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EFFECT OF NICKEL CONTENT ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AUSTEMPERED DUCTILE CAST IRON

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ABSTRACT

Alloyed ductile Cast iron samples were produced using induction coreless furnace. The designed alloys have the following composition (3.4-3.8 % C , 2.3-2.7 % Si , 0.15-0.54 % Mn , 0.02 % S , 0.02 % p , 0.4-0.5 % Mo and variable Ni content from 0.5-4 %) The austempering heat treatment was performed using Salt bath furnaces, at a temperature of 900° c for 30 min. and the isothermal transformation was carried out at temp. of 220° C and 400° C . Austempering transformation time was varied from 10 min. to 24 hrs. to investigate its effect on the final structure and mechanical properties .

The results showed that, the best ductility and impact toughness for Austempered alloyed ductile Cast iron at 400° C was obtained by holding time equal to 60 min., while the optimum holding time at 220° C was 2 hrs. More over the alloy containing 0.5 % Mo & 2-4 % Ni provokes increase in hardenability and mechanical properties .

NOMENCLATURE

C	**Carbon**	(%)
Hv	**Hardness**	(Vickers)
IT	**Impact Toughness**	(Joule/Cm^2)
Mn	**Manganese**	(%)
Mo	**Molybdenum**	(%)
Ni	**Nickel**	(%)
P	**Phosphorus**	(%)
S	**Sulpher**	(%)
Si	**Silicon**	(%)
σu	**Ultimate Tensile Strength**	(Mpa)
δ	**Elongation**	(%)

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INTRUDUCTION

Austempring ductile cast iron importance in production of highly stressed components competes with low alloyed high quality steel giving comparable mechanical properties, fig . 1 better machinability, high castability and shorter time for heat treatment.

Austempring treatment is applied when bainitic matrix is desired. Bainite is a term applied primarily to those transformation products of austenite that form at temperatures between those at which pearlite and martensite form. In steels, austempring results in a bainitc structure normally consisting of acicular ferrite with carbides.

However, in cast Iron, precipitation of the carbide phase is suppressed due to the high silicon content and a lamellar structure of acicular ferrite and high carbon austenite is obtained [2].

The best mechanical properties are obtained by the first method [4].

Nodular iron is austenitized at a temperature between 850 °C and 950 °C. The holding time at this temperature depends on the alloying elements present and ranges from 15 min. to 5 hrs. Part of the graphite dissolves in the austenite up till matrix is carbon saturated. Thus, the carbon content of the matrix after austenitization depends on the austenitization temperature and the holding time. The amount of carbon in the austenite that is in equilibrium with the graphite increases with increasing the austenitization temperature, and is also influenced by the chemical composition of alloy.

During austempering, acicular ferrite plates grow in the austenite. The ferrite nucleates on suitable sites at the grain boundaries and at interface between austenite and graphite. Due to the ferrite formation, the carbon is rejected from the ferrite into the surrounding austenite. High silicon content suppresses the cementite phase normally associated with baintic transformation and a carbon – enriched stabilized austenite remains . This cementite – free bainite forms at temperature ranging from 175 °C and it can contain large amounts (up to 50%) of retained austenite which, because of its high carbon content, is stable to temperatures below – 80 °C [6]. The amount of retained austenite increases with the increase of the austenitization temperature due to higher carbon before quenching [5].

Austempring at temperature of 370 °C or higher produces a course structure of acicular ferrite needles in austenite at lower temperatures. The structures are much finer and resemble typical bainites having alternate platelets of ferrite and austenite. The ferrite austenite spacing decreases with decreasing the transformation temperature due to the close relation between structure and mechanical properties, it is understandable that strength and toughness of baintic ductile iron can vary widely. Highest tensile strength and relatively small elongation are obtained zone. Increasing the austempering temperatures results in a gradual decrease in the ultimate tensile strength and elongation. However increase and passes through a maximum [6].

Some investigator [7], [8] have shown that extended holding time during austempering causes a reduction of ductility and impact toughness. Increasing austempering time form one hour to two hours at 375 °C is

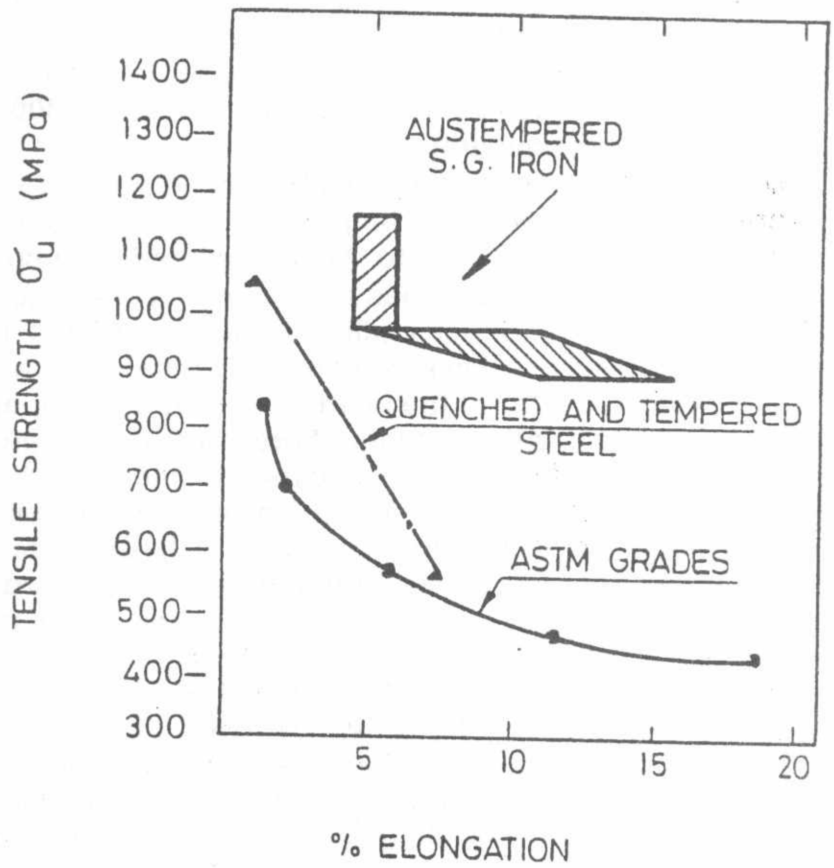


Fig .1. Comparison of austempered nodular irons to current standard grades of nodular iron [1] sufficient to reduce elongation and toughness by more than 50 % as shown in fig .2 [7] .

