Austempered Nodular Cast Irons

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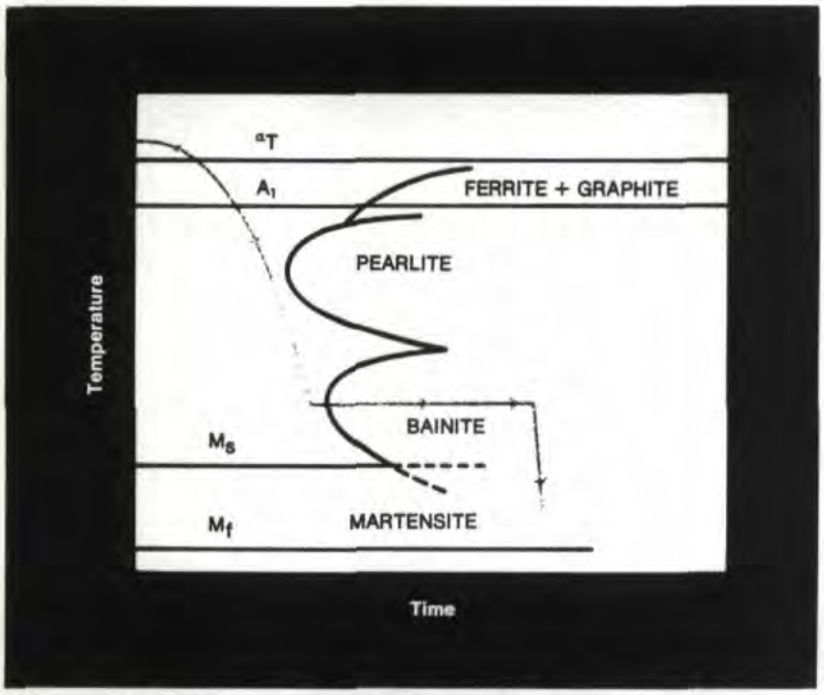

Fig. 1 – Representation of Austempering Heat Treatment (– –) Imposed on Hypothetical Nodular Iron CCT Diagram

Austempering heat treatments (austenitizing followed by rapid cooling to the tempering temperature) have been applied to nodular irons on an experimental basis for a number of years, but commercial interest in the process has only recently come to the surface. Research in the seventies in Europe, Japan and the United States has shown that austempering is capable of producing irons with strengths over 1000 MPa (145 ksi), ductilities in the order of 10% and toughness levels approaching those of ferritic nodular irons.(1-5)

Austempering as a treatment for alloy steels was discovered in the 1930's as a result of work on the subcritical transformation of austenite. The principal advantages are (1) good control of the transformation process and (2) freedom from residual stress, distortion and cracking associated with rapid cooling from the austenitizing temperature to room temperature.

In steels, austempering results in a bainitic structure consisting of acicular ferrite with carbide needles. In irons, however, the high silicon content suppresses precipitation of the carbide phase, and a lamellar structure of acidular ferrite and high carbon austenite is produced. Fig. 1 schematically represents the austempering treatment superimposed on a hypothetical nodular iron transformation diagram. Rapid cooling from the austenitizing temperature is necessary to avoid precipitation of ferrite or pearlite. Unalloyed irons must be severely quenched in oil or water, but alloying that moves the ferrite and pearlite regions to longer times allows parts to be cooled at lower rates as, for example, in salt baths or forced air systems. Thus alloying is a necessity as section size increases or when distortion and cracking from rapid cooling rates cannot be tolerated. Approximate alloy contents required to avoid pearlite formation on cooling nodular irons to the austempering temperature have been proposed as follows:(4)

Section	Alloy Content*	
mm(in.)	Salt Quench	Forced Air
8 (0.3)	None	0.3% Mo
10 (0.4)	None	0.35% Mo + 1% Cu or 0.48% Mo
25 (1)	0.3% Mo.	0.3% Mo + 1% Ni or 0.3% Mo + 1.5% Cu
37 (1.5)	0.35% Mo. + 1% Cu or 0.5% Mo	0.5% Mo + 2% Ni or 0.7% Mo + 1% Cu or 1% Mo + 0.6% Ni
50 (2)	–	0.5% Mo + 2.3% Ni

*Alloy content required in typical nodular base irons containing 3.4–3.8% C, 2.0–2.6% Si, 0.1–0.4% Mn

Molybdenum is technically necessary as an alloying element in austempered irons in heavy sections, and it is cost effective in light sections because it permits the use of lower cooling rates and/or bulk heat treating of parts.

