Austempering and Austempered Ductile Iron Microstructure in Copper Alloyed Ductile Iron

Uma Batra, S. Ray, and S.R. Prabhakar

(Submitted 19 February 2003)

The variation in the austempered microstructure, the volume fraction of retained austenite, X_γ, the average carbon content of retained austenite, C_γ, their product $X_\gamma C_\gamma$ and the size of bainitic ferrite needles with austempering temperature for 0.6% Cu alloyed ductile iron have been investigated for three austempering temperatures of 270, 330, and 380 °C for 60 min at each temperature after austenitization at 850 °C for 120 min. The austempering temperature not only affects the morphology of bainitic ferrite but also that of retained austenite. There is an increase in the amount of retained austenite, its carbon content, and size of bainitic ferrite needles with the rise in austempering temperature. The influence of austempering time on the structure has been studied on the samples austempered at 330 °C. The increase in the austempering time increases the amount of retained austenite and its carbon content, which ultimately reaches a plateau.

Keywords austempered ductile iron, austenite, bainitic ferrite

1. Introduction

Austempered ductile iron (ADI) offers a combination of high strength, toughness, and good wear resistance with low cost and thus has received much publicity. Many applications of ADI have been reported earlier.[1,2] Achieving optimal mechanical properties of ADI is a function of the constituents of austempered microstructure,[3-6] which in turn depends on the austempering treatment temperature and time. Therefore, it is necessary to undertake a detailed characterization of austempered structure of a wide range of compositions of ductile iron treated by different austempering processes. The effect of austempering parameters on the microstructure and mechanical properties of low manganese austempered ductile iron has been studied earlier.[6,7] This paper studies the austempering transformations and microstructural changes during austempering of copper alloyed ductile iron with respect to austempering parameters by taking three austempering temperatures of 270, 330, and 380 °C and austempering time periods from 5-150 min. The changes in austempered microstructure and structural parameters (like austenite volume fraction, X_γ and its carbon content, C_γ, the product, $X_\gamma C_\gamma$ and the size of bainitic ferrite, d_α) with austempering temperature and time have been reported.

2. Experimental Procedure

A ductile iron of composition (3.48C, 2.028Si, 0.22Mn, 0.05Cr, 0.016Ni, 0.6Cu, 0.04Ti, 0.03Mo, 0.0079Sn, 0.012V, 0.02Al, rest Fe) was prepared in a commercial foundry using an induction-melting furnace and cast in the shape of a 1 in. Y block. The cast microstructure of ductile iron consists of 4% ferrite and 96% pearlite with nodule count of 250. Unnotched Charpy specimens of 55 × 10 × 10 mm as per ASTM specification A 327-80[8] machined from the leg part of Y block castings were austenitized at 850 °C for 120 min and transferred rapidly to a salt bath held at a preselected temperature for different time periods before quenching in water. Samples for metallography were polished, etched, and examined using standard metallographic techniques. The average amount of austenite, X_γ, and its average carbon content, C_γ, were determined by using x-ray diffraction (XRD) patterns taken with Cukα radiation ($\lambda = 1.54$ A°).[9] The mean size of bainitic ferrite particles, d_α, has been obtained through the use of the Scherrer equation.[9].

3. Results and Discussion

The qualitative variation in morphology, size, and distributions of bainitic ferrite needles and retained austenite in austempered microstructure with the austempering temperature may be observed in Fig. 1. Austempering generally occurs by nucleation of bainitic ferrite preferentially at the graphite austenite interface, thereby rejecting carbon to austenite matrix. The austempered microstructure of ADI formed by austempering at 270 °C for 60 min consists of lower bainite in the form of fine needles distributed more uniformly throughout the structure, with the retained austenite appearing as silvers in between these ferrite needles (Fig. 1a). At lower austempering temperature the nucleation of bainite may be expected to be faster, but the carbon rejected during formation of bainite may diffuse only to shorter distances thereby forming fine bainite and austenite. The presence of lower as well as upper bainite with blocky austenite in the microstructure observed in the sample austempered at 330 °C (Fig. 1b) reveals the change in the morphology of bainitic ferrite with austempering temperature. The amount and size of retained austenite have also in-