The austempering transformation can be considered as two-stage reaction. In the first stage , austenite decomposes to ferrite and carbon – enriched austenite. This is followed by the second stage in which austenite decomposes to ferrite and carbides, as can be seen from fig.3 Austempering transformation of steels can be described in the same way, as can be seen from fig .4 the final stage of austenite decomposition to ferrite and carbides has been observed at temperature as low as 300 °C and has been to occur at even lower temperature.
The addition of alloying elements to the ductile cast iron is essential for successful austempering heat treatment. The process of alloying delays the pearlitic reaction and allows quenching to the austempering temperature without forming pearlite or ferrite. Nickel has a graphitizing character. It can be used in place of silicon to offset chilling tendency. Nickel pearlite structure is readily annealable. Ni is weak in refining pearlite, but it acts as a graphitizer, facilitates break down of the pearlite at elevated temperatures during austenitization as shown from the work of previous investigators.
The previous study of hardenability for unalloyed ductile iron by Barta, Dorazil [8] showed poor hardenability, which lowers the possibility of utilization of austempered ductile iron for production of large section sizes and limits the thickness of hardened components. To improve the hardenability of unalloyed ductile cast iron Ni is added by different amounts. The following comparison of resulting structure and hardness values published by Climax 1982 [9] show the effect of Ni on the continuous cooling transformation diagrams. Fig.5. shows the CCT diagram of unalloyed ductile iron – where both pearlitic and bainitic transformation start are within the first minute of cooling so the time delay available for cooling before transformation is limited and the half cooling time for hardened structure is less than 1 min.
This means to obtain hard structures the cooling rate must be high enough to ensure bainitic or martensitic transformation which is about 8 °C /sec.
This critical rate of cooling cannot be reached for thick sections more than 10-mm thickness.
The addition of 4.8% Ni + 0.5% Mo increases the hardenability of ductile iron as shown in fig .5.a where the half cooling time of hardened layer 20 min and critical cooling rate of 0.3 °C /sec. That allows larger section size during hardening. Structures while d is pearlitic + ferrite
This means better hardenability by higher addition of Ni. The optimum addition of Ni to the ductile iron alloy is governed by the required critical cooling rate and the section sizes. Higher addition of Ni decreases the critical cooling rate and allows more thickness of hardened layer. The production of an alloyed ductile cast iron may satisfy the required hardness and strength for highly stressed components. The cast ductile iron does not satisfy these requirements. Austempering heat treatment confirms better combination of mechanical properties, which satisfy the required properties [10,11,12].

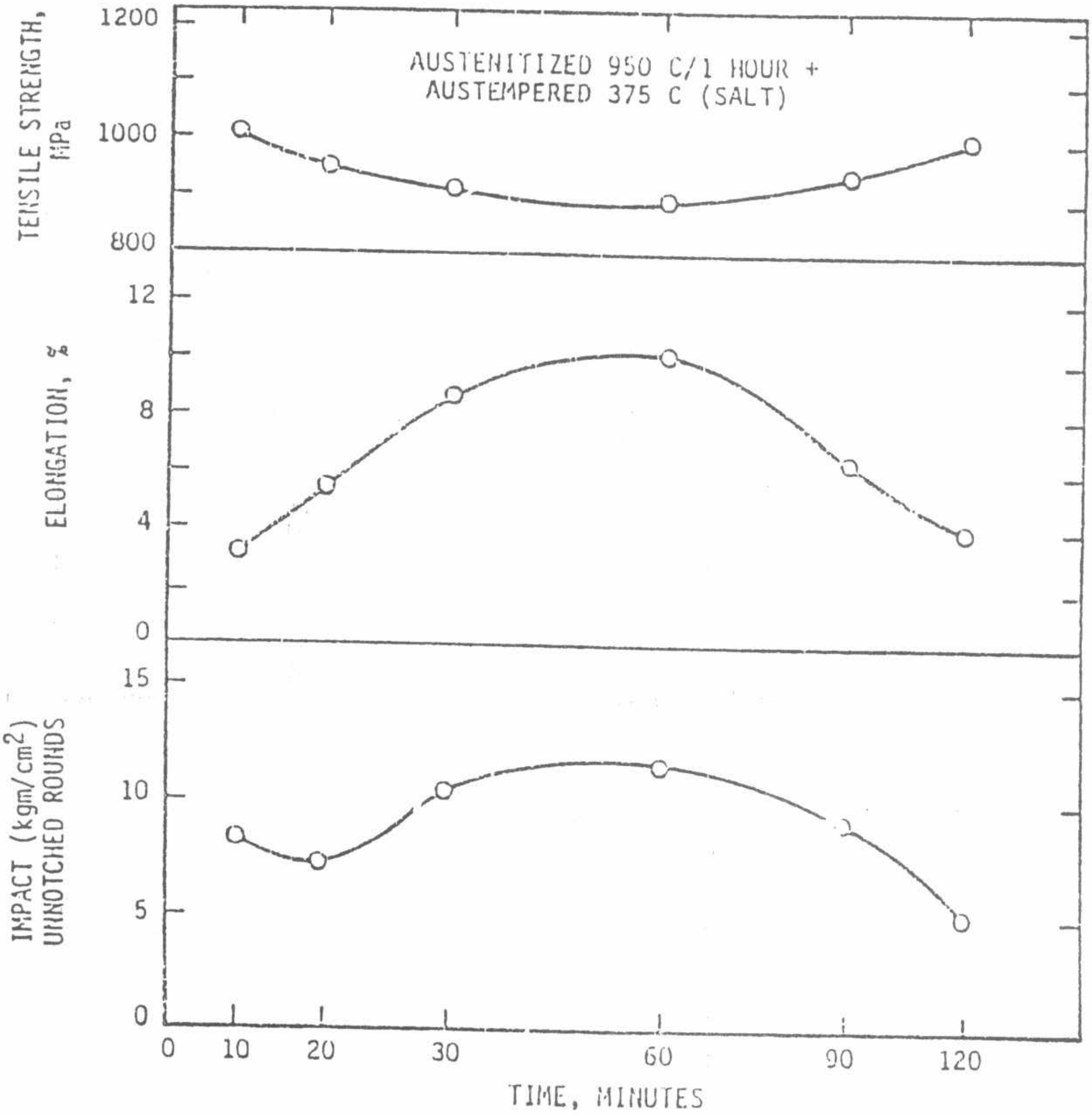


Fig .2. Influence of austempering time on the mechanical properties of unalloyed nodular iron [6]

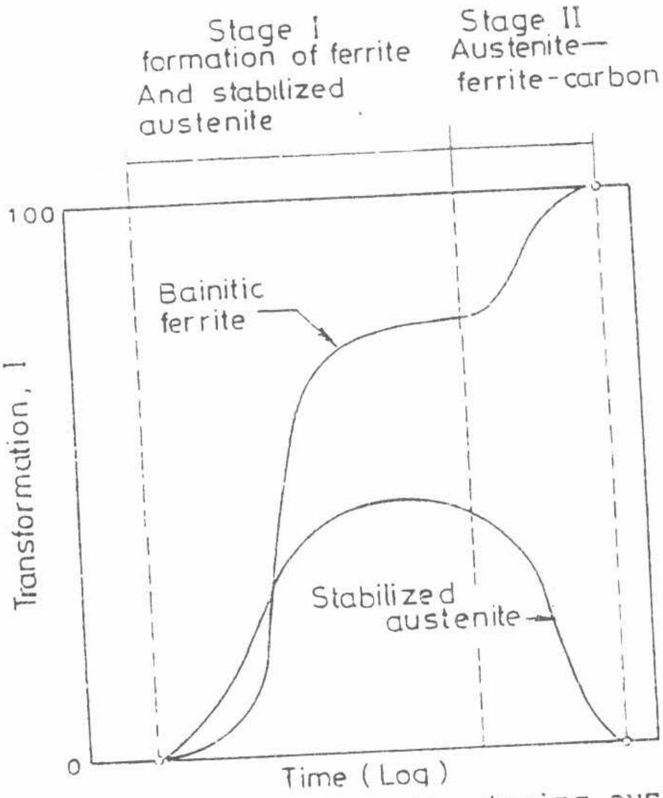


Fig .3. Transformation of austenite during austempering [2]