To further pursue the effects of alloying, it should be recognized that silicon, an element used to control carbides, has a negative effect on hardenability, and it segregates to the solid during solidification resulting in a gradient in the direction of lower levels in the intercellular material. Nickel can be added to compensate for the hardenability loss due to silicon, but the nickel content must be

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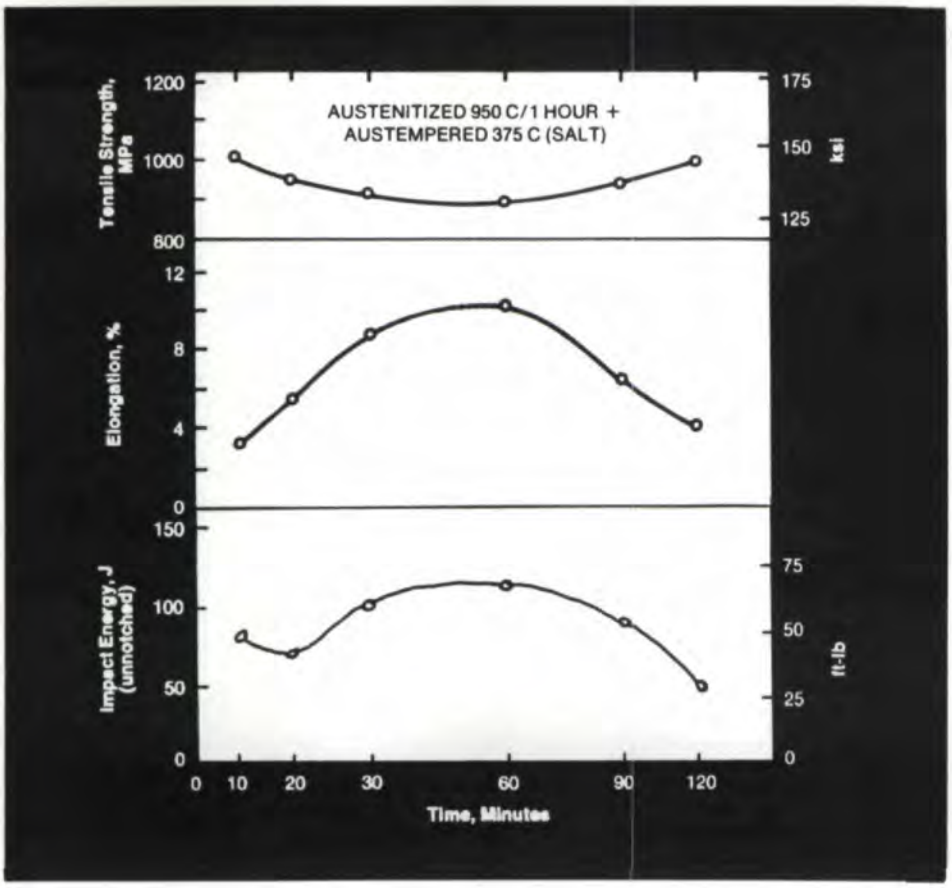

Fig. 2 – Influence of Austempering Time on the Mechanical Properties of Unalloyed Nodular Iron

limited because of its stabilizing effect on austenite. Molybdenum is effective in austempered nodular irons because (1) it retards pearlite formation while allowing the acicular ferrite transformation to proceed, (2) it segregates in an opposite manner to nickel, thereby, providing a better balanced microhardenability without promoting massive intercellular cementite, and (3) it does not delay intermediate transformations, thereby, keeping austempering times reasonable.

Typically, austempering treatments for nodular iron components consist of quenching from the austenitizing temperature to a tempering temperature in the 175 to 425 C (300 to 800 F) range, holding at that temperature for a predetermined time, then cooling to room temperature. Tempering at the high end of the range, above about 370 C (700 F), produces a coarse structure of acicular ferrite in austenite. At lower tempering temperatures, structures are finer and resemble typical upper bainites with lath formations containing alternate platelets of ferrite and austenite.

Holding time at the austempering temperature is important from the standpoint of microstructure and mechanical properties. Too short a holding time results in the formation of martensite on quenching to room temperature, and extended holding can result in carbide precipitation depending on the alloy content (hence stability) of the austenite. Consequently optimum toughness is achieved by holding times sufficiently long to suppress martensite, but not so long that carbide precipitation occurs.

