When and how to choose ferroalloys for cast iron foundry

R. R. Dash
S. Ghosh
G. N. Rao*

ABSTRACT

Ferroalloys find extensive use in foundry for various specific purposes. The present paper discusses the use of ferroalloys in cast iron foundry as an, additive to moulding sand, as an inoculant for the production of graded cast irons, as an alloying element for the production of alloy cast irons, also as an inoculant for the production of special cast irons such as S. G. iron, Malleable iron, compacted graphite cast irons. The paper also discusses the scope of production of complex inoculants as a present day need for foundry industry.

Introduction

Ferroalloys find extensive use in foundry because they are comparatively cheaper and considerably easier to add to the molten iron and steel. Further, their specific gravity and melting points approach those of iron and steel which facilitate their use. Since the pertinent member of a ferroalloy is the alloying element, the iron content is relatively not very important, thus, they are identified generally by the principal base metal present.

In any particular ferroalloy, gradation is normally done according to the percentage of the base metal present, Further gradation or sub-division is usually based upon the specific elements of technical importance like carbon, silicon, phosphorous, sulphur, etc. From the point of view of its use, ferroalloys can be classified into two main classes - the conventional ferro-alloys and the special ferroalloys. Conventional ferroalloys like, Fe-Mn, Fe-Si, Fe-Cr have been in use for a long time while special alloys such as Fe-Mo, Fe-V, Fe-Ti etc. have been developed recently to cater to the special needs of Iron and Steel production.

In a cast iron foundry, ferroalloys are used for the following purposes :

1) As an additive to moulding sand

2) As an inoculant for the production of graded cast irons.

3) As an alloying element, either in furnace or ladle for production of alloy cast iron.

4) An an inoculant for the production of special cast irons such as S. G. Iron, Malleable iron, compacted graphite cast iron, etc.

* Authors are Scientists in the National Metallurgical Laboratory, Jamshedpur.

As an additive to moulding sand

Though use of ferroalloys in mould preparation is un-usual, Fe-Si is used as a hardener for sodium silicate bonded sands to produce self set moulds. The process relies upon exothermic reaction between sodium silicate and pulverised silicon causing dehydration of binder which causes the mould to harden. The strength obtained is mainly due to the formation of a glassy silicate and silica gel.

However, due to some disadvantages such as defects produced by liberated hydrogen, availability of cheaper hardeners, etc. the process has become less popular.

As an Inoculant for production of graded cast iron

The purpose of inoculation of molten metal is to modify its microstructure on solidification and thereby improve mechanical and physical properties which are not explainable in terms of composition change. Ferroalloys, particularly silicon based, improve the mechanical properties of cast iron by changing the shape, size and distribution of graphite flakes.

The usual silicon based inoculants are Fe-Si containing 75 to 80% Si, calcium silicide containing 60% Si and alloys of silicon with other metals such as Mn, Fe, Zirconium or copper. Ferro silicon acts as a good inoculant only when it contains 1-2% aluminium and upto 1.0% calcium. There is a risk with aluminium containing inoculants as the molten cast iron may pick up hydrogen from moisture in the mould, thus encouraging the development of sub-surface pinholes in the castings. Manufacturing process of Fe-Si must aim at producing ferrosilicon with required level of aluminium for use in cast iron foundries. Studies have shown that inoculating power of aluminium free Fe-Si can be increased by incorporating small percentage of strontium in ferrosilicon.

Fig. 1 shows the inoculant mesh size and inoculating temperature on the effectiveness of Fe-Si and Ca-Si addition to grey iron. Fig. 2 shows the influence of the inoculant on eutectic cell count in grey iron. As silicon percentage is increased, the eutectic cell count in grey iron also increases. Fig. 3 depicts the influence of type of inoculant on decay in inoculation effect (chill depth) in grey cast iron. It is seen that Ba-Si is a more potent inoculant compared to Fe-Si.

