may form. Increasing carbon and silicon contents in gray iron promotes the appearance of massive ferrite in the microstructure of the iron and thus have a softening and weakening effect on the iron.

Phosphorus: In the presence of phosphorus beyond 0.10% in the iron, an additional constituent appears in the microstructure. This is a phosphorus rich structure known as steadite. Phosphorus concentrates in the remaining liquid during eutectic cell formation and at a certain concentration, steadite appears as the last solid to form in the iron. It is a eutectic type structure consisting of iron with phosphorus in solution and iron phosphide (Fe₃P). With increasing phosphorus in the iron the amount of steadite formed increases.

Carbon Equivalent Value (CEV): Phosphorus increases the effectiveness of carbon and silicon. Therefore, the amount of eutectic graphite formed in the structure of a gray iron depends on its carbon, silicon and phosphorus contents. The effects of these elements are expressed interms of a carbon equivalent value (CEV) where:

Carbon equivalent value = % total carbon + % silicon/ 3 + % phosphorus/3

i.e. the carbon equivalent is the total carbon content plus onethird of the silicon content plus one-third of the phosphorus content. As the carbon equivalent value increases so the amount of graphite in the structure of the iron increases. Irons with CEV < 4.30 are hypoeutectic and irons with CEV > 4.30 are hypereutectic and contains primary graphite in the structure.

Carbon equivalent value (CEV) can not be directly measured but can be calculated from the final analysis of the iron. However, in control testing in the foundry, a Carbon Equivalent Liquidus (CEL) is determined in order to assess metal composition interms of its suitability for use to pour a given grade of iron. The carbon equivalent liquidus (CEL) is determined by the expression as:

CEL = % total carbon + % silicon/4 + % phosphorus/2

Sulphur and Manganese: Sulfur is one of the important modifying elements present in gray irons. A low-sulfur iron-siliconcarbon alloy containing sulfur < 0.01% will graphitize most completely. Higher sulfur percentages favour the retention of a



Fig. 6.9: A General view of Graphite Spheroids in a Ferritic Matrix (From J. H. Frencis, Applied Science in the Casting of Metals (ed. K. Strauss), Pergamon Press Oxford, 1970, p. 200)

in the melt (like O, S etc.) that lower the surface tension and the beneficial effects of eliminating surface-active elements or of adding elements that raise the surface tension. This suggests that in melts with a high surface tension, nodular graphite growth may either be a consequence of an attempt to minimize the surface area of the graphite and thus minimize the total free energy of the melt system, or that the nodular graphite results from the absence of certain elements that adsorb onto the graphite lattice and change the interfacial energy and the growth mode.

The former theory can be simply explained as the addition of Mg, Ce etc. to the iron melt removes oxygen and sulfur like impurities which will otherwise decrease the surface tension of the molten iron by segregation in the melt surface. Therefore, by their removal the interfacial surface tension between graphite particles and the melt increases which constraints the graphite to decrease its surface area per unit volume which is done by acquiring a spherical shape.

Regarding the second alternative i.e. the change in the interfacial energy and the growth mode, it can be explained with the help of the Fig. 6.10 schematically illustrating the mode of growth of the of 4:8:3 are used. The optimum pouring time can be obtained with the equation as given below.

Pouring Time (t) = $0.65\sqrt{\text{pouring weight}}$

Usually the metal should enter the bottom of the mould cavity through a sufficient number of in gates so that a minimum amount of metal flows from each gate. It is also desirable to provide runners with a height equal to twice the width. The total ingate area is function of the pouring weight and the pouring time.

Risering of S.G. iron is more difficult than gray iron due to its different solidification mode. S.G. iron does not freeze in skin forming manner as do most gray irons and steels. The solidification takes place with pasty zone throughout over a large temperature range. This, makes feeding difficult and depending on composition, dispersed shrinkage porosity may result. Generally, large risers and with a lot of risers are required to feed S.G. iron castings properly.

The danger of mould wall movement is much more pronounced in S.G. iron than gray iron and the need of a very stable and strong mould is very much there. However, less risering is needed in hypereutectic irons cast in dry sand moulds.

The cleaning and finishing operations used for S.G. iron castings are similar to those used for gray iron castings. However, removal of gates, risers etc. is not so easy because of the ductility and toughness of these castings.

6.6.4 Heat Treatment of S.G. Iron Castings

Some S.G. iron castings are used as-cast but great majority of them are heat treated. This is because a very wide range of properties can be obtained by controlling the compositions, foundry operations and/or heat treatment given. A variety of matrix structures can be obtained varying from all ferrite, ferrite and pearlite, all pearlite, martensite, tempered martensite or banite and in some special alloys, containing carbides or an austenitic matrix.

The main heat treatments given include :

6.6.4.1 Stress Relieving

This is used to reduce residual casting stresses such as those in complex castings in as-cast state or after normalizing. It is obtained



Compacted (Vermicular) Graphite Irons and Foundry Practice

7.1 INTRODUCTION

Compacted Graphite (CG) Iron has received considerable attention as an important engineering material in the past few years, even though it has been recognized for three decades or more. It is since 1965 that this iron has occupied its place as an important member of the family of cast irons with distinct properties requiring special manufacturing technologies. Compacted graphite irons are irons that exhibit graphite morphology intermediate to the interconnected flake graphite in gray cast irons and the spheroidal graphite in ductile cast irons. Compacted graphite, when observed under an optical microscope, appears as thickened flakes with rounded ends. It is therefore also called as VERMICULAR GRAPHITE (VG) and both the terms have been generally accepted for this intermediate form of the graphite.

Vermicular graphite thus represents a transition form from the stand point of compactness between flake and spheroidal graphite which is characterized by a low length (*l*) to thickness (*t*) ratio. The l/g ratio is generally between 2 and 10 and therefore much smaller than that of flake graphite (l/g > 50) but larger compared to that of spheroidal graphite (l/g = 1). In literature, this form of graphite is variously called^[45] as type "P" graphite, "P₄₄₁" graphite, "quasi-flake" Form III, pseudo-lamellar, "chunky graphite", melkoplastin "catyjgrafit" etc. The mechanical properties of compacted graphite irons are strongly dependent on the shape, size and compactness of their graphite. It is well known that such cast irons are noticeable for their outstanding strength having a higher tensile strength, and particularly, a higher elongation than gray cast irons.