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IMPACT TOUGHNESS OF AUSTEMPERED DUCTILE CAST IRON

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ABSTRACT

The influence of austempering temperature and time, as main austempering control parameters, on the impact toughness and microstructure of a ductile cast iron alloy having a carbon equivalent of 3.88 percent has been investigated. Two transformation temperatures were chosen at 270°C and 400°C such as to obtain microstructure falling within the zones of lower and upper bainite,respectively. Austempering time intervals ranging from 5 minutes to 5 hours were selected for each austempering temperature. Peak values of U-notch Charpy impact toughness of 7.55 and 17.23 Joule/cm^2 have been attained at time interval of 60 minutes for specimens austempered at 270°C and 400°C, respectively. The changes in mechanical properties with the transformation temperature and time has been observed to be directly related to the phase transformations in the microstructure. The study of fracture surfaces of impact toughness samples revealed the great complexity of the crack propagation process in austempered ductile iron due to the nature of its structure.

KEYWORDS

Austempered ductile iron; microstructure; upper bainite; lower bainite; mechanical properties.

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INTRODUCTION

Austempered ductile iron castings can compete favourably with steel forgings in the manufacture of engineering components such as gears and crankshafts(1-5). This is due to the exceptional combination of high strength,ductility and toughness attained by austmpering beside its well known excellent castability,machinability,wear resistence and damping properties. Austempered ductile iron has a wide variety of mechanical properties which can be achieved by altering the austempering control parameters such as the austenitization temperature, isothermal transformation temperature and holding time at the transformation temperature(6,7). The present work aimed to investigate the effect of selected transformation temperatures and time intervals on the microstructure and impact toughness of an unalloyed ductile iron having a carbon equivalent of 3.88%.

EXPERIMENTAL WORK

Impact test specimens were cut from a circular cast ring,of outer diameter 1000 mm,wall thickness 23 mm and width 65 mm, made of a ductile iron of the chemical composition shown in Table 1,and having a ferritic matrix in the as-received state. The U-notch specimen dimensions shown in Fig. 1,were chosen according to the ASTM standard(8).

TABLE 1 Chemical Composition(Wt%) of the Ductile Iron Used(C.E.= 3.88%)

C%	Si%	Mn%	P%	S%	Mg%
3.1	2.31	0.24	0.04	0.017	0.05

The austempering treatment processes were performed using commercial neutral salt bath to prevent oxidation and decarborization. All specimens were austenitized at 900°C for 45minutes. To avoid specimen cracking or warping which might result from rapid heating to this temperature,the specimens were first heated to 400°C inside a chamber furnace for 20 minutes,then completely immersed in the salt bath at 900°C. Some of these austenitized specimens were then quenched to 270°C while the others were quenched to 400°C. Specimens were held at these two austempering temperatures for different periods of time ranging from 5 to 300 minutes after which they were quenched in oil to room temperature. Fig. 2 shows a schematic representation for the different austempering thermal cycles used.

A pendulum type impact testing machine was used to perform the impact toughness tests. The pendulum weight was 15 Kg and the initial lifting angle was 160°. After specimen fracture,metallo graphic examinations and hardness testing of samples were carried out using optical microscope type Neophot-2 and microhardness tester type Zwick-3212 with load of 4 Kg for 60 seconds. Fractographic examinations of the fracture surfaces of impact toughness specimens were performed using scanning electron microscope type Jeol 35 SEM at 25 KV accelerating voltage.

RESULTS AND DISCUSSION

Figure 3 shows the effect of austempering time on the matrix hardness of austempered specimens at 270°C and 400°C. Minimum values were obtained after 60 minutes of transformation at both transformation temperatures.

These results can be directly related to the microstructure changes that take place during austempering for different times. The photographs of Fig. 4(a),(b) and(c) show the microstructure of specimens austempered at 270°C while that of Fig. 5(a),(b) and(c) show the microstructure of specimens austempered at 400°C. For specimens austempered at 270°C, the value of matrix hardness for specimens austempered for 5 minutes indicates that martensite is the predominant phase in the matrix.Increasing austempering time will decrease the matrix hardness due to increased amount of retained austenite and decreased amount of hard phase martensite. Beyond 60 minutes austempering time,the matrix hardness will increase due to the decomposition of austenite(soft phase FCC) into lower bainite(hard phase). Increasing the austempering temperature from 270°C to 400°C results in a decrease of hardness due to formation of upper bainite instead of lower bainite. A similar trend is observed for specimens austempered at 400°C.