Uma Batra, Department of Metallurgical Engineering, Punjab Engineering College, Chandigarh, India; **S. Ray,** Department of Materials and Metallurgical Engineering, IIT Roorkee, India; and **S.R. Prabhakar,** Rayat College of Engineering and Information Technology, Dist. Nawan Shahar, Punjab, India. Contact e-mail: umabatra2@yahoo.com.

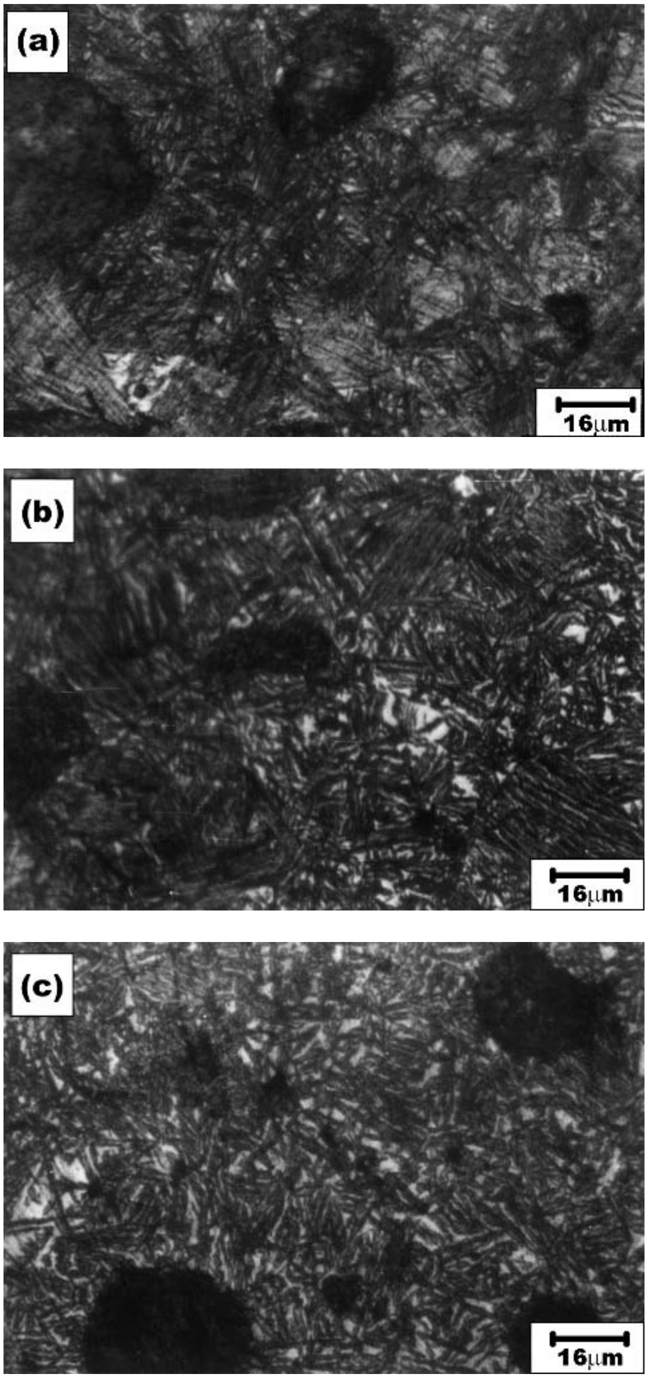

Fig. 1 Austempered microstructure of copper alloyed ADI when austempered at **(a)** 270, **(b)** 330, **(c)** 380 °C for 60 min after austenitization at 850 °C for 120 min

