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# MICROSTRUCTURE AND MECHANICAL PROPERTIES OF CuNiMo AUSTEMPERED DUCTILE IRON

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## Abstract

*Microstructure and mechanical properties of Cu, Ni and Mo alloyed cast ductile iron have been investigated after austempering. Samples were austenitised at 860°C for 1h and then austempered at 320°C and 400°C in the interval from 0,5 to 5h. The X-ray diffraction technique and the light microscopy were utilized to investigate the bainitic transformation, while tensile and impact tests were performed for characterization of mechanical properties. By austempering at 320°C in the range between 2 and 5h, a microstructure typical for austempered ductile iron was produced, i.e. a mixture of free bainitic ferrite and highly carbon enriched retained austenite. The characteristic of the whole range of austempering at 400°C is the appearance of martensitic structure. The maximum impact energy (133 J) coincides with the maximum value of volume fraction of retained austenite that was obtained after 2,5h of austempering at 320°C. The appearance of martensite during austempering at 400°C is the main cause for much lower tensile properties than at 320°C.*

*Keywords:*austempering, ductile cast iron, retained austenite, impact energy

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## 1. Introduction

Depending on the applied austempering conditions an attractive combination of mechanical properties of austempered ductile iron may be produced [1-4]. This renders the austempered ductile iron useful in a relatively large number of applications as an economical substitute for high strength steels [5-8]. The important microstructural features of austempered ductile iron are the morphology of the ferrite, the volume fraction of retained austenite, the carbon content in retained austenite, and the presence or absence of carbide in austenite or ferrite. A mixture of bainitic ferrite and retained austenite, along with graphite nodules, is the most desirable combination of phases in these cast irons. Undesirable phases, such as martensite and iron carbides, may also be present in smaller quantities, but it is understood that the high volume fraction of retained austenite is very important towards the achievement of optimum combination of mechanical properties [9]. Thus, the mechanical properties of austempered ductile iron may be related to three microstructural variables: bainite morphology, austenite volume fraction and the formation of martensite [10].

Large amount of silicon present in ductile iron suppresses the precipitation of carbide during austempering reaction and retains substantial amount of stable high carbon austenite. Small amount of alloying elements such as copper, nickel and molybdenum are generally added to ductile iron in order to attain sufficient hardenability without formation of pearlite during cooling from austenitising to austempering temperature. [11]. It was found that strength decreases with increasing austempering temperature, but ductility changes in the opposite direction [10].

During austempering ductile iron undergoes two-stage transformation process. In stage I, the austenite ($\gamma$) decomposes into ferrite ($\alpha$) and high carbon austenite ($\gamma_{HC}$):

$$\gamma \rightarrow \alpha + \gamma_{HC} \qquad \text{(stage I)}$$

If the sample is held at the austempering temperature for too long, then a next reaction (stage II) takes place where high carbon austenite further decomposes into ferrite and carbide:

$$\gamma_{HC} \rightarrow \alpha + \text{carbide} \qquad \text{(stage II)}$$

The product of this second reaction is undesirable because it embrittles the

material and degrades the mechanical properties. Therefore, this reaction should be avoided during heat-treatment.

The objective of this paper was to study the effect of austempering time and temperature on microstructure and mechanical properties of Cu, Ni and Mo alloyed cast ductile iron.

## 2. Experimental

### 2.1. *Material and procedure*

A ductile cast iron (designated as CuNiMo SG iron) produced in a commercial foundry electric furnace has been used for the experiments. The dimensions of casting in the form of "Y"blocks were.25x55x300mm.The chemical composition (in wt.%) of castings was as follows: 3,55C, 2,5Si, 0,3Mo, 0,8Cu, 0,95Ni, the balance was Fe. Samples for tensile tests and Charpy impact tests were machined from the "Y" blocks. Screw-type samples (ASTM.A370-68) with.14mm in diameter and.75.mm in gauge length were used for tensile tests. All tensile tests were performed at room temperature at a strain rate $1.3x10^{-3}s^{-1}$. The dimensions of unnotched Charpy samples (ASTM A 327M-91) were 10x10x55mm. Impact tests were also performed at room temperature applying 150J impact energy. Prior to testing samples were austenitised at 860$^{o}$C for 1h and then austempered in a salt bath at temperatures of 320 and 400$^{o}$C from 0,5 to 5h. After austempering samples were air-cooled to the iced-brine. A minimum of three samples was tested for each heat-treatment condition.