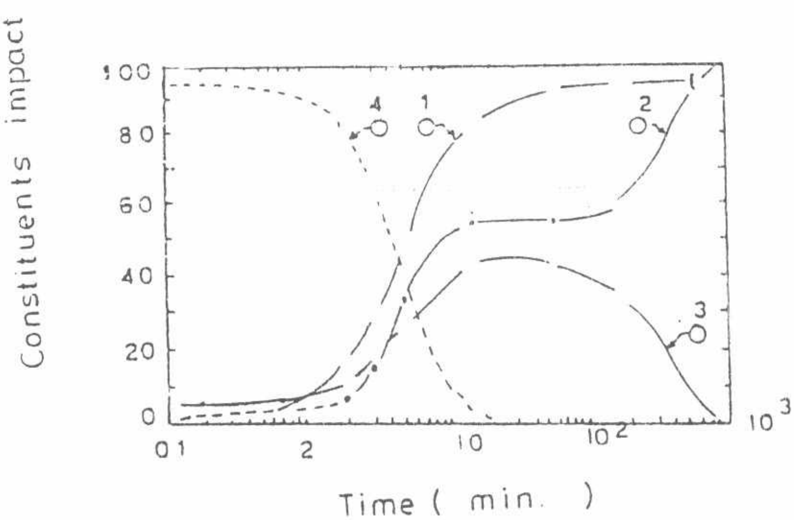
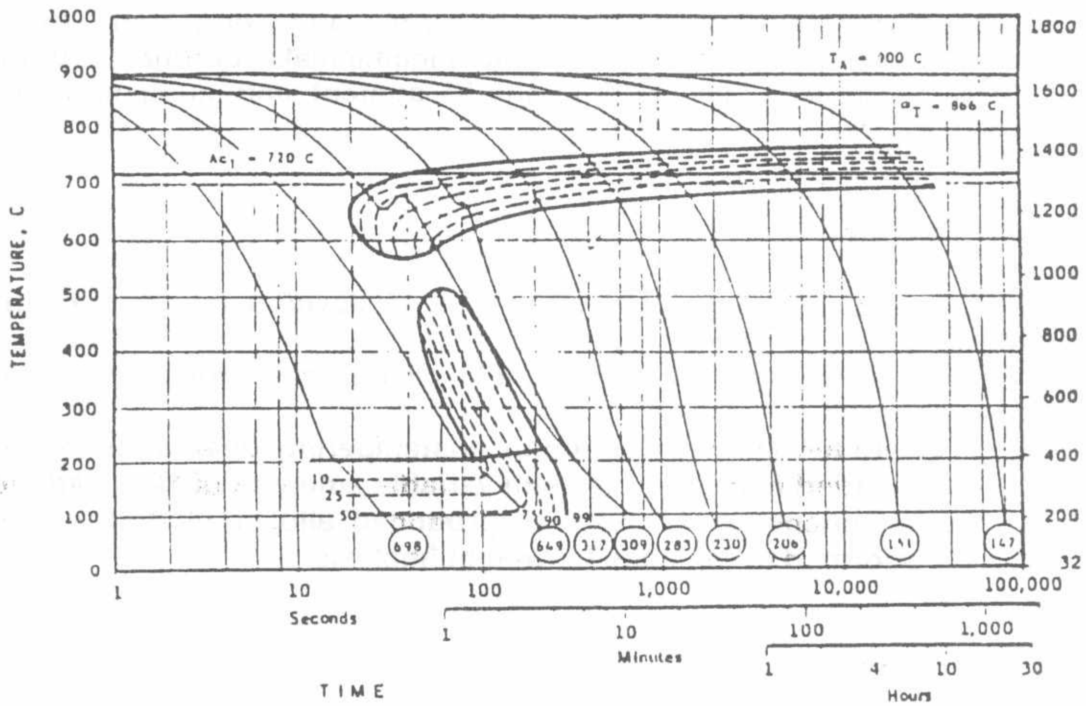


Fig .4.): Inflence of austempring time on the proportion of various constituents in bainitic silicon steel : 1- apparent bainite, , 2- transformed austenite, 3- retained austenite, and 4- martensite. [3]

Chemical Composition: 3.37% C, 2.62% Si, 0.31% Mn, 0.022% P, 0.009% S.



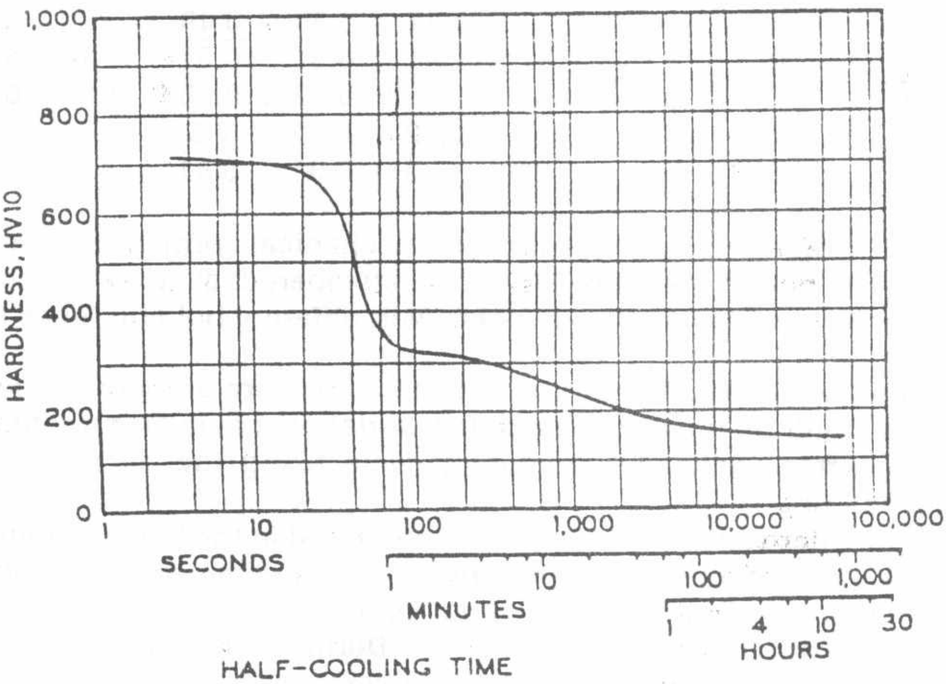


Fig .5. CCT-diagram for unalloyed ductile iron [9]

The aim of this research work is to study the effect of austemoering isothermal transformation temperature and time on the resulting morphology, and to evaluate various mechanical properties of the alloyed ductile cast iron having different Ni content and austemperd at different temperature.

EXPERMENTAL WORK

The program of experimental work is devided into two main parts as follows:

1 – Production of alloyed ductile cast iron samples using in – mould process.

2 – Determination of optimum austempering heat treatment cycles for alloyed ductile cast iron with variable amounts of Ni % - additions . The chemical analysis of produced alloyed ductile cast iron were performed in the state by weight analysis

Table 1. Chemical composition of alloyed ductile iron.

Element / Melt NO.	C%	Si%	Mn%	Mo%	Ni%	P%	S%
1	3.29	2.32	0.26	0.49	0	0.02	0.01
2	3.32	2.41	0.31	0.51	0.49	0.023	0.011
3	3.34	2.25	0.32	0.48	101	0.023	0.011
4	3.28	2.42	0.32	0.5	1.98	0.024	0.008
5	3.24	2.34	0.31	0.51	4.1	0.024	0.008

The Prepared specimens for mechanical properties (tensile, impact resistance and hardness) were austempered at 220 °C according to heat treatment cycle shown in fig.6. with different holding times from 10 min to 24 hr.

Samples for microstructure observation were prepared simulatneously for each holding time to detect the variation of microstructure with holding time. After each heat treatment cycle using the micro hardness tester of load 10 gr.

The microstructure of samples austempred in the lower bainite region 220 °C were examined by optical microscope after etching with 4% nital.