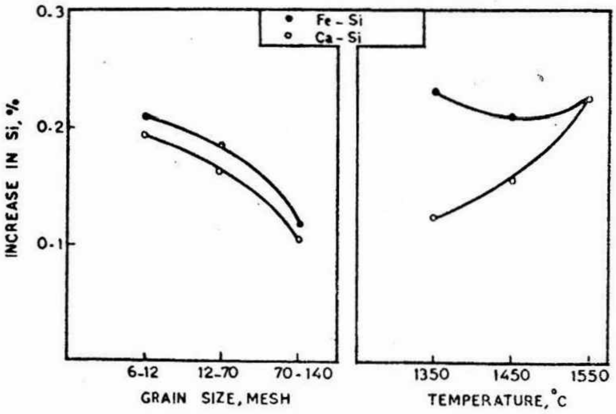

FIG. 1: INFLUENCE OF INOCULANT MESH SIZE AND INOCULATING TEMPERATURE ON RECOVERY OF Fe-Si AND Ca-Si IN GREY IRON

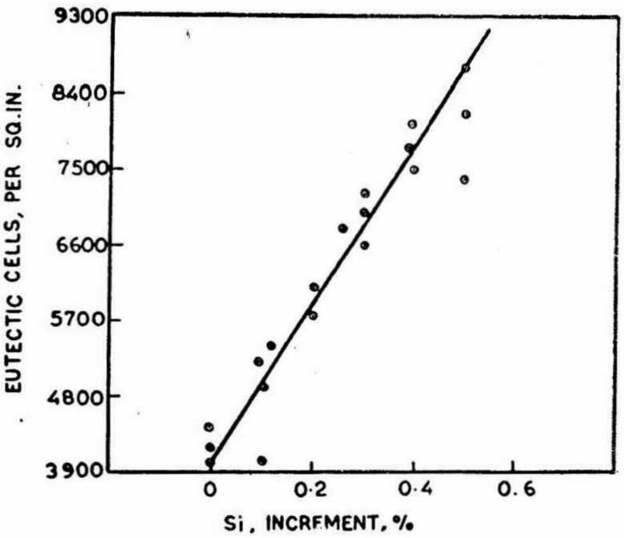

FIG. 2: INFLUENCE OF AMOUNT OF ADDED INOCULANT ON EUTECTIC CELL COUNT IN GREY IRON

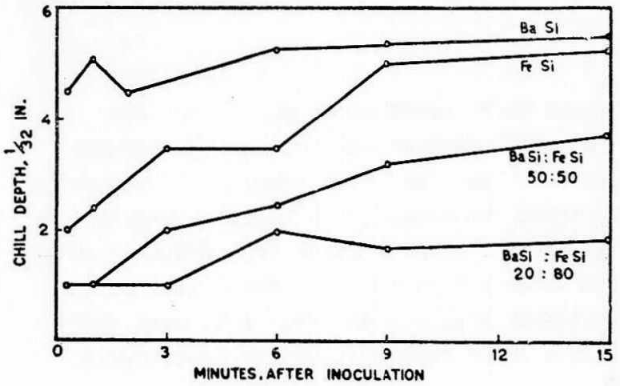

FIG 3: INFLUENCE OF TYPE OF INOCULANT ON DECAY IN INOCULATION EFFECT (CHILL DEPTH) IN GREY IRON

As an alloying element for production of alloy cast iron

Ferroalloy additions in melt preparation

The selection of a particular grade of ferro-alloy for use as alloying addition depends upon the type of melting unit employed, the alloy composition and the specification of the castings to be produced. In jobbing foundries where a cold blast cupola is available, ferroalloys such as Fe-Si, Fe-Mn, which are higher in Si and Mn are preferred due to their lower melting temperatures. Ferroalloys can either be added in cupola or in the ladle. In the later case excessive loss of ferroalloys can be prevented. In modern foundries where electrical melting units are available, additions of ferroalloys can be made late in the furnace for higher recovery.

The losses encountered in the process of addition, particularly during the cupola melting of iron are as follows :

Elements in Ferroalloy	% Losses
Silicon	10 to 15
Manganese	15 to 20
Chromium	10 to 15
Titanium	20 to 30
Molybdenum	No Loss
Vanadium	10 to 15

Since ferroalloy addition is expensive, they must be added only when essential after making a judicious selection of the ferroalloy, based on metallurgical considerations.

Selection of ferroalloys

Ferroalloys like Fe-Si, Fe-Mn, Fe-Cr, Fe Mo, Fe-Ti, Fe-V, are extensively used in the process control of grey iron melts to obtain special characteristics and produce castings to part'cular specifications.

In case of Fe-Si, low grade as well as high grade is in use in the foundries. Apart from the silicon content, size as well as composition, especially, the aluminium content of the ferro-alloy should be within specified limits. The aluminium content should not exceed 1.0%, 60% grade is used for bulk furnace additions in lump form, while 75% or 85% silicon grades are used for ladle additions.

High carbon ferro-manganese containing 70% manganese is used in grey iron foundries, though low carbon variety has added advantage when used in large quantities as they have low phosphorous content facilitating final adjustment. Normally lumps are used for furnace additions while 4 to 15 mm sized ferroalloys are used for ladle additions. Pearlite is stabilized using small quantities of Fe-Mn along with Tin.