The minimum hardness values attained at 60 minutes for both temperatures can be attributed to the maximum amount of stablized retained austenite. Similar results have been reported by Verhoeven etal(4). For specimens austempered at 400°C for time intervals beyond 60minutes, the increased values of hardness may be due to the decomposition of austenite into ferrite and carbides(9,10).

Figure 6 shows the relation between the average values of Charpy impact toughness,IT, and the austempering time for specimens austempered at temperatures of 270°C and 400°C. Peak values of 7.55 and 17.73 Joule/cm^2 were attained for specimens austempered for 60 minutes at temperatures of 270°C and 400°C, respectively.These peak values are attributed to the expected maximum amount of retained austenite in the matrix.Increasing the austempering temperature from 270°C to 400°C causes the impact toughness values to increase by more than 100%. This is due to the higher amount of stabilized austenite in the matrix with upper bainite. It is clear from Fig. 6 that a reduction of more than 50% in impact toughness is obtained by increasing the austempering time from one to 3 hours for specimens austempered at 400°C. Similar results have been reported by previous investigators(11,12). This is related to the decomposition of retained austenite into ferrite and carbides. Carbides are known to degrade impact toughness of ductile cast iron(9,10). Fig. 6 shows also that the 5 minutes austempering time interval at 270°C is not enough to cause the impact toughness value to change much from the value observed for martensitic ductile

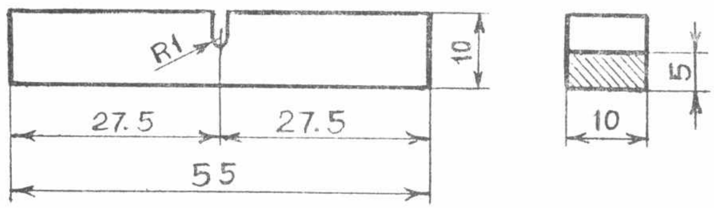


Fig. 1 Shape and dimensions of the U-notch specimen.

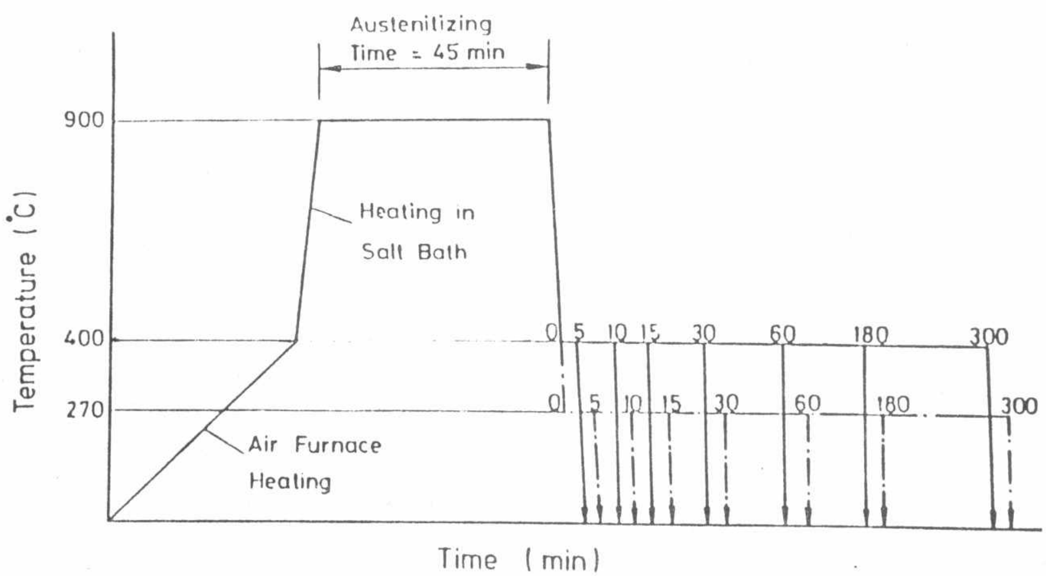


Fig. 2 Representation of the applied austempering thermal cycles.