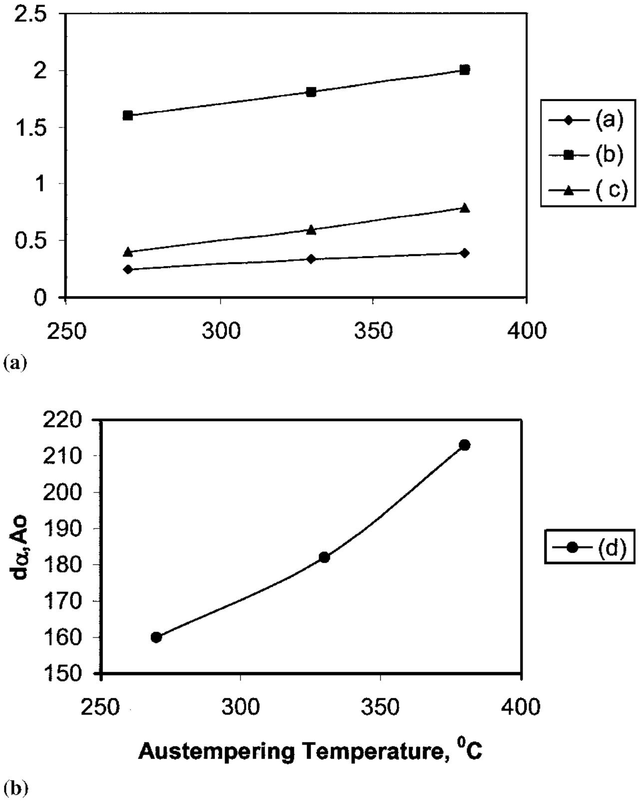

Fig. 2 Variation of **(a):** (a) X_γ, (b) C_γ, (c) X_γ C_γ, and **(b):** (d) d_α with austempering temperature for a constant austempering time of 60 min for Cu-alloyed ADI when austenitized at 850 °C for 120 min

creased. Austempering the samples at a still higher austempering temperature of 380 °C results in coarser upper bainite with no lower bainite along with relatively more retained austenite present in large blocky form (Fig. 1c). At higher austempering temperature the carbon rejected during formation of bainite can diffuse to longer distances and thus forms coarser bainite and blocky austenite. However, the quantitative variation of the volume fraction of retained austenite, X_γ, its average carbon content, C_γ ,the product, X_γ $C_{\gamma,}$ and the size of bainitic ferrite needle, d_α, with austempering temperature is shown in Fig. 2 (a-d), respectively. The X_γ = 0.25 at the lower austempering temperature of 270 °C, which increases to 0.33 at T_A = 330 °C, and 0.39 at T_A = 380 °C, whereas their average carbon contents are 1.6, 1.8, and 2.0, respectively. The higher amount of carbon that diffuses from upper bainite at higher austempering temperature may be responsible for the formation of more austenite, its carbon content, and thus the product $X_\gamma C_\gamma$. If austempering at higher temperature is followed by austenitization at higher austenitization temperature, which is expected to lead to coarser austenite grains, the areas between the ferrite needles will be enriched by carbon by diffusion over longer diffusion distance. However, if the carbon does not diffuse to the center of austenite grain, then this region may transform to martensite during quenching. Thus, the stability of retained austenite appears to be independent of whether there is lower bainite or upper bainite in the structure. It may be inferred that the stability of austenite depends on the initial carbon content and the grain size of austenite before austempering. The latter controls the size of bainitic ferrite and retained austenite in austempered microstructure. The size of bainitic ferrite needle, d_α, increases from 160-213 Å with the rise in austempering temperature from 270-380 °C (Fig. 2d). The trends of variation of the structural parameters with austempering temperature were similar to those obtained by Darwish[7] and Rouns[10] for the ductile irons of composition given in Table 1.

