Effects of copper in nodular (SG) iron

Copper is widely used as a deliberate alloying element in nodular iron, in amounts varying from about 0.2 to 2 per cent. The structure and properties of both as-cast and heat-treated nodular irons are affected by their copper content.

The effect on structure

Free copper—Copper has a limited solubility of about 3.5 per cent in molten cast iron, and any excess is present in the structure as globules of insoluble primary copper. The solubility of copper is further reduced by the presence of magnesium in the iron, so that with a magnesium content greater than about 0.08 per cent, copper as low as 1.5 per cent can lead to the presence of free copper particles.

![Graphite](image)

**Fig. 2** An abnormal form of graphite growth on a nodule in an annealed iron containing 1% copper. Etched in 4% picral. x 1000

Graphite—Up to about 3 per cent copper has no detrimental effect on the formation of nodular graphite in magnesium-treated irons; however, its presence makes the iron more sensitive to the influence of subversive elements such as titanium (Fig. 1) and lead, in producing flake graphite forms and hence reduced mechanical properties. Such effects are mostly avoided by the addition of cerium mischmetal.

When a pearlitic nodular iron containing more than about 0.75 per cent copper is annealed an unusual form of secondary growth of graphite occurs on some nodules, as shown in Fig. 2.

Eutectic carbide—Copper is a moderately graphitizing element, and when added to nodular iron it slightly reduces the risk of eutectic carbide (chill) formation, particularly in thin sections.
Matrix

- With increasing copper content, increasing amounts of pearlite form in preference to ferrite in both as-cast (Fig. 3) and normalized irons. The range of copper contents over which the rate of increase of pearlite content from 20 to 80 per cent is most rapid is dependent upon the levels of other pearlite-promoting elements in the iron. Copper has a pearlite-promoting effect intermediate between those of manganese, and tin and arsenic.
- Graphitization of the pearlite during annealing occurs less rapidly with increase in copper content (Fig. 4). When the copper exceeds about 0.75 per cent it is difficult to obtain a fully ferritic matrix even with extended heat treatment time, and some spheroidized pearlite is retained. The maximum solubility of copper in ferrite at room temperature is about 0.3 per cent, and excess copper separates, during cooling, as fine secondary particles of copper which are more readily apparent in annealed ferritic irons (Fig. 5).
- The hardenability of the iron increases with increasing copper content, which enables thicker sections to be quenched from the austenitizing temperature without th...
The effect of copper content on the tensile properties and pearlite content of an as-cast nodular iron produced from a high-purity charge.

formation of ferrite and pearlite in the structure. Copper is used, often in conjunction with additions of nickel and molybdenum, in the production of irons which are to be hardened and tempered, or isothermally transformed (Fig. 6), or in as-cast high-strength irons with bainitic (acicular) or martensitic matrix structures.

The effect on mechanical properties

As-cast irons—An increase in pearlite content which results from an addition of copper increases proof stress, tensile strength and hardness and reduces elongation, as shown in Fig. 7. When the matrix is fully pearlitic, further additions of copper reduce the rate of change of properties and eventually, at high copper contents, the iron becomes embrittled and both the tensile strength and elongation fall (Fig. 8), although the proof stress may continue to increase.

Annealed ferritic iron—The proof and tensile strengths of annealed ferritic nodular iron increase with increasing addition of copper, but elongation falls, as shown in Fig. 9. For a 1 per cent copper increment the changes are:

0.2 per cent proof stress and tensile strength—increased by about 70 N/mm²;

elongation—reduced by about 6 percentage points;

hardness—increased by about 24 HB.

In the V-notch impact test, increasing copper content raises the impact ductile-to-brittle transition temperature by about 45°C for a 1 per cent copper increment, and reduces the maximum value found in the ductile range (Fig. 10).

Figure 8: The effect of copper content on the tensile strength and hardness of as-cast and normalized pearlitic nodular iron.

Figure 9: The effect of copper content on the properties of annealed ferritic nodular irons.

Figure 10: Charpy V-notch impact transition curves for annealed ferrite irons with different copper contents.
high copper contents it is difficult to obtain a fully ferritic matrix by annealing, and the amount of fine secondary copper present in the ferrite increases.

Mere copper may be retained in solid solution if the iron is water-quenched from 760 °C. Subsequent ageing at about 500 °C results in an increase in tensile strength and hardness but with good retention of ductility (Table 1), and provides a combination of properties which may be better than those realized with irons having a pearlitic matrix.

**Normalized pearlitic irons**—In amounts up to about 2 per cent, copper increases tensile strength and hardness, (Fig. 8) and only slightly reduces elongation, indicating that the iron is not embrittled. The use of the pearlite-promoting effect of copper is of particular advantage in the normalizing of large castings which cool slowly after withdrawal from the furnace at 875–900 °C.

**Quenched-and-tempered and austempered irons**—Additions of copper to martensitic and bainitic heat-treated irons are primarily made to increase hardenability. The effects of the additions on mechanical properties are small.

### Maximum levels of copper in nodular irons

The levels of copper used in the production of the various grades of nodular iron depend upon the levels of other elements present, the section of the casting, and whether the casting is to be heat-treated.

**Ferritic nodular iron**—In as-cast nodular iron any level of copper is detrimental, and it must be less than 0.2 per cent. When castings are annealed, higher levels of copper may be tolerated if the annealing cycle is adjusted to ensure a ferritic matrix. Additions up to about 1 per cent may be used to obtain a combination of high proof-stress and tensile strength with good ductility (Fig. 9).

**As-cast ferritic-pearlitic irons**—Between 0.2 and 0.5 per cent copper according to the pearlite content required, and to the levels of other pearlite-promoting elements in the iron.

**As-cast and normalized pearlitic nodular irons**—Between 0.75 and 1.5 per cent copper according to the levels of other pearlite-promoting elements in the iron, and the section of the casting.

**Quenched-and-tempered and austempered irons**—Between 0.5 and about 1.5 per cent copper according to the section of the castings and the levels of other hardening elements, such as Ni and Mo, in the iron.

**Sources of copper**

**High-purity copper**—This is in finely divided forms of shot, sheet cuttings and wire, notched bar or stick.

**Copper-bearing process scrap**—Selected scrap must be used, to avoid the presence of elements such as Pb, Sb, and Te which may result in the formation of flake graphite with serious reduction in strength—even when mischmetall is added.

**Steel scrap**—This can contain up to about 0.4 per cent copper according to the specification of the steel.

**Copper magnesium alloy**—This usually contains about 85 per cent copper and 15 per cent magnesium. It is occasionally used as a nodularizer when as-cast or normalized pearlitic irons are produced.

- The melting-point of copper, 1083 °C, is well below that of cast iron. If copper is added to metal having a clean, slag-free surface, none of it is lost.

### RECOMMENDED READING

*B.C.I.R.A Broadsheet 30: Addition of copper to cast iron.*


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