Fig. 2 shows that ductility and toughness of unalloyed austempered irons decrease at longer holding times because of carbide precipitation and decreasing austenite content.

As shown in Fig. 3, austempering can be described as a two-stage reaction. In the first, austenite decomposes to acicular ferrite and carbon-enriched austenite. In the second, austenite further decomposes to ferrite and carbide. Most alloying elements have been shown to retard austenite decomposition, and, therefore, reduce sensitivity to austempering time.

The interesting properties of austempered nodular irons, particularly high toughness and wear resistance, result from the austenite content. The nature

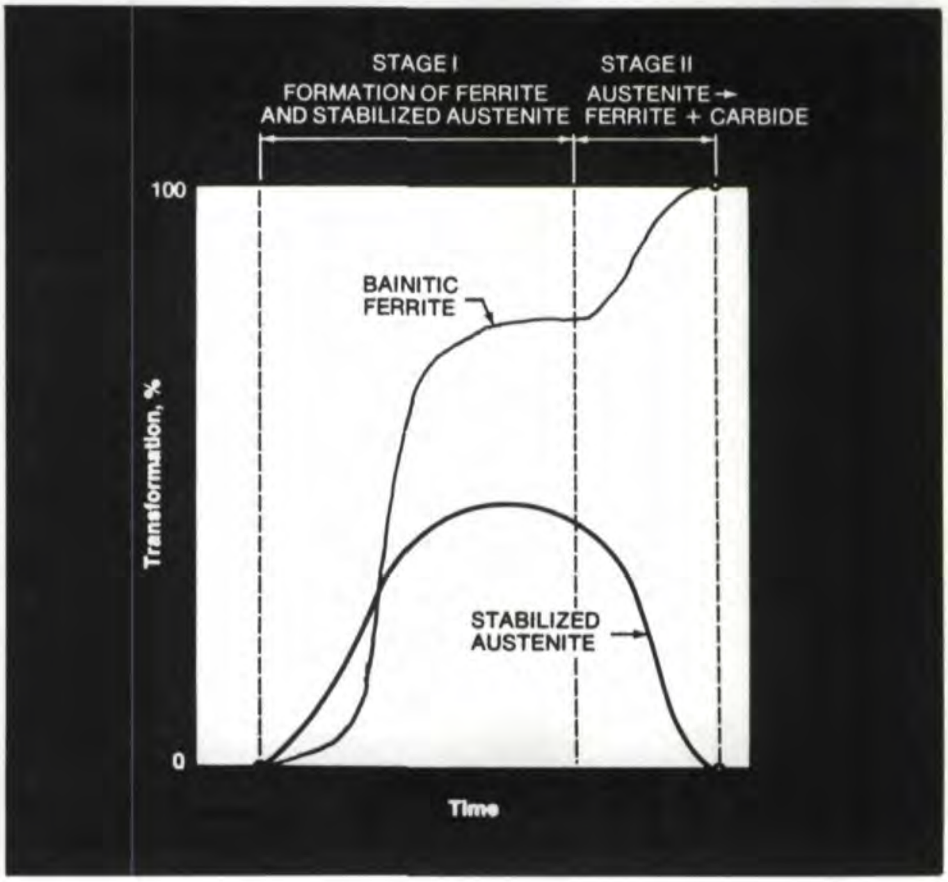

Fig. 3 – Transformation of Austenite During Austempering

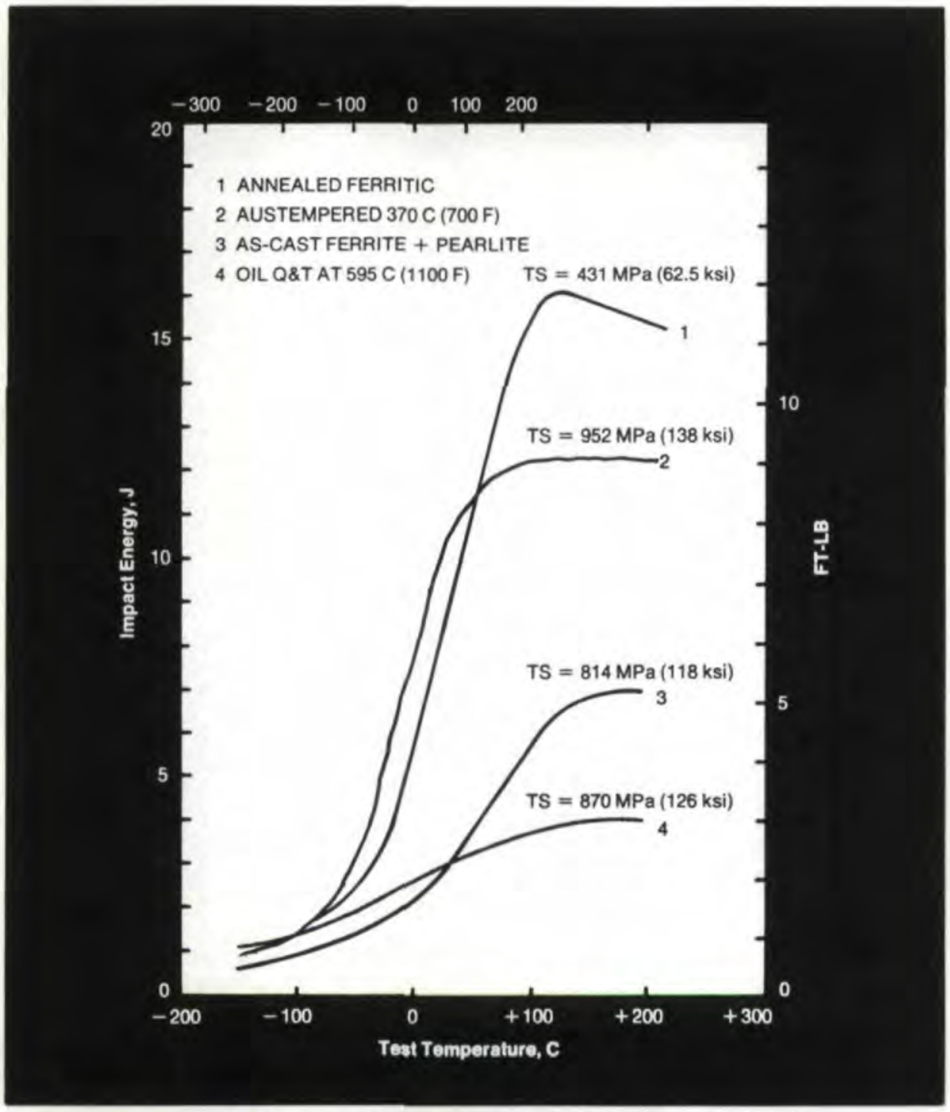

Fig. 4—Impact Properties of Indicated Nodular Irons

of the austenite is markedly influenced by its carbon content. For example, work hardening rate, resistance to stress-induced martensite transformation, low temperature structural stability and toughness are considered dependent on the carbon content of the austenite, which, in turn, is controlled by the austenitizing conditions and also influenced by chemistry.

Fig. 4 shows impact transition temperature curves for nodular irons in four different conditions. The austempered iron, Curve 2, has by far the best combination of tensile strength, transition temperature and upper shelf energy.