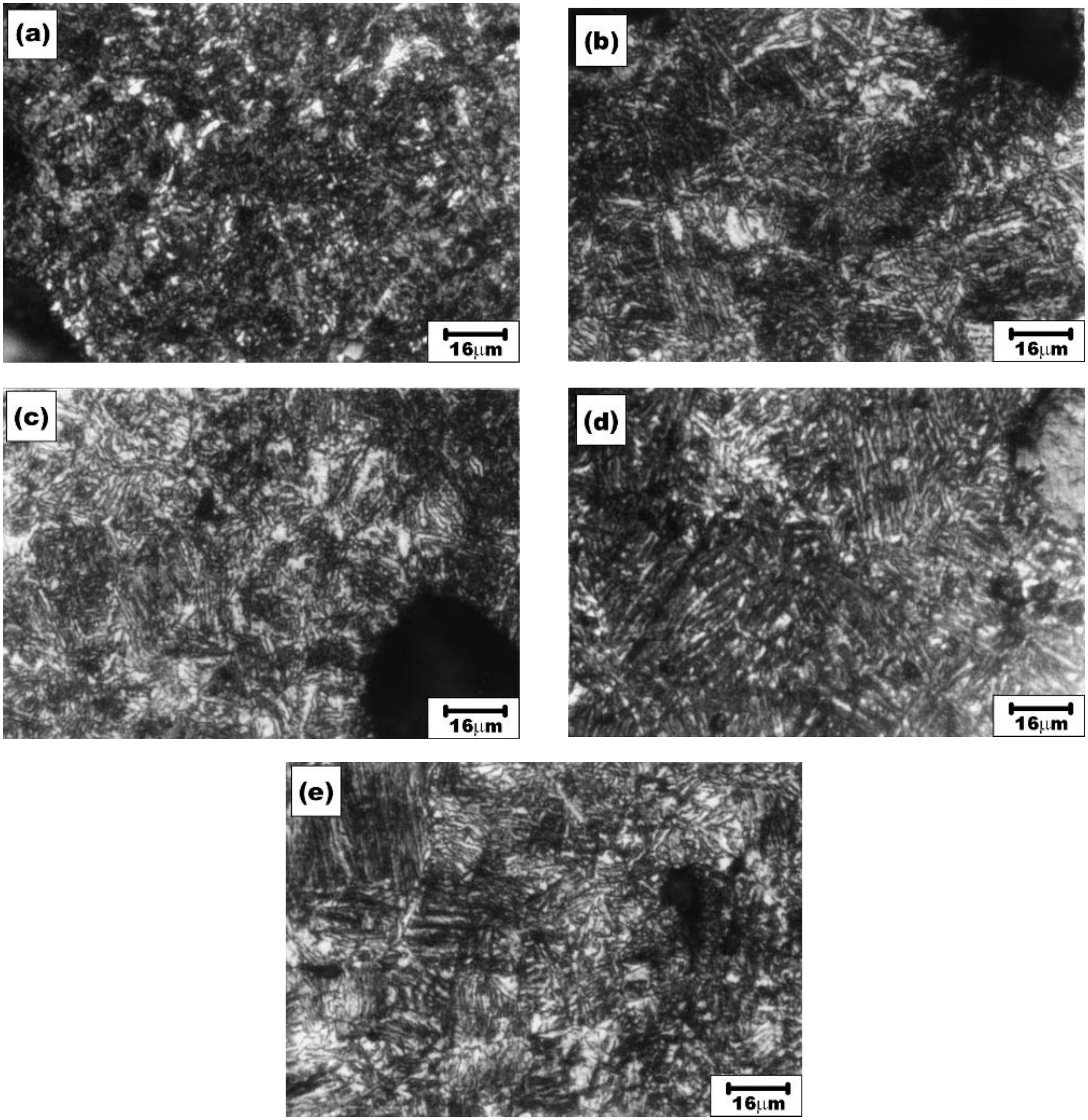

Fig. 3 Influence of austempering time on the austempered microstructure of Cu alloyed ADI when austempered at 330 °C for different time periods: **(a)** 30, **(b)** 60, **(c)** 90, **(d)** 120, **(e)** 150 min after austenitization at 850 °C for 120 min