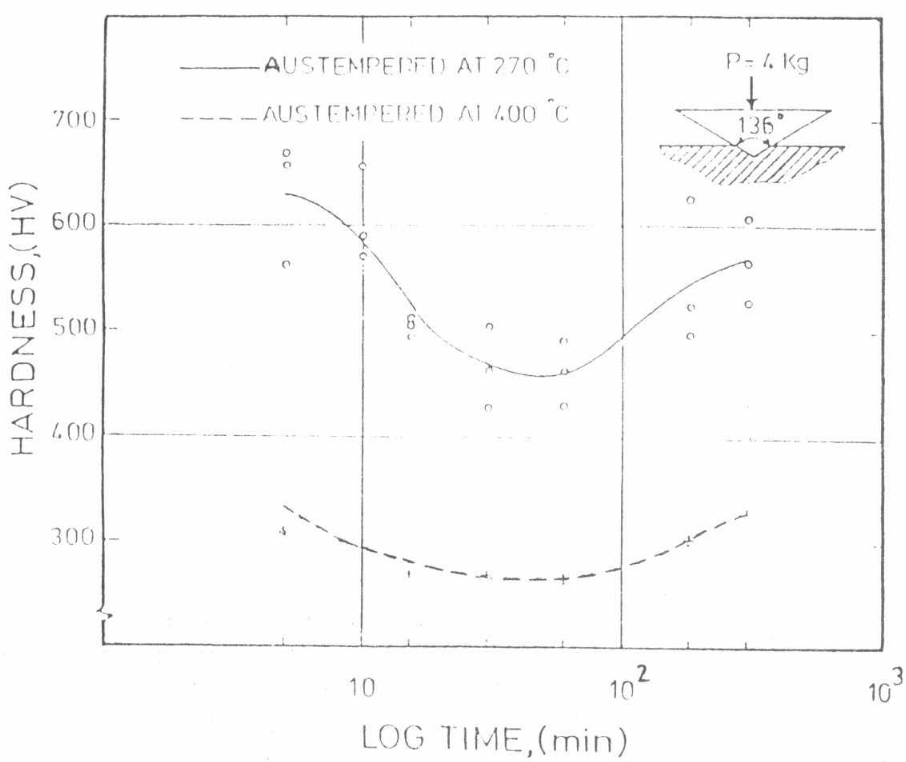
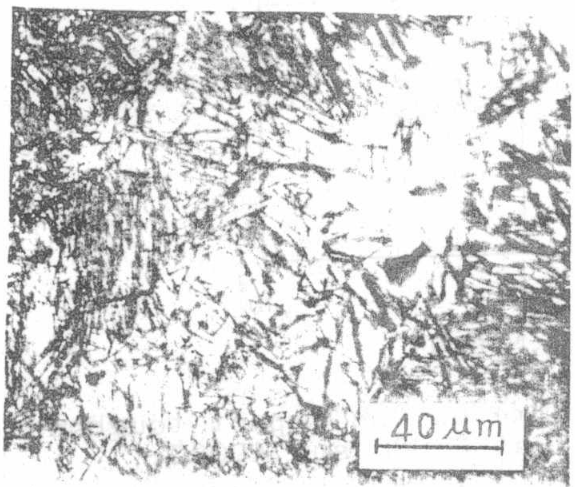
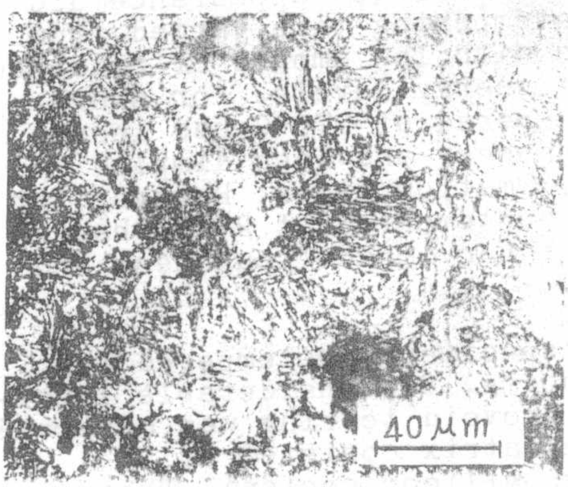


Fig. 3 Effect of austempering time on matrix hardness.