Samples for light microscopy were prepared by standard metalographical technique, then etched in Nital and examined using "Leitz" microscope. "Opton Axioaplan" light microscope equipped with the software program "Vidas" was applied to measure the quantitative distribution of graphite nodules. Volume fraction of retained austenite was estimated by the X-ray diffraction technique using "Siemens D-500" diffractometer with monochromated nickel filtered Cu $K_{\alpha}$ radiation at 35kV and 20mA.

The applied method [12] for calculation of volume fraction is based on the fact that the integrated intensity of a reflection is directly proportional to the

volume fraction of the phase considered, *i.e.*:

$$I_\gamma/I_\alpha=R_\gamma/R_\alpha * f_\gamma/f_\alpha \quad (1)$$

where: $I_\alpha$ and $I_\gamma$ are integrated intensities from a given hkl of the $\alpha$ and $\gamma$ phase, $f_\alpha$ and $f_\gamma$ are the volume fractions of $\alpha$ and $\gamma$ phase.

$R_\alpha$ and $R_\gamma$ values are calculated according to:

$$R=(1/\nu^2)[|F|^2\ p(1+\cos^2 2\theta)/\sin^2\theta\cos\theta)](e^{-2M}) \quad (1a)$$

where: F-structural factor, p-multiplicity, θ-Bragg angle, $e^{-2M}$ –temperature factor (a function of θ), ν-volume of the unit cel and $(1+\cos^2 2\theta)/\sin^2\theta\cos\theta)$-Lorenz polarization factor.

Once the ratio $f_\gamma/f_\alpha$ is found the value of $f_\gamma$ may be obtained from the relationship:

$$f_\alpha + f_\gamma + f_g = 1 \quad (2)$$

where $f_g$ is the volume fraction of graphite nodules which can be obtained by the image analysis.

### 3. Results and discussion

It appears that the graphite nodules in all specimens of as-cast CuNiMo SG ductile iron were not uniform in size and distribution. Spheroidisation was evident (more than 90%) with an average nodule size varying between 30 and 70μm, and an average nodule distribution of about 100 per $mm^2$ (Fig. 1). The effect of austempering temperature and time on the microstructure of austempered ductile iron is shown in Fig. 2 (a-d). When austempered at 320°C for 0,5h the large amount of martensite formed from the unreacted austenite during cooling to the room temperature is present in the microstructure (Fig. 2a). The formation of martensite after short austempering time is inniciated because of the lower carbon content of some austenitic regions. As austempering time increases to 3h the amount of martensite decreases with the simultaneous increase of the amount of bainitic ferrite and highly enriched carbon austenite (Fig. 2b). Austempering at 400°C for 0,5h results in a microstructure is shown in Fig. 2c. At these austempering conditions martensite with some unstable austenite is present in the dark areas, stable retained austenite may be seen in the white areas, whereas the plate-like martensite is the major microstructural constituent. With the prolonged time of austempering to 3h the

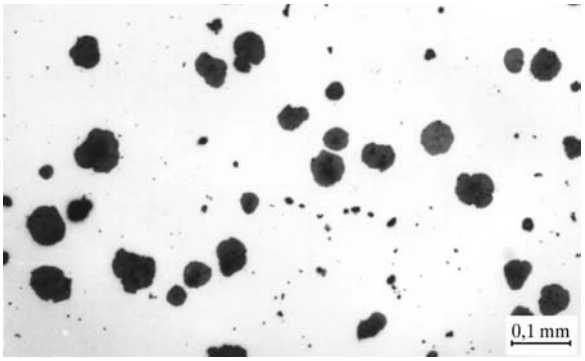
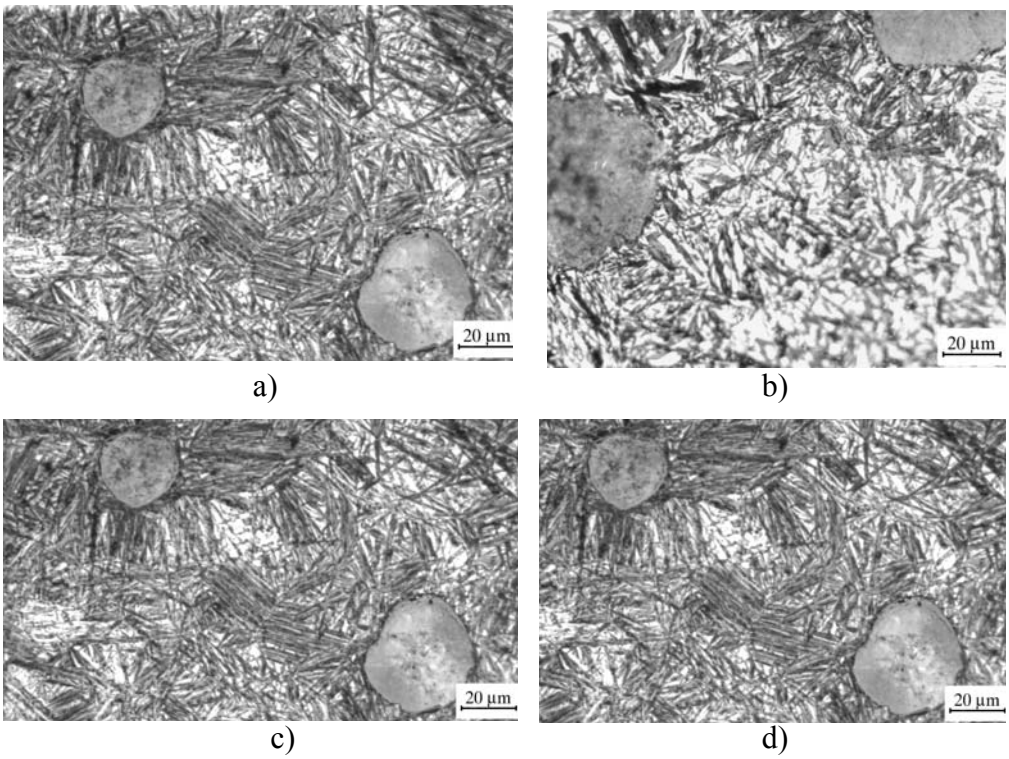