The effect of austempering time, t_A, on austempered microstructure is shown in Fig. 3 for ADI austempered at 330 °C for different time periods, after austenitization of 120 min at 850 °C. The ADI austempered for 30 min consists of bainitic ferrite, retained austenite, and a substantial amount of martensite (Fig. 3a). At longer austempering periods of 60 min, the structure consists of bainitic ferrite and retained austenite; no martensite is visible in the microstructure as is clear from Fig. 3(b). No noticeable change in the microstructure could be observed with further increase in austempering time, t_A, until 150 min (Fig. 3c-e). During austempering, the bainitic ferrite forms by rejection of carbon to the residual austenite. As the austempering progresses, there is more bainitic transformation accompanied by rejection of more carbon in surrounding austenite, resulting in the increase in the amount of austenite and that of its carbon content. At short treatment times, the carbon content of austenite is insufficient to make it stable and therefore, it transforms to martensite. However, at longer treatment times,

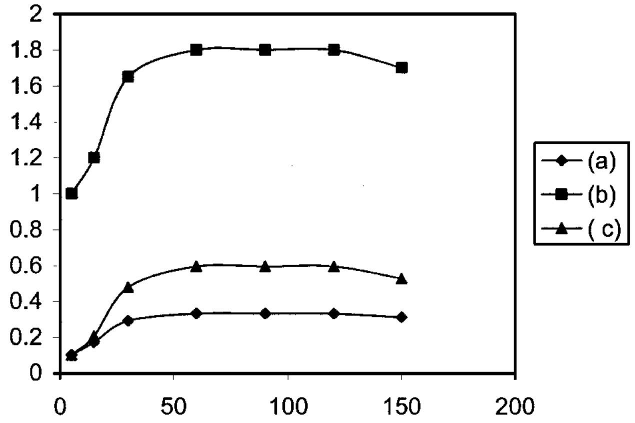

Fig. 4 Variation of (a) X_γ, (b) C_γ, and (c) X_γ C_γ with austempering time for Cu-alloyed ADI when austempered at 330 °C after being austenitized at 850 °C for 120 min

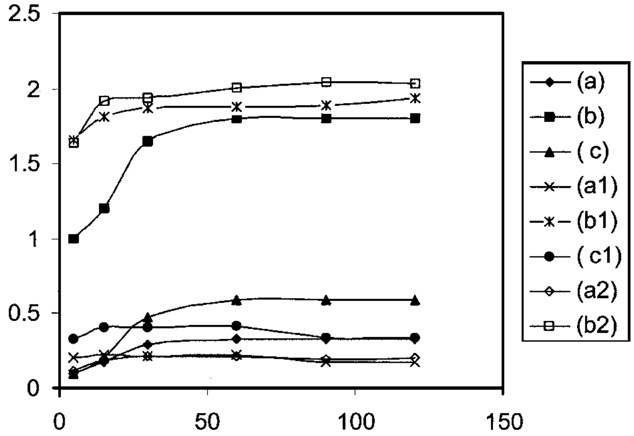

Fig. 5 Variation of (a) X_γ, (b) C_γ, and (c) X_γ C_γ with austempering time in this paper compared with the results of Ref. 7 and 10

Table 1 Composition of Ductile Irons in wt.% Studies by Darwish[7] and Rouns[10]

Reference	C	Si	Mn	P	S	Cr	Ni	Cu	Ti	Mo	Mg
Darwish[7]	3.8	2.77	0.37	0.03	0.02	0.02	0.07	0.33	0.03	…	0.034
Rouns[11]	3.59	2.51	0.134	…	0.007	0.045	0.061	0.057	…	0.007	0.050

carbon enrichment of austenite may be sufficient to result into retained austenite on cooling.