(a) Austempering for 5 min.

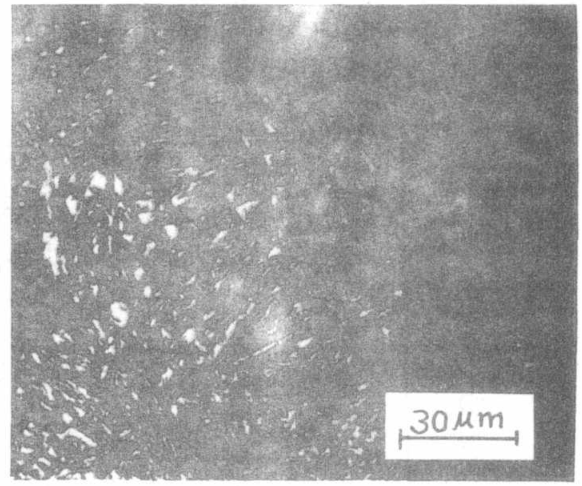


(b) Austempering for 60 min.

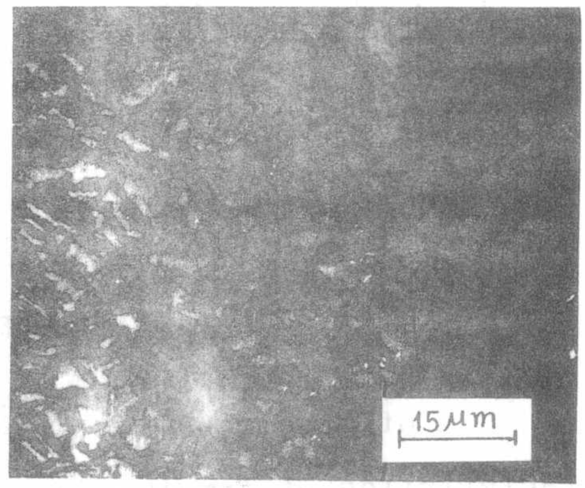


(c) Austempering for 300min.

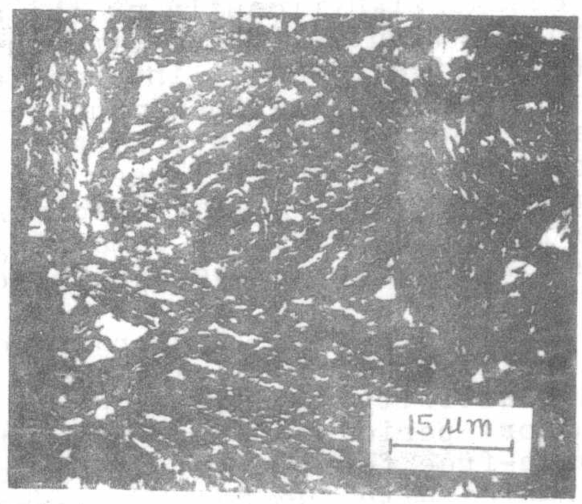
Fig. 4 Microstructures of specimens austempered at 270°C (lower bainite).



(a) Austempering for 5 min.



(b) Austempering for 60 min.



(c) Austempering for 300 min.

Fig. 5 Microstructure of specimens austempered at 400°C(upper bainite).

cast iron(impact toughness of martensitic ductile cast iron, IT = 4.7 Joule/cm^2)

