Effects of manganese in nodular (SG) iron

The structure and properties of as-cast and heat-treated nodular iron are affected by the manganese content. In nodular iron all of the manganese behaves as an alloying element; manganese is not partly present in the form of manganese sulphide, as occurs in flake graphite irons.

Effect on structure
As manganese content increases:
- Eutectic carbide is more likely to occur as-cast (Fig. 1). In thin-section castings the carbide is distributed uniformly across the section, but in larger slowly cooled sections the manganese segregates to the cell boundaries and results in intercellular carbides.
- Pearlite forms in preference to ferrite, in both as-cast (Fig. 2) and heat-treated irons. Manganese is a less powerful pearlite-promoting element than tin, copper or arsenic.
- Graphitization of eutectic carbides and pearlite during annealing occurs less rapidly. When the manganese content exceeds about 0.75 per cent it segregates to the cell boundaries even in thin sections, and prolonged heat treatment is unlikely to produce a fully ferritic matrix.

Fig. 1. The effect of increasing manganese content on chill depth in nodular iron produced from a high-purity pig iron: Mn contents 0.02, 0.10, 0.19, 0.28 per cent.

Fig. 2. Structures of 30mm-diameter as-cast nodular iron bars showing the increased pearlite content resulting from the addition of manganese, containing left, 0.03 per cent manganese and right 0.28 per cent manganese.

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The hardenability of the iron increases, and enables thicker sections to be hardened by quenching from the austenitizing temperature without the formation of ferrite and pearlite in the structure. The effect of increasing manganese content on end-quench hardenability is shown in Fig. 3. Hardenability is an important consideration in the production of irons which are to be hardened and tempered.

![Graph showing the effect of manganese content on end-quench hardenability of nodular iron.](image)

**Fig. 3** The effect of manganese content on end-quench hardenability of nodular iron.

(see BCIRA Broadsheet 209-4) or, isothermally transformed—"austempered" (see BCIRA Broadsheet 209-3). Manganese has an effect intermediate between those of molybdenum and nickel, but is a stronger promoter of retained austenite than either of these.

Effect on mechanical properties

**As-cast irons**—When an increase in the manganese content of the iron results in an increase in the amount of pearlite, the hardness, proof stress and tensile strength are increased and the elongation reduced (Fig. 4).

![Graph showing the effect of tensile properties when increasing manganese content increases the amount of pearlite in an as-cast nodular iron.](image)

**Fig. 4** The effect on tensile properties when increasing manganese content increases the amount of pearlite in an as-cast nodular iron.

**Annealed ferritic irons**—In amounts up to about 0·5 per cent manganese usually has little effect upon tensile properties. At higher contents there is a small strengthening effect. A 1 per cent manganese increment gives an increase of 30–50 N/mm² in proof stress and tensile strength, and a reduction in elongation of 5–10 per cent.

In the V-notch impact test, increasing manganese content raises the ductile-to-brittle transition temperature and decreases the maximum value found in the ductile range (Fig. 6). Since high manganese content increases the difficulty of obtaining a fully ferritic matrix by heat treatment, residual pearlite is likely to occur in the structure and further reduces impact values.

![Graph showing the effect of manganese content on the V-notch Charpy impact transition temperature (after Pellini).](image)

**Fig. 5** The embritting effect of increasing manganese content in a fully pearlitic as-cast nodular iron.

**Fig. 6** The effect of manganese content on the V-notch Charpy impact transition temperature (after Pellini).
Normalized pearlitic irons—In amounts of up to about 1 per cent, manganese increases the proof-stress, tensile strength and hardness values and reduces elongation, as shown in Fig. 7. The embrittling effect of manganese in as-cast pearlitic nodular irons may be reduced by normalizing.

Manganese may be beneficial in ensuring a fully pearlitic structure in large castings which cool slowly after withdrawal from the normalizing furnace, at 875–920 °C. In irons having more than about 1 per cent manganese, intercellular carbides may be retained after heat treatment, reducing tensile strength and elongation.

**Hardened and tempered irons**—Increasing manganese content raises the proof-stress, tensile strength and hardness values of fully hardened and tempered nodular irons but reduces elongation (Fig. 8). The strength falls and elongation increases as the tempering temperature is raised. It is important to limit the manganese content if the detrimental effects of residual intercellular carbides provided by high manganese contents are to be avoided.

**Austempered nodular (ductile) irons**—At any given austempering temperature, increasing the manganese content results in a progressive reduction in tensile properties (Fig. 9) but does not affect hardness. The changes are attributed to the structural heterogeneity induced by the intercellular segregation of manganese during solidification, which is not eliminated during heat treatment.

Manganese causes an increase in retained austenite and affects work-hardening characteristics.

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**Fig. 7** The effect of increasing manganese content on the tensile properties of normalized pearlitic nodular iron (3·6 per cent TC and 2·2 per cent SI).

**Fig. 8** The effect of increasing manganese content on the tensile properties of hardened and tempered (560 °C) nodular iron; (TC 3·5 per cent, Si 2·0).

**Fig. 9** The effect of manganese content on tensile strength and elongation for irons austempered for 1 hour in the temperature range 300 – 400 °C.
**Maximum levels of manganese in nodular iron**

Working ranges for manganese in nodular iron depend upon the grade of iron required, the levels of other elements, the section of the casting, and whether castings are heat-treated. As section size increases the intercellular segregation effects are more pronounced, and the reduction in properties correspondingly greater.

_Ferritic nodular iron—_Any level of manganese in as-cast ferritic nodular iron is detrimental and it should be less than 0.2 per cent.

For castings to be annealed, manganese up to 0.5 per cent may be tolerated.

_As-cast ferritic/pearlitic iron—_A maximum of 0.1–0.5 per cent manganese, according to the pearlite content required.

_As-cast and normalized pearlitic iron—_up to 1.0 per cent.

_Hardened and tempered irons—_0.3 to 0.8 per cent maximum.

_Austempered irons—_up to 0.4 per cent maximum.

The main source of manganese in nodular iron is steel scrap. It may vary from about 0.25 per cent for light scrap to 1 per cent for heavy constructional steel scrap. When an increase in manganese content is required to promote a pearlite matrix, ferro-manganese can be added. Low manganese contents, of less than about 0.15 per cent, are obtained by adding high-purity pig iron.

**RECOMMENDED FURTHER READING**

*BCIRA Broadsheet 212: Factors influencing the ductile or brittle behaviour of nodular irons.*

*BCIRA Broadsheet 176–d: Notes for guidance—charge material for electric induction furnaces.*

*Each of these Broadsheets is a proof copy: please draw the Editor’s attention to any omissions or apparent errors. It will be reprinted in final form for inclusion as a loose copy in the next BCIRA Journal. Extra copies of the reprinted Broadsheet can be ordered for your staff, by use of the reader service card—inside the back cover of this Journal.*

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