Melting was carried out using 20 kg capacity induction furnace in the Helwan the Helwan iron fundraises. During melting of the base charge – The unnecessary superheating was prevented in order not to promote carbide formation . The base charge was melted and heated to temperature 1550 °C. The ladle was preheated before ladling . slag skimming of melt surface was performed in the ladle before the addition of the graphitizaing inoculate

The graphitizaing inoculation was carried by adding of 75% Fe-Si foundry grade in granular form size 3-5 mm.

The melt was then poured into the mould. The pouring temperature was 1450 ° C.

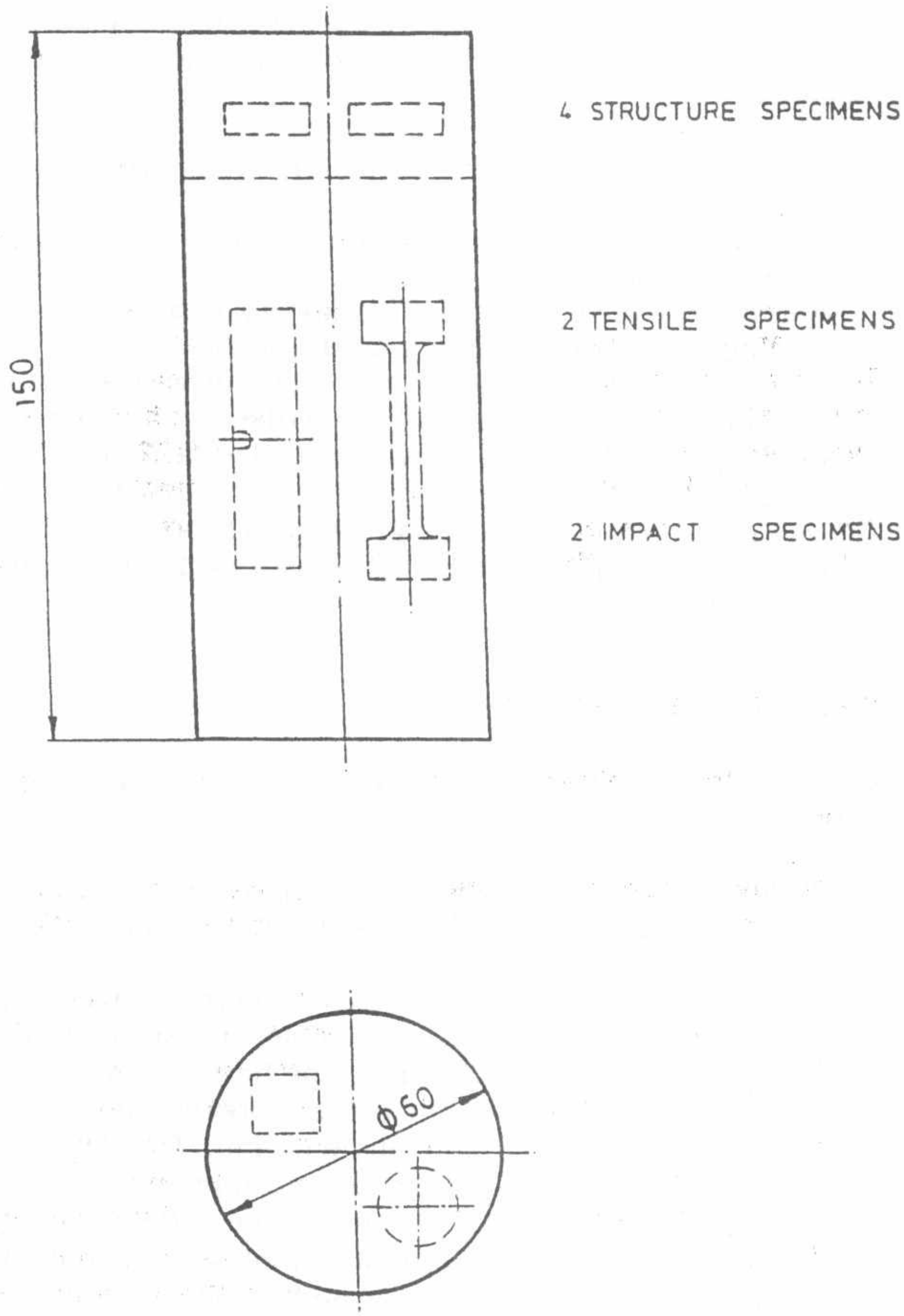


Fig .6. Test samples prepared from the cast bar.

A chilled cast specimen, for spectral analysis was poured in a metallic mould.
After solidification and cooling of the casting, shaking out and cleaning by sand blast machine.
The test samples were machined from the cast bar according to the drawing shown in fig .6. The following tests were then carried on the prepared specimen:

1 – Determination of the chemical composition by spectrographic analysis of the chilled cast specimen and by weight analysis of specially cut drilling chips.
2 – Optical microscope observation and nodule counting of the produced ductile cast iron
3 – Mechanical properties testing tensile, impact and hardness tests were carried out on standard prepared samples.

To investigate the effect of the subcritical isothermal transformation temperature on the mechanical properties of both upper and lower bainite, two austempring temperatures were selected (220 ° C, 400 ° C)
To study the effect of holding time the mechanical properties the test specimens were austemepred at temperature 220 ° C and 400 ° C for 6 different holding times (10 min, 30 min, 1 hr, 2 hrs, 10hrs, 24 hrs) as shown in fig .7. and fig .8.

RESULTS AND DISCUSSIONS

The results obtained through out this work can be divided into two main groups :

I - Microstructure observation of austempered alloyed ductile iron.
II- Mechanical properties of austempered alloyed ductile cast iron.

I – Microstructure observation of austempered alloyed ductile iron:

Illustrative Microstructure of samples is shown in fig .9. a, b and c. The dark areas represent the apparent bainite amount transformed during holding time while the white areas represent the retained austenite which is not transformed during austempring. The apparent bainite areas are composed of lower bainite plates appearing in the needle form and retained austenite captured between the bainite plates.

Microstructure observation of samples austempered at 400°C, (upper bainite region) in fig.10. a, b and c. the upper bainite structure is more coarse than observed lower bainite. It has a feathery like structure arranged in stacks of parallel lathes or needles of bainite.

II - Mechanical properties of austempered alloyed ductile cast iron.

The tensile properties of austempered alloyed ductile cast iron were tested using standard tensile test specimens 8.76× 35mm. For each austempring temperature table (3) austempered alloyed ductile cast iron at 400 ° C all samples were tested by the universal testing machine INSTRON 8032 at room temperature 25 °C and relative humidity 60% The