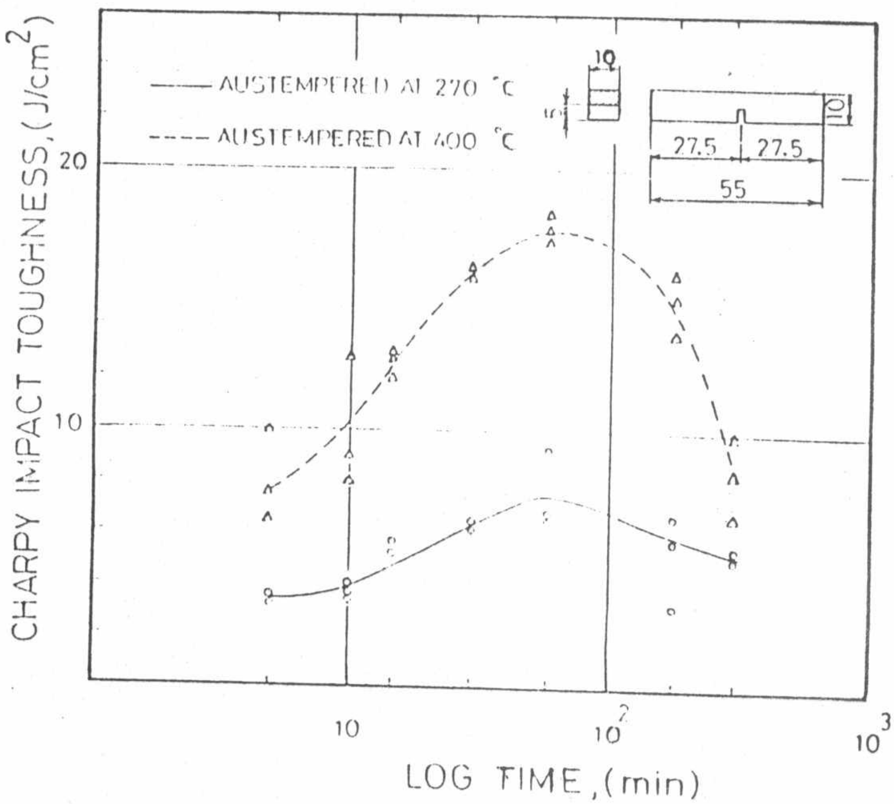


Fig. 6 Effect of austempering time on the impact toughness of specimens austempered at 270°C and 400°C.

Characteristics of fracture surfaces of specimens austempered at 270°C are shown in Fig. 7. Fracture surface appearance did not change significantly as the austempering time varied from 15 to 300 minutes. These structures with low amount of retained austenite fractured at intermediate energy levels. For short transformation time,specimens austempered at 270°C had less retained austenite,lower impact toughness and less dimpled rupture than those of longer transformation times. However,for long transformation time specimens austempered at 270°C had some retained austenite remaining,higher impact toughness and some dimpled rupture were observed.

The fracture surface appearance of specimens austempered for various times at 400°C are shown in Fig. 8. Considerable localized plasticity and considerable microvoid tearing was observed for short periods of time where the matrix cosisted of carbide-free ferrite due to the high silicon content. This was contrasted with the fracture appearance of specimens further transformed to a matrix of ferrite and carbides where quasi-cleavage fracture was observed with no evidence of microvoid tearing. Carbide formation is primarily responsible for the fracture mode change and the reduction in energy absorbed during fracture.