*Fig.1 Light microscopy (unetched)-size, shape and distribution of graphite nodules in as-cast CuNiMo SG iron*




a) b)

c) d)

*Fig.2. Light microscopy (etched)-microstructure of ADI austempered at 320°C; (a) for 0,5h and (b) for 3h. Austempered at 400°C; (c) for 0,5h and (d) for 3h*

dark blocky areas containing a high fraction of plate-like bainite may be seen (Fig. 2d). It should be mentioned that the prevailing martinsitic structure is the main characteristics for austempering at 400°C. At higher austempering temperature the driving force for the stage I reaction is lower than that for stage II. [7]. Consequently, the austempered microstructure is less uniform and contains blocky austenite areas in which martensite forms during cooling to room temperature. These results support previous findings obtained by Harding [13].

A typical X-ray diffraction pattern of a sample austempered at 320°C for 2,5h is presented in Fig.3. It was found that in all samples the volume fraction of retained austenite was between 18 and 40% volume fraction. The maximum value of volume fraction of retained austenite was obtained after austempering at 320°C for 2,5h.

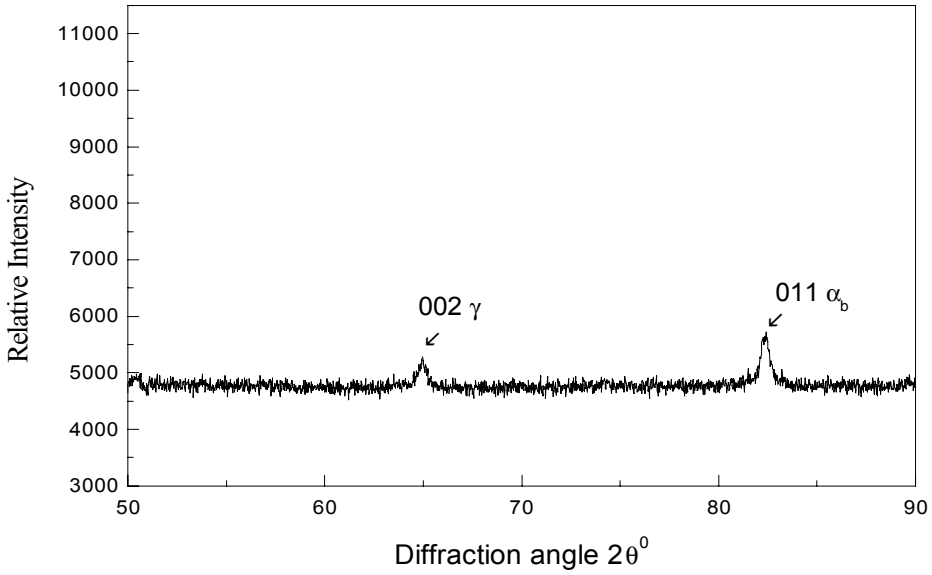
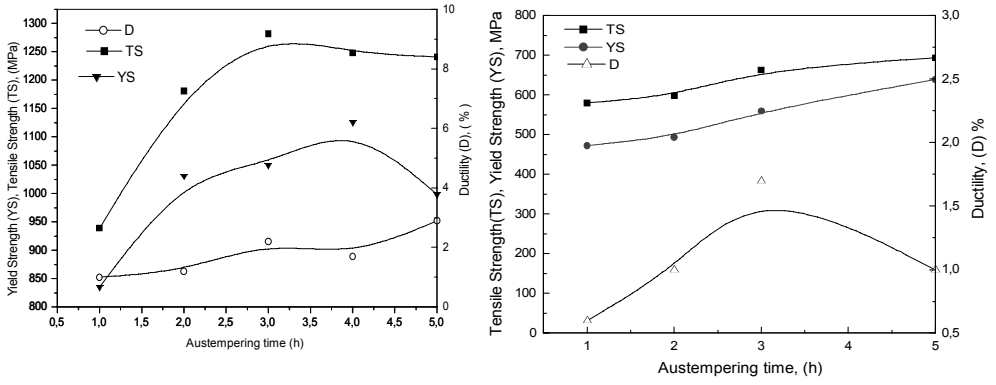