The variation in X_γ, C_γ, and $X_\gamma C_\gamma$ with austempering time, t_A, for ADI austempered at 330 °C after austenitization at 850 °C for 120 min, as calculated from XRD peaks, is shown in Fig. 4 (a-c), respectively. The volume fractions of retained austenite, $X_{\gamma,}$ and its carbon content, C_γ and $X_\gamma C_\gamma$, are small at short austempering time, increase until $t_A = 60$ min, and remain constant until $t_A = 120$ min. After $t_A = 120$ min, these X_γ, C_γ, and $X_\gamma C_\gamma$ start decreasing. The trend of variation in the structural parameters with austempering time in this work is similar to that reported by Darwish[7] and Rouns[10] for the alloy compositions given in Table 1, as shown in Fig. 5. However, the maximum value of X_γ, C_γ, and $X_\gamma C_\gamma$ and the austempering time corresponding to the maximum values are found to be different. This difference may be attributed to a difference in the composition of the ductile irons, austenitization, and austempering temperatures. The progress of bainitic transformation with continuing carbon enrichment of residual austenite reduces the driving force for further transformation of austenite to bainitic ferrite with the result that further transformation slows down and thus X_γ, C_γ, and $X_\gamma C_\gamma$ reach a plateau. The decrease in Xγ, C_γ, and $X_\gamma C_\gamma$ with further increase in austempering time may be due to onset of stage II of austempering when retained austenite decomposes to give bainitic ferrite and carbide. However, due to the submicroscopic nature of stage II, the phases could not be detected by metallography.

4. Conclusions

Increasing austempering temperature changes the bainite morphology from lower bainitic to upper bainite. The average austenite volume fraction of austenite, its carbon content, and the size of bainitic ferrite also increase with increasing austempering temperature. Increasing the austempering time initially increases the amount of retained austenite and its carbon content, both of which then reach a plateau. The plateau extends over a period of stability of retained austenite, after which there is a decrease of both.

References

1. R. Harding: "Prospects for the Exploitation of ADI" in *2nd International Conference on Austempered Ductile Iron*, ASME Gear Research Institute, Ann Arbor, MI, 1986, pp. 39-54.
2. B. Kovacs: "Austempered Ductile Iron Fact and Fiction," *Mod. Cast.*, 1990, *Mar,* pp. 38-41.
3. D.J. Moore, T.N. Rouns, and K.B. Rundman: "Structure and Mechanical Properties of Austempered Ductile Iron," *Trans. AFS*, 1985, *103,* pp. 705-18.
4. D.J. Moore, T.N. Rouns, and K.B. Rundman: "Effect of Manganese on Structure and Properties of Austempered Ductile Iron," *Trans. AFS,* 1986, *48,* pp. 255-64.
5. T.S. Shih, C.S. Chang, and L.Z.Huang: "Mechanical Properties and Microstructures of Austempered Ductile Iron," *Trans. AFS,* 1991, *107,* pp. 793-808.
6. A.S. Hamid Ali, K.I. Uzolov, N. Darwish, and R. Elliot: "Austempering of Low Manganese Ductile Irons, Part 4. Relationship Between Mechanical Properties and Microstructure," *Mater. Sci. Technol.*, 1994, *10,* pp. 35-40.
7. N. Darwish and R. Elliot: "Austempering of Low Manganese Ductile Irons, Part 3. Variation of Mechanical Properties With Heat Treatment Conditions," *Mater. Sci. Technol.,* 1993, *9,* pp. 882-89.
8. K.D. Mills: "Spheroidal Graphite Cast Iron—Its Development and Future," *Br. Foundryman*, 1972, *65,* p. 34.
9. B.D. Cullity: *Elements of X-Ray Diffraction*, Addison Wesley Publishing Company, Inc., Reading, MA, 1956, pp. 390-96.
10. T.N. Rouns and K.B. Rundman: "Constitution of Austempered Ductile Iron and Kinetics of Austempering," *Trans. AFS,* 1987, *116,* pp. 851-74.