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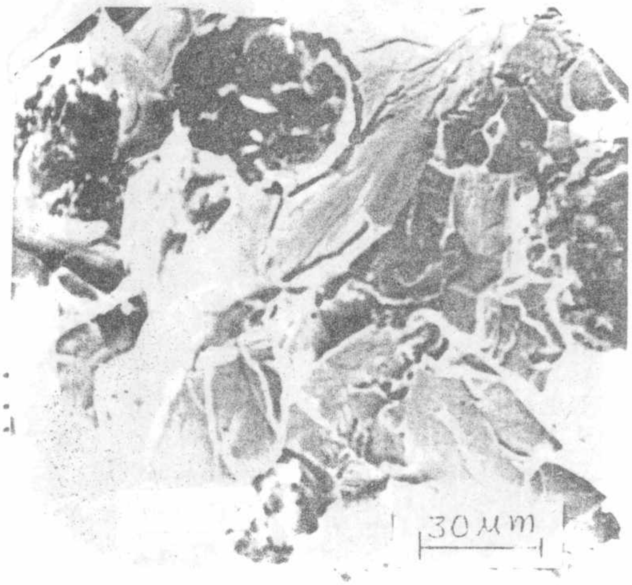
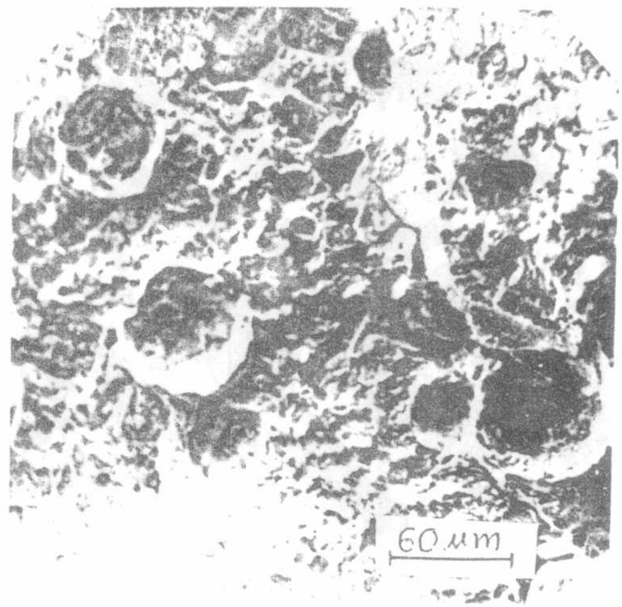
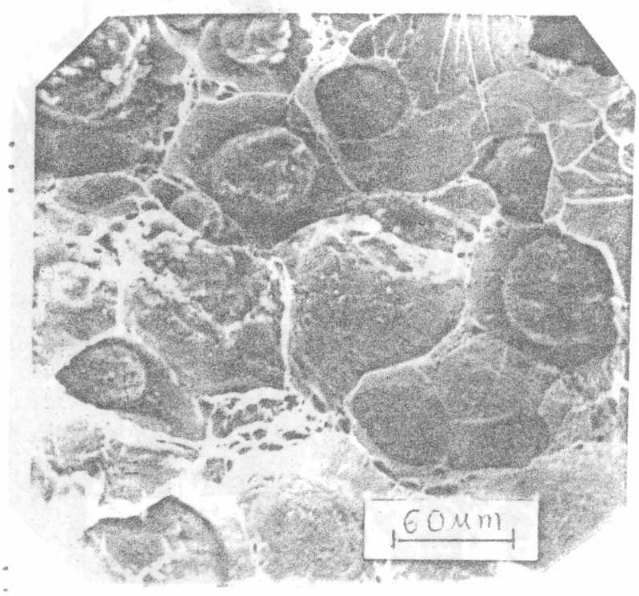


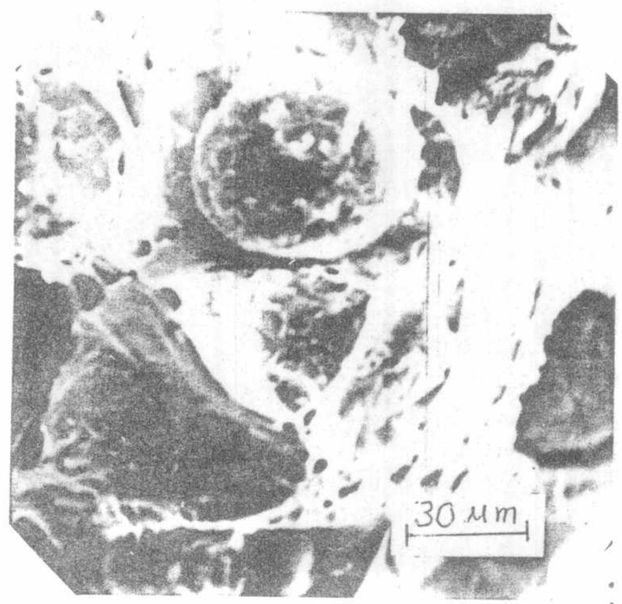
(a) Austempering for 5 min.



(b) Austempering for 15 min.



(c) Austempering for 60 min.



(d) Austempering for 300min.

Fig. 7 SEM microfractographs of fracture surfaces of specimens austempered at 270°C.

