (6): 643–649.

****