55th Indian Foundry Congress 2007

55th Indian Foundry Congress
GATEWAY TO GLOBAL MARKETS

Inoculation of Cast Irons – An Overview

J.N. Harvey and G.A. Noble

J.N. Harvey
Tennant Metallurgical
Group Ltd,
Chesterfield,
United Kingdom

G.A. Noble
Tennant Metallurgical
Group Ltd,
Chesterfield,
United Kingdom

Inoculation of Cast Irons – An Overview

J.N. Harvey and G.A. Noble

INTRODUCTION

- ❏ Why inoculate?
- ❏ How to inoculate?
- ❏ What inoculant?
- ❏ Case Studies.

INOCULATION OF DUCTILE & GREY IRON

The main purpose of inoculation is to achieve best mechanical properties and optimum machinability characteristics by:

1. Control of graphite structure.
2. Elimination or reduction of chill/carbide.
3. Reduction of casting section sensitivity.

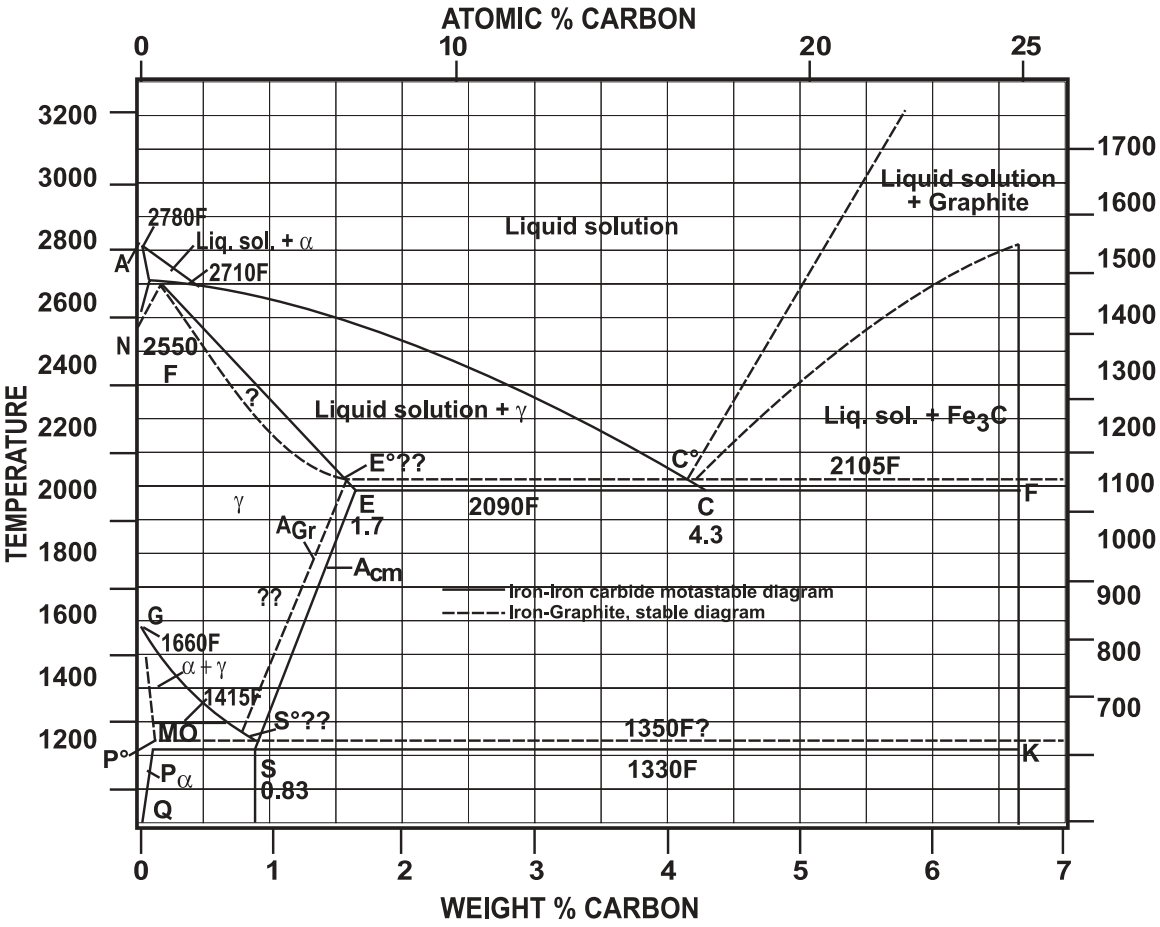


Fig. 1 : *Iron Carbon equilibrium diagram*

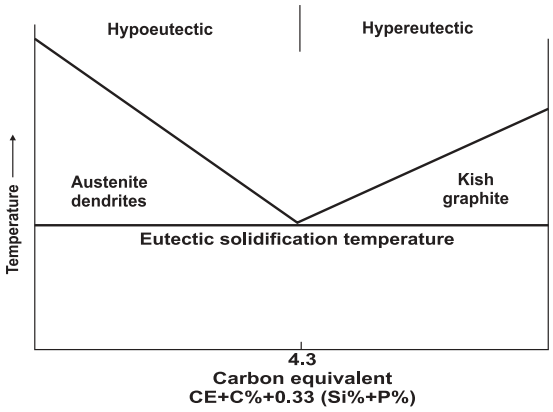


Fig. 2 : *Carbon equivalent diagram*

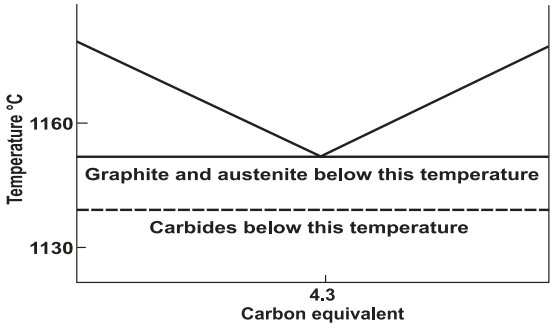


Fig. 3 : *Eutectic transformation*

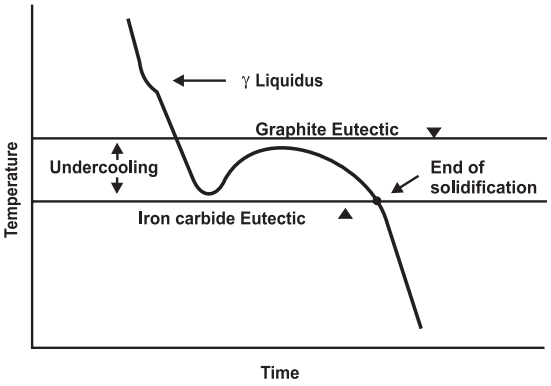


Fig. 4 : *Cooling Curve*

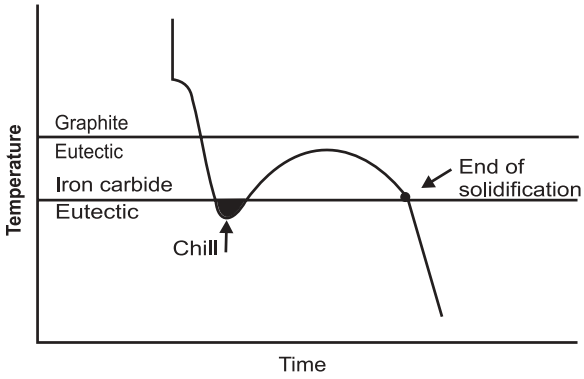
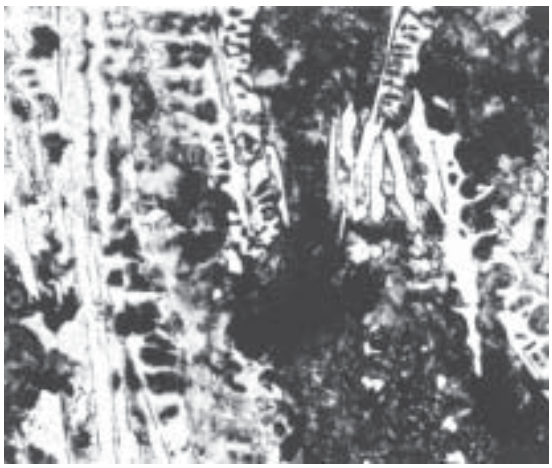