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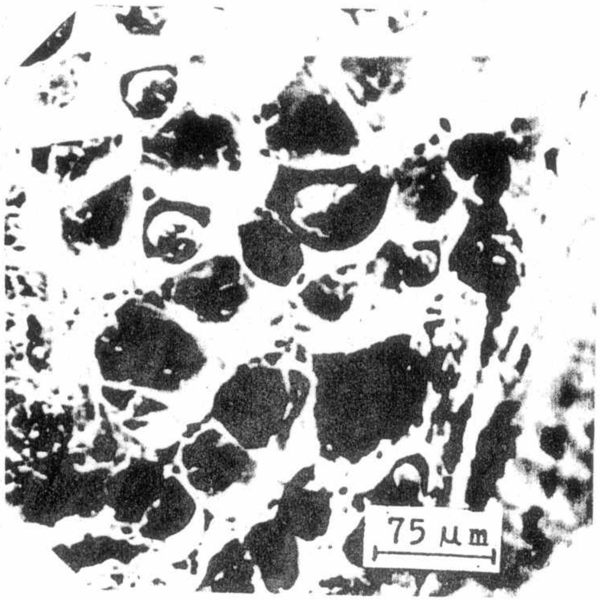
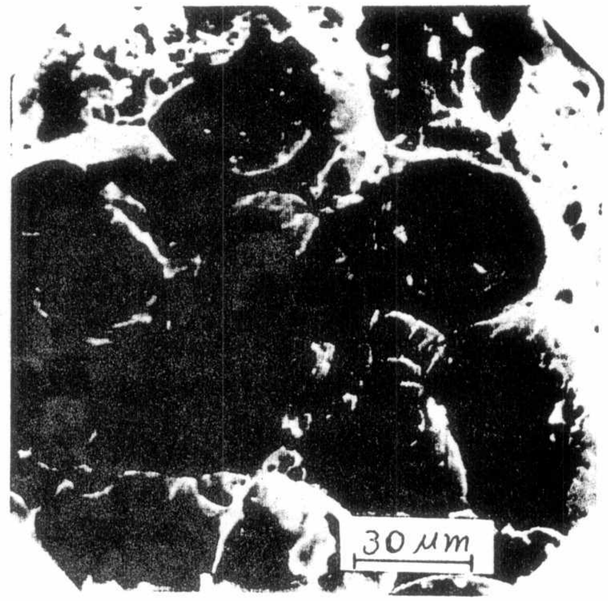
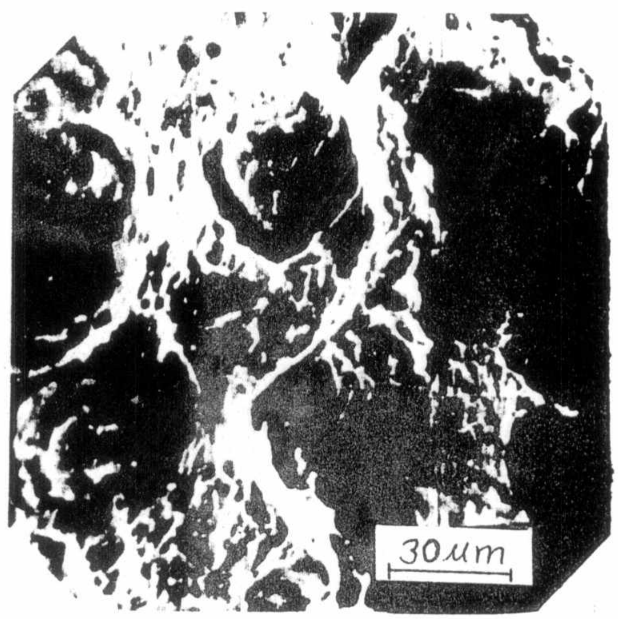


(a) Austempering for 5 min.



(b) Austempering for 15 min.

(c) Austempering for 60 min.



(d) Austempering for 300 min.

Fig. 8 SEM microfractographs of fracture surfaces of specimens austempered at 400°C.

Generally, the suitable combination of hardness and impact toughness required for certain application can be achieved by proper choice of austempering temperature and transformation time.

CONCLUSIONS

The microstructure and hence the mechanical properties of austempered ductile iron are strongly depentant on the austempering temperature and time of transformation.

For both transformation temperatures 270°C and 400°C, the maximum amount of retained austenite is obtained at 60 minutes transformation time. This gives the peak values of impact toughness of bainitic ductile iron.

Increasing the austempering temperature from 270°C to 400°C causes impact toughness peak value to increase by more than 100%.

Increasing theaustempering time from 60 to 300 minutes at 400°C results in decreasing the impact toughness by more than 50%.

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