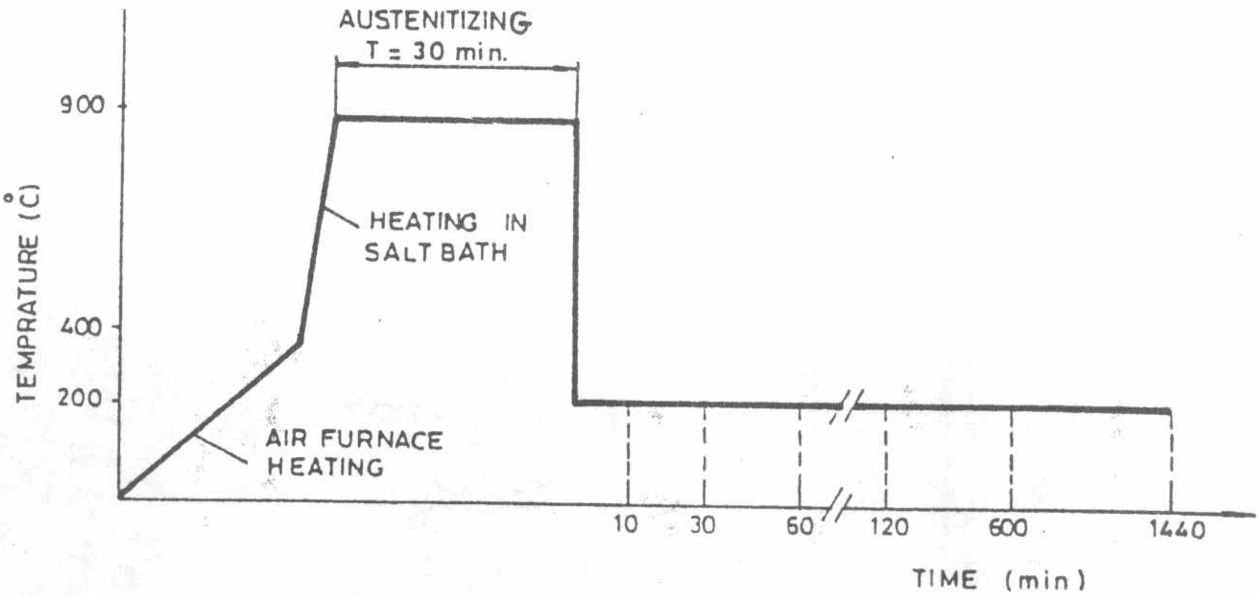


Fig .7. Representation f the applied austempering thermal cycle (220°C)

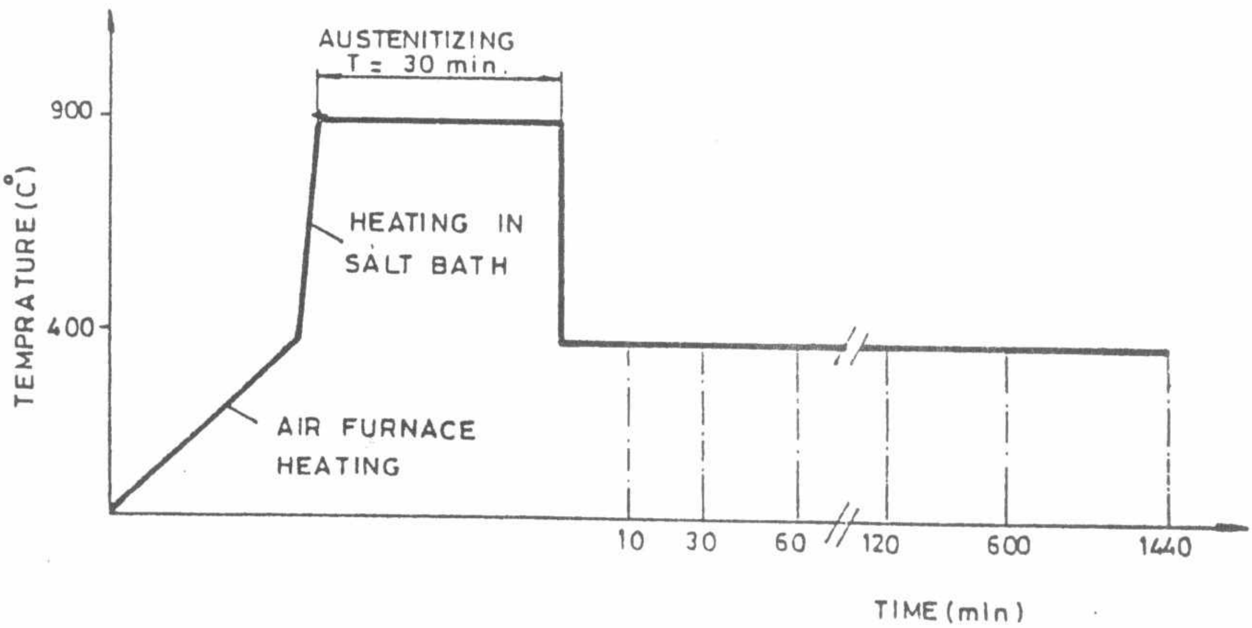
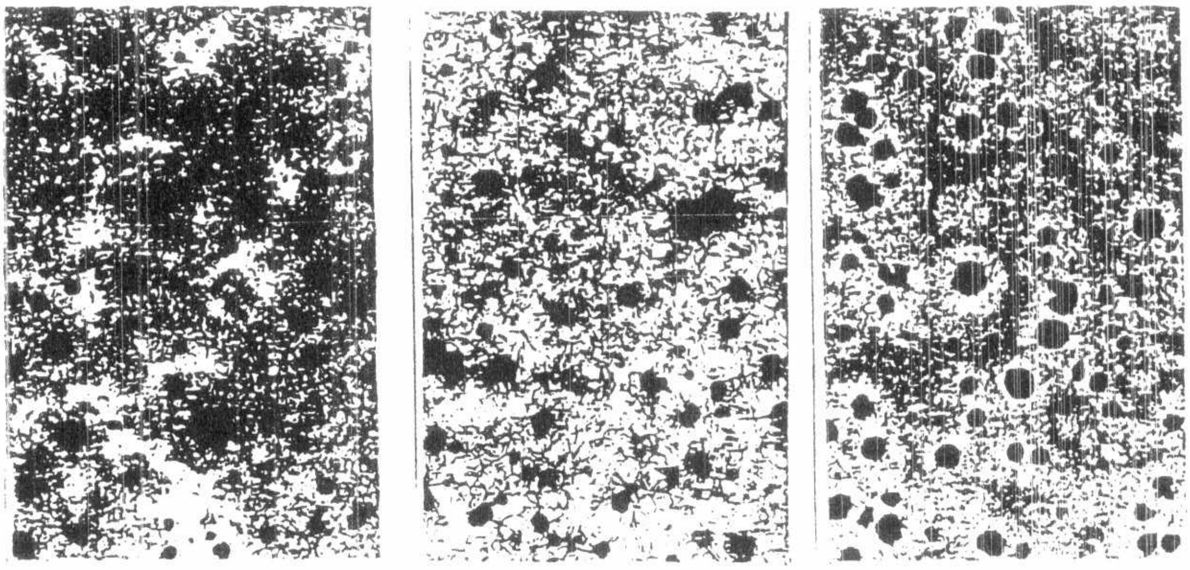


Fig .8. Representation of the applied austempering thermal cycle (400 °C)