Ferrochrome is a carbide former and when used in small quantities increases tensile strength and hardness. Usually high carbon ferrochrome is used in lump form for furnace addition and for ladle addition, 50 mm size is used.

Fe-Mo is added to impart high wear resistance. Molybdenum is specially effective in strengthening and hardening irons because of its property of causing austenite to transform to fine pearlite or bainite. Lumps are used for furnace additions while crushed to 20 mm size is used for ladle additions.

The behaviour of titanium, when Fe-Ti is added is similar to aluminium. Titanium added upto 0.05 to 0.25% promotes graphitization, reduces chilling tendency and refines the graphite flake size. Above this value, however, increasing titanium percentages results in the formation of titanium carbide, which is stable even at high temperatures.

Vanadium acts as a carbide former when added as Fe-V. Small additions to the extent of 0.05% increases the strength, hardness, and impact strength of grey irons.

Ferro-alloys in alloy cast irons

Alloy cast irons are classified depending on their specific use as corrosion resistant, heat resistant and wear resistant cast irons.

Silicon as Fe-Si when added to cast iron in the range of 6 to 8% Si imparts better resistance to scaling compared to ordinary irons. With 13 to 18% Si, cast irons develop resistance to acid corrosion.

The property of heat resistance is improved by alloying grey iron with chromium as Fe-Cr; or silicon as Fe-Si. Other elements which increases carbide stability or raise the critical temperature range are also used.

The aim in manufacturing wear resistant alloys is that their microstructure should contain the largest possible quantity of hard constituents, carbide and martensite. However, in applications where toughness or impact resistance is also important, it is essential that the size and distribution of the hard phases should be well controlled and product should be free from internal stresses, micro-cracks, and other structural discontinuity. Chromium is the principal alloying element which imparts wear resistance; chromium addition in wear resistant cast irons vary from 2 to 28%. In addition to chromium, manganese upto 3% is also used alongwith Cu, Mo, V and Ti. While Table - 1 gives the details of wear resistant and heat resistant cast irons commercially available, Table - 2 gives the microstructure and commercial applications of high chromium cast irons. High Cr alloyed cast iron have been grouped as follows for practical purposes :

1) 15-17% Cr for heat and wear resistant application.
2) 26-28% Cr for abrasion resistant applications.
3) 30-35% Cr for heat and corrosion resistant application.

Corrosion resistance property of cast iron can not be generalised with particular composition range as there are a number of corrosive agents with varying concentrations, temperatures and conditions. It is, therefore, better to develop the different grades of corrosion resistant cast iron depending on their actual use in service. For example, cast irons containing upto 2% nickel and 0.5% chromium resists caustic alkali attack. 'Ni-resist' austenitic iron containing, Ni 1.2 to 16.0%, Cr. 1.5 to 4.0%, Cu 6.0 to 8.0% has been found satisfactory to withstand sulphuric acid corrosion. Cast irons containing 33%Cr and just over 1% of carbon retains enough chromium in the solid solution to ensure good resistance to oxidising acids. High silicon cast iron having 1.19% Cr, 15.0% Si, and 0.118% Ce exhibits good resistance to acid attack and can also be used against other corroding media.

Ferroalloys in malleable iron production

Malleable iron castings are in fact, heat treated products obtained from white iron. The ferroalloys which are extensively used in the production of malleable iron are Fe-Mn and Fe-B.

In ferritic malleable cast iron, too high Mn content is undesirable and is kept deliberately low, only to normalize sulphur content. In pearlitic malleable irons, 0.7 to 0.9% Mn is tolerated since it suppresses second stage graphitization. The addition of Fe-Mn therefore must be made judiciously.

The effect of Boron in malleable iron is two fold. It neutralizes small amounts of chromium but more important it acts as an inoculant. It is

TABLE—1

Composition of alloy cast iron

% Total C		%Si		%Mn		%Ni		%Cr		%Cu		%S		%P		%Mo		Use
Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2.60	3.00	1.25	2.20	1.00	1.50	13.5	17.5	1.8	3,5	5.5	7.5		0.10		0.20	—	—	High alloy for
2.60	3.00	1.25	2.20	0.80	1.30	18.0	22.0	1.75	3.5		0.50		0.10		0.20	—	—	resistance to corrosion, scaling warpage & growth
	3.00	1.00	2.80	1.00	1.50	13.50	17.50	1.75	2.50	5.50	7.50		0.12					Austentic
	3.00	1.00	2.80	1.00	1.50	13.50	17.50	2.50	3.50	5.50	7.50		0.12					grey iron
	3.00	1.00	2.80	0.80	1.50	18.00	22.00	1.75	2.50	—	0.50		0.12					castings used
	3.00	1.00	2.80	0.80	1.50	18.00	22.00	3.00	6.00	—	0.50		0.12					primarily for
	2.60	1.00	2.00	0.40	0.80	28.00	32.00	2.50	3.50	—	0.50		0.12					their resistance
	2.60	5.00	6.00	0.40	0.80	29.00	32.00	4.50	5.50	—	0.50		0.12					to heat,
	2.40	1.00	2.00	0.40	0.80	34.00	36.00	—	0.10	—	0.50		0.12					corrasion
	3.00	1.50	2.50	0.80	1.50	18.00	22.00	1.00	2.00	3.50	5.50		0.12				1.00	and wear.