*Fig.3 X-ray diffraction pattern of ADI austempered at 320°C for 2,5h*

Change of tensile properties as a function of austempering time at 320 and 400°C are shown in Fig. 4 a,b, respectively. During austempering at 320°C (Fig. 4a) the highest values of yield strength (1100 MPa), and tensile strength

(1270 MPa) are achieved in early stage of austempering (before 2h), then tensile strength decreases. On the other side, ductility shows a steady increase reaching the value of 3,5% after 5h of austempering. It should be noted that strength shows a small minimum, whereas a small maximum of ductility was observed after about 2,5h of holding. The results from Fig. 4a indicate that even after 5hours of austempering at 320°C the stage i of bainitic reaction was not terminated. The fine dispersion of ferrite is responsible for the high strength of alloy at 320°C. On the other side, during austempering at 400°C values of yield strength, tensile strength and ductility are twice as lower than at 320°C. The initiation of stage II that coincides with the appearance of martensite reflects on the decrease of strength and ductility.




a) b)

*Fig.4 Effect of austempering time on yield strength (YS), tensile strength (TS) and ductility (D) of ADI at 320°C (a), at 400°C (b)*

Values of impact energy and volume fraction of retained austenite as a function of austempering time at 320°C are shown in Fig. 5. The maximum impact energy of 133 J corresponds to the maximum value of the austenite volume fraction (40vol%) that was reached after austempering for 2,5h. Small minimum of tensile strength and small maximum of ductility (see Fig. 4) also coincide with the maximum of impact energy. Although the volume fraction of retained austenite decreases very slowly with increasing time of austem-

pering, impact energy decreases steeply, but after 3h becomes stable at a value of 85 J. High values of toughness (in the range from 85 to 133 J) are ascribed to high volume fraction of retained austenite that is continuously distributed throughout the microstructure.

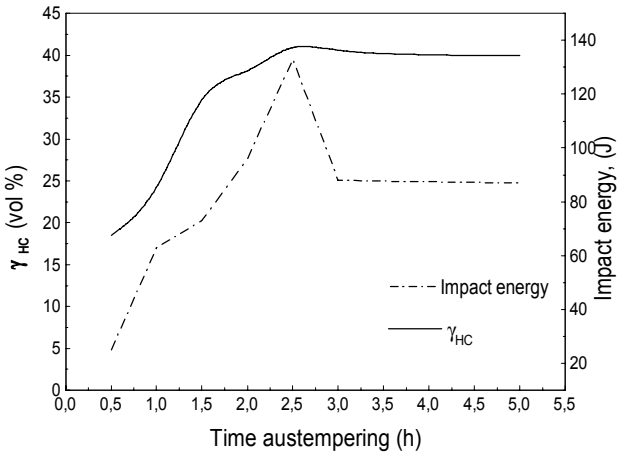



*Fig.5 Variation of the volume fraction of retained austenite and impact energy of ADI austempered at 320$^{O}$C*

## 4. Conclusions

- The results indicate that after austempering of CuNiMo SG alloyed ductile iron a correlation between microstructure and mechanical properties exists.

- Austempering at 320$^{o}$C in the range between 2 and 5h produces a typical austempered ductile iron microstructure consisting of free bainitic ferrite and a stable, highly carbon enriched retained austenite. The maximum value of impact energy (133 J) corresponds to the maximum volume fraction of retained austenite (40vol%) which was reached after 2,5h.

- The whole range of austempering time at 400$^{o}$C is distinguished by the presence of blocky austenite in which martensite was formed during subsequent cooling to the room temperature.

- During austempering at 400ºC yield strength, tensile strength and ductility are twice as lower than at 320ºC. The low values of tensile properties coincide with the appearance of martensite in the microstructure.

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