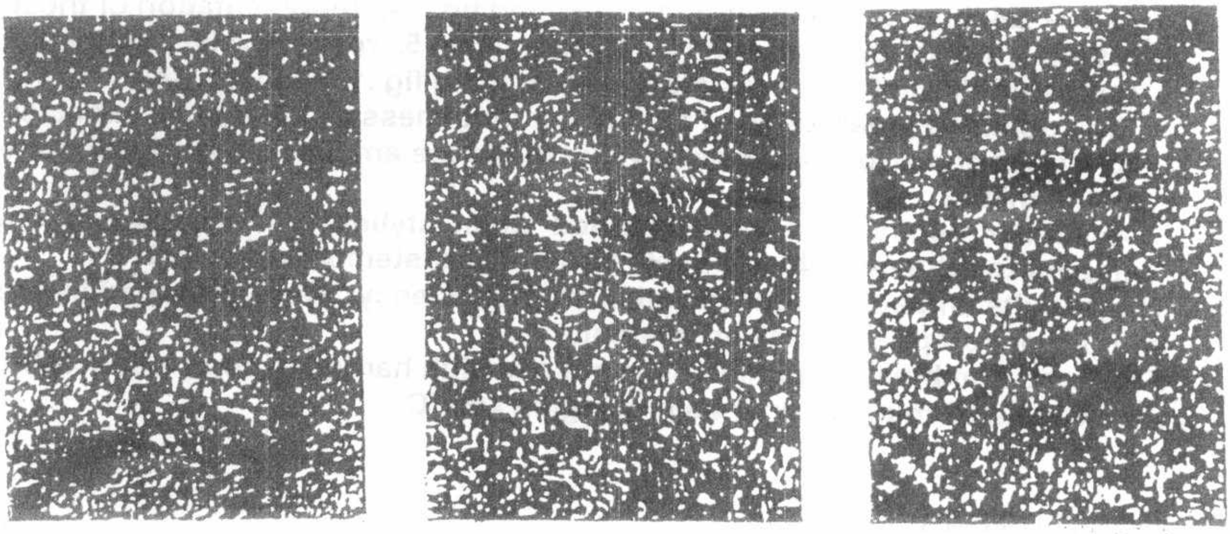


4 % Nital 100 X | 4% Nital 100 X | 4% Nital 100 X

(A) 0.5% Ni | (B) 1% Ni | (C) 4% Ni

Fig .9. Effect of Ni content on microstructure variation of lower bainite austempered ductile iron austempering temperature 220 °C , austempering time 10 min.

(A) (B) (C)



4% Nital 500 X | 4% Nital 500 X | 4% Nital 500 X

(A) 0.5 % Ni | (B) 1% Ni | (C) 4% Ni

Fig .10. Effect of Ni content on microstructure variation of upper bainite austempered ductile iron, temperature 400°C austempering time 30 min.

results of mechanical properties for lower bainite samples and upper bainite are represented graphically in fig .11. and fig .12.

Form the results of tensile testing and micro-hardness testing lower bainite samples austempered at 220 °C with different holding times, Its clear that the ultimate tensile strength is increasing by increasing the holding time till reaching maximum value at two hours.

Future increase of holding time gives no significant change in tensile strength. The hardness curve shows decrease in hardness by increasing holding time reaching a minimum after two hours.

Future more than two hours at 220 °C will increase the hardness slightly.

The result of impact toughness tests for alloyed ductile cast iron samples austempered at 220 °C and 400 °C with variable holding times from 10 min – 24 hrs. are shown in fig .13. and fig .14. representation of these results are shown in table 4. and table 5. respectively , graphical representation of these results is shown in fig fig .13. and fig .14.

The obtained peak value of the impact toughness at 120 min. is expected to correspond to a maximum value of the the amount retained austenite in the matrix .

A similar behavior is also obtained when styling the variation of the impact toughness value of ductile iron with austempering at 400 °C.

The results Impact toughness should consistency were governed by the amount of soft phase retained austenite .

For best combination of high strength and high hardness choice of holding time will be 60 min. at upper bainite region 400 °C.

CONCLUSIONS

From these research work we can come to the following conclusion :

1 – Best ductility and impact toughness foe austemperd alloyed ductile cast iron at 400 °C was obtained by holding time equal 60 min. The addition of 4 % Ni increased the impact toughness level to 154 joule/cm² which represent 25% increase compared with unalloyed ductile cast iron, austempered at 400 °C for 1 hr. holding time (130 joule/cm²).

2 – The optimum holding time at (lower bainite region) 220 °C was 2 hrs giving the maximum possible σ and reasonable Hv. For highly stressed components.
Addition of 4% Ni increased both the obtained maximum strength and ductility.

3 – Addition of 0.5 % Mo and 2-4 % Ni showed increase in hardenability of ductile cast iron if compared with unalloyed one, allowing austempering of large section sizes reaching (35-50mm)

ACKNOWLEDGEMENTS

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Table 2. Mechanical Properties of Austempered Alloyed Ductile Iron after Holding Time At 220 °C

Ni% Content	Mechanical Properties	Holding time					
		10 min	30 min	1 hr	2 hrs	10 hrs	24 hrs
0.0	σu Mpa	860	960	1230	1240	1240	1240
	δ %	0.9	1.8	3.0	4.0	2.0	1.0
	Hv10	600	580	530	470	480	500
0.5	σu Mpa	870	1000	1240	1250	1250	1250
	δ %	1.1	2.0	3.5	5.0	2.5	2.0
	Hv10	620	600	550	490	500	510
1.0	σu Mpa	880	1100	1250	1280	1280	1280
	δ %	1.3	2.2	4.0	5.5	3.0	2.0
	Hv10	640	620	570	510	520	550
2.0	δ %	900	1220	1270	1300	1300	1300
	δ %	1.5	2.5	4.5	6.0	3.5	3.5
	Hv10	660	640	290	530	540	550
4.0	σu Mpa	910	1250	1290	1350	1350	1350
	δ %	1.7	3.0	5.0	6.5	4.0	3.0
	Hv10	680	660	610	550	560	570

Table 3. Mechanical Properties of Austempered Alloyed Ductile Iron after Holding Time At 400 °C

Ni% Content	Mechanical Properties	Holding time					
		10 min	30 min	1 hr	2 hrs	10 hrs	24 hrs
0.0	σu Mpa	765	900	940	950	890	820
	δ %	1.6	4.5	7.0	5.0	3.5	3.3
	Hv10	365	315	290	295	300	310
0.5	σu Mpa	780	830	960	970	915	850
	δ %	1.7	5.0	7.0	6.0	4.0	3.2
	Hv10	390	330	300	305	320	350
1.0	σu Mpa	800	850	980	990	935	860
	δ %	1.8	5.5	8.0	7.0	4.5	3.8
	Hv10	410	350	320	325	340	360
2.0	σu	820	870	1000	1005	950	900
	δ %	2.2	6.0	8.5	7.5	5.0	4.2
	Hv10	440	370	350	355	380	400
4.0	σu Mpa	840	990	1030	1035	980	920
	δ %	2.5	7.0	9.5	8.0	6.0	5.0
	Hv10	460	400	370	375	390	420

Table 4. Variation of Impact Toughness (IT) For Austempered Ductile Iron At 220 °C With Variable Ni Content (average of 3 readings)

Ni% content	Mech. Prop. (joule)	Holding Time					
		10 min	30 min	1 hr	2 hrs	10hrs	24 hrs
0.0	IT	61	64	68	69	62	59
0.5	IT	65	70	73	75	68	66
1.0	IT	69	74	78	80	73	70
2.0	IT	73	78	82	85	77	74
4.0	IT	78	84	87	90	82	86

Table 5. Variation of Impact Toughness (IT) For Austempered Ductile Iron At 400 °C With Variable Ni Content (average of 3 readings)

Ni% content	Mech. Prop. (joule)	Holding Time					
		10 min	30 min	1 hr	2 hrs	10hrs	24 hrs
0.0	IT	112	127	130	128	108	106
0.5	IT	115	132	134	130	114	110
1.0	IT	120	136	142	138	117	112
2.0	IT	125	142	145	143	122	115
4.0	IT	130	146	154	148	126	118