In applications requiring good wear resistance, service-induced work hardening of the austenite is the key to successful uses of austempered nodular irons.

Austempered nodular irons are being used or are being comtemplated for use in a number of applications formerly thought of as being in the exclusive province of wrought steels. Further, the interesting combinations of properties that can be achieved plus the inherent part-to-part uniformity that is possible are certain to increase the uses of these materials.

References

1. M. JOHANSSON, "Austenitic-Bainitic Ductile Iron," AFS Trans. 85, 1977, pp. 117-122.
2. E. DORAZIL, "Zwischenstufenumwandeln von Gusseisen mit Kugelgraphit," Gusseisen-Praxis, Heft 18, 1979, pp. 355-366.
3. T. SHIOKAWA, "On the Austempering of Ductile Cast Irons, Their Mechanical Properties and Some Practical Applications," 59th Japan Ductile Cast Iron Assoc. Licensee Conf., Nov. 17, 1978.
4. J. DODD, "High Strength, High Ductility, Ductile Irons," Modern Castings 68, No. 5, 1978, pp. 60-66.
5. J. F. JANOWAK, R. B. GUNDLACH, G. T. EDS and K. ROHRIG, "Technical Advances in Cast Iron Metallurgy," 48th International Foundry Congress, Varna, Bulgaria, October 4-7, 1981.

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