Fig. 5 : *Cooling Curve - Chill Formation*

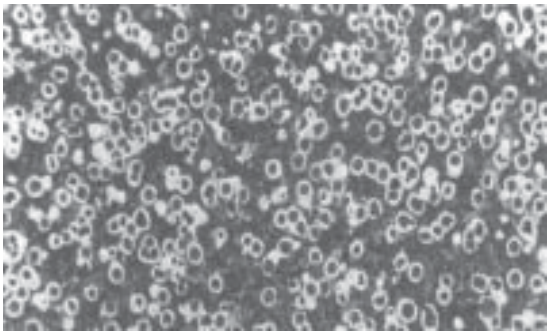
DUCTILE INOCULATION

- ❏ Optimum nodule shape
- ❏ Degree of nodularity
- ❏ Improves nodule count
- ❏ Prevention of formation of carbides
- ❏ Increases ferrite content.

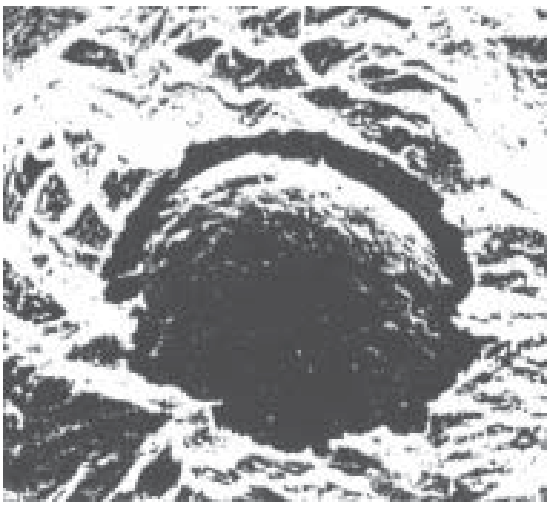


Uninoculated Ductile Iron

OPTIMUM NODULE SHAPE

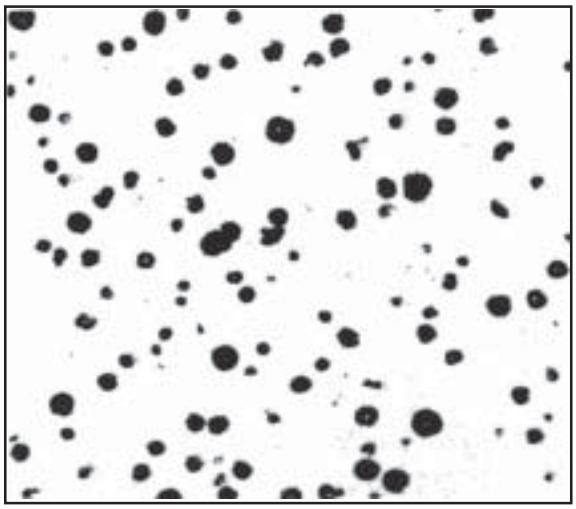


Nodular Graphite

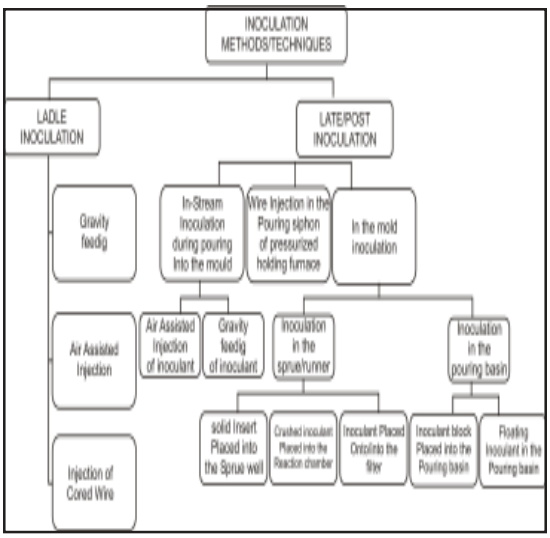


Nodular Graphite
Stereoscan × 950