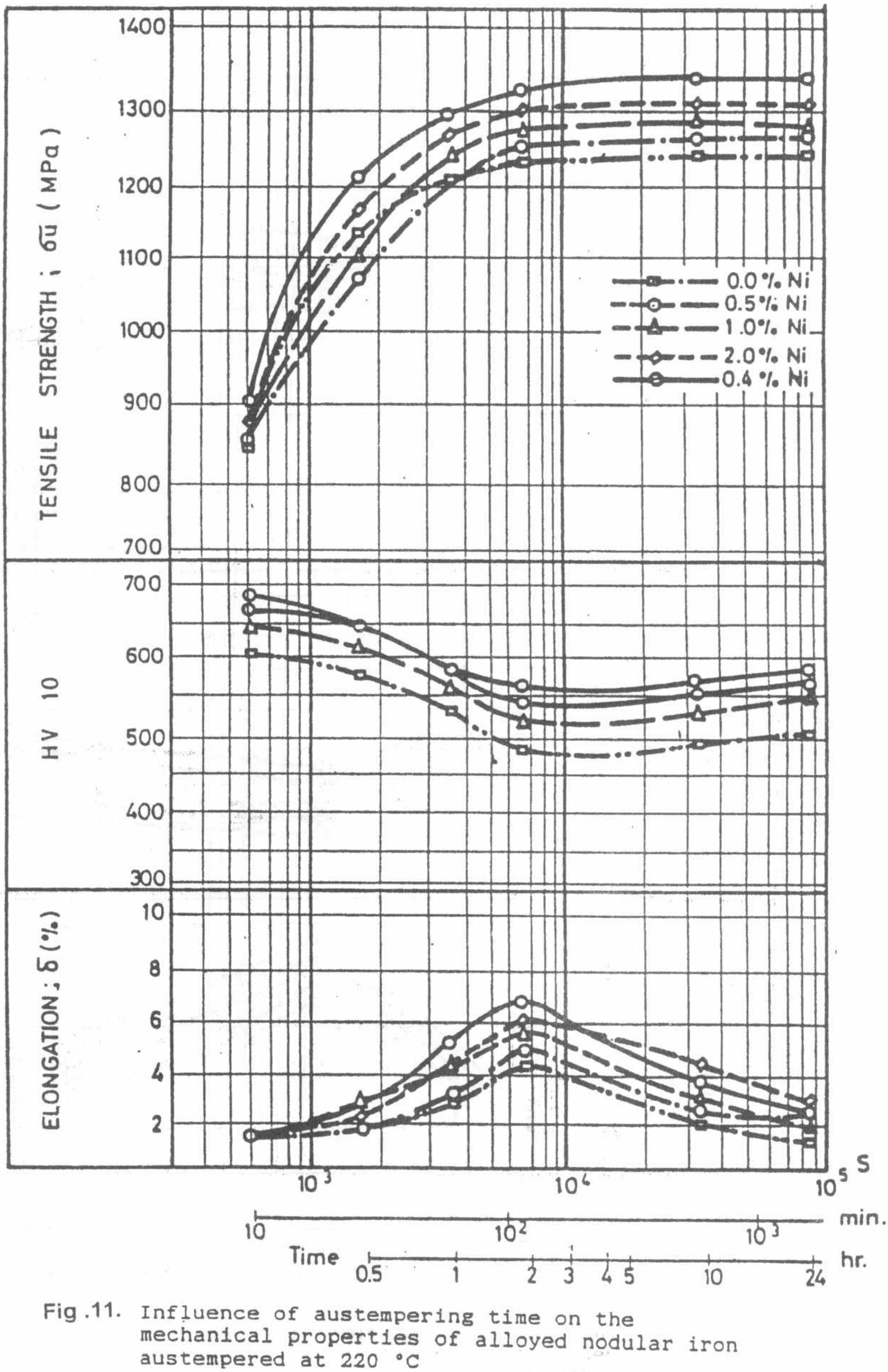

Fig .11. Influence of austempering time on the mechanical properties of alloyed nodular iron austempered at 220 °C

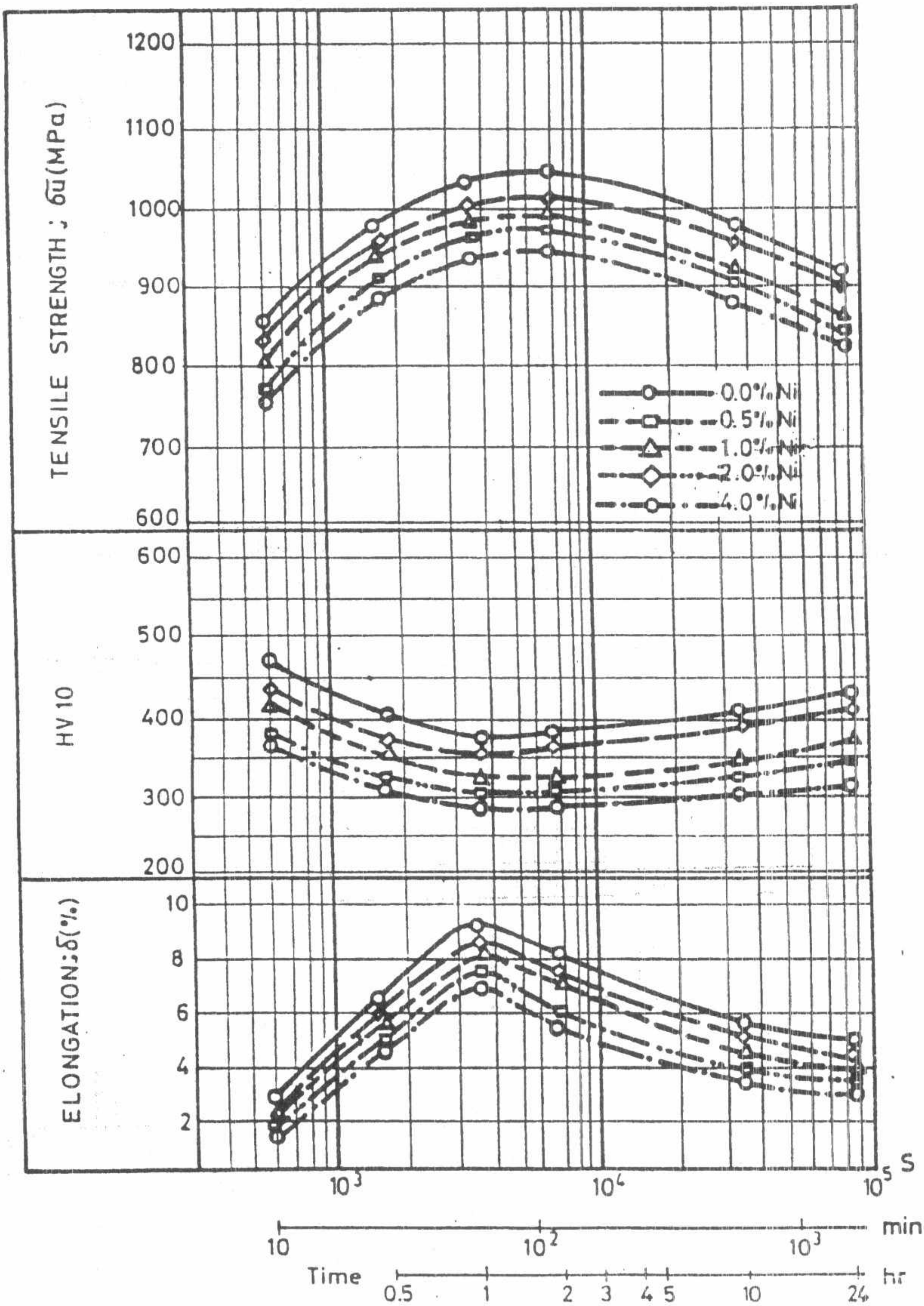

Fig.12. Influence of austempering time on the mechanical properties of alloyed nodular iron austempered at 400 °C