TABLE – 2

High chromium cast irons produced commercially

% Cr	% C	Microstructure	Application
10 — 18	2.4 — 3 6	Eutectic carbide in pearlitic matrix	Mainly abrasion resistant, but also heat resistant upto 700°C.
25 -- 29	2.5 — 2 9	Eutectic carbide in a matrix of austenite and martensite or ferrite and precipitated carbide.	Mainly Abrasion resistant, but alsa heat reslstant upto 700°C,
27 — 35	1.0 — 2.0	Eutectic carbide in ferritic matrix.	Heat resistant upto 1050°C, and corrosion resistant Also useful abrasion resistant.

a strong nitride former. Boron nitrides or carbo-nitrides formed during solidification act as centres of crystallization and reduce the annealing time. Too high a Boron content reduces the mechanical properties.

Ferro-alloy in S. G. and C. G. cast iron production

Ferre-alloys are being extensively used for making master alloys for the production of spheroidal graphite cast iron. S. G. cast iron is essentially a cast iron in which graphite is present in the form of tiny balls or spherulites rather than flakes as in normal grey iron.

This shape of graphite can be obtained by inoculating grey iron with Mg. Since Mg is a very reactive metal and its vapour pressure is very high at the temperature of the molten cast iron, it is added in the form of a master alloy. Chemical composition of the master alloys is shown in Table - 3.

TABLE—3

Chemical composition of master alloys for S. G. Iron

1. Magnesium-Nickel Alloys : % Composition					
	Mg	Ni	Si		
a)	15	85	—		
b)	15	55	30		
2. Magnesium-Ferro Silicon Alloys : % Composition					
	Mg	Si	Ca	Ce	Fe
a)	9	45	1.5	—	Balance
b)	9	45	1.5	0.50	Balance
3. Magnesium-Silicon Alloys : % Composition					
	Mg	Si	Ca	Ce	Fe
a)	18	65	2.0	0.60	Balance

Fe-Si of 75% grade is made use of for the preparation of the master alloys. National Metallurgical Laboratory has developed technical knowhow for the production of nickel magnesium and Fe-Si Mg master alloys for the production of S. G. Iron.

Compacted graphite iron is produced by the the simultaneous action of a nodulariser and a denodulariser. For this purpose master alloy is prepared using 75% Fe-Si grade, Magnesium and Ferro-titanium. Composition of the master alloy is same as that of alloy used for the production of SG iron except that it contains 4 to 4.5% Ti which acts as denodulariser.

Production of complex inoculants

Metallurgical considerations lead to the development of complex inoculants which produce irons of higher strength and uniform micro-structure. Multi component alloys such as Si-Ca-Mg-Fe have advantages over Si-Mn and other types of alloys, since they make it possible to produce high strength irons with no black spots or chill crystals and with better casting properties. However, it is almost impossible to melt inoculants with increased Mg contents by carbo thermal process at atmospheric pressure owing to high vapour pressure of Mg at the processing temperature. Complex inoculants with a Si-Ca-Mg-Fe composition is reported to have been melted on an industrial scale by silico thermal method following a method based on the technology of producing Ferrosilicon calcium.

Barium or strontium containing inoculants are also reported to have been produced likewise, where-in the charge materials consisted of 200 Kg. of lime, 190 Kg. Fe-Si, 50 Kg. fluorspar and 100-122 Kg. of barium sulphate. The resulting alloy analysed as :

% Ba	% Ca	% Fe	% Mg.
5.8	15.0	27.0	1.2

After melting with Mg, the composition of complex inoculant included :

% Ba	% Ca	% Fe	% Mg.
5.1 - 5.7	12 - 14	24 - 26	5 - 6.

The utilization of Mg was 82%. The cost of the alloy containing 8-12% Mg produced by melting was lower than the cost of the alloy made by the silico-thermal method using dolomite.

With the use of complex inoculants high strength iron could be produced without using autoclaves for introducing Mg. Cast iron foundry will be largely benefitted if such alloys are produced.

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