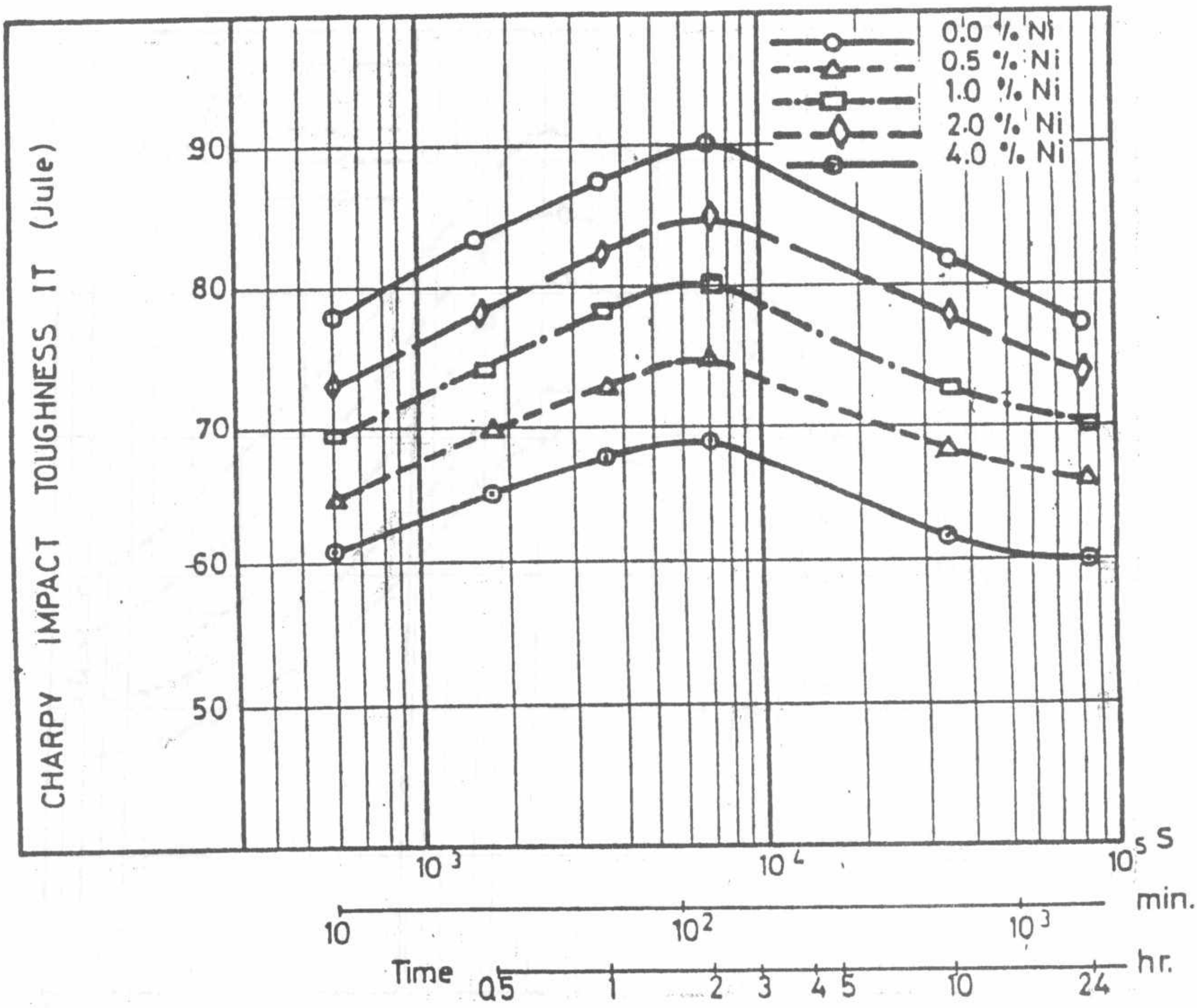

Fig .13. Influence of austempering time on the Charpy U-notch impact toughness of D.C.I. austempered at 220 °C.

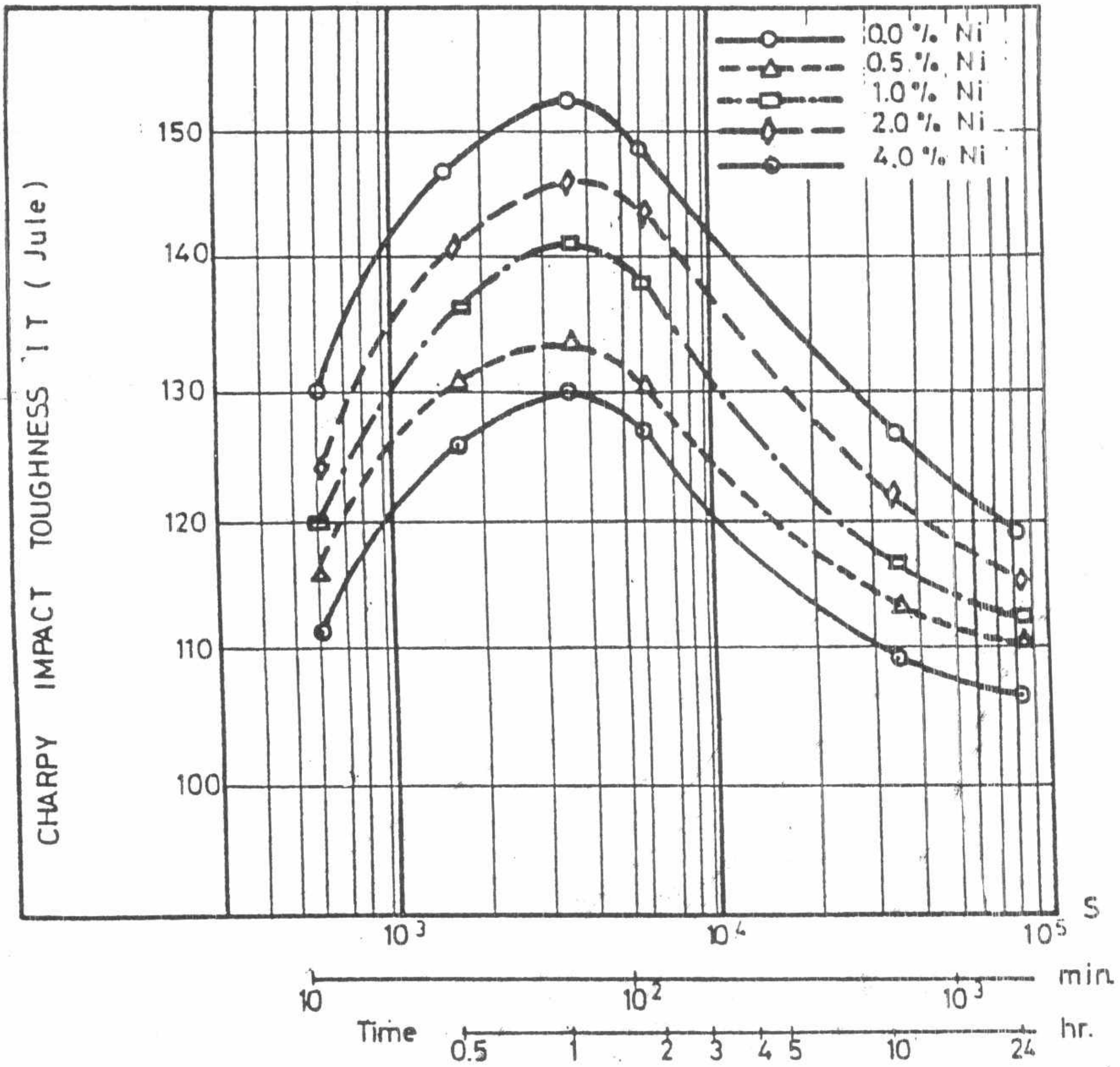

Fig .14. Influence of austempering time on the Charpy U-notch impact toughness of D.C.I. austempered at 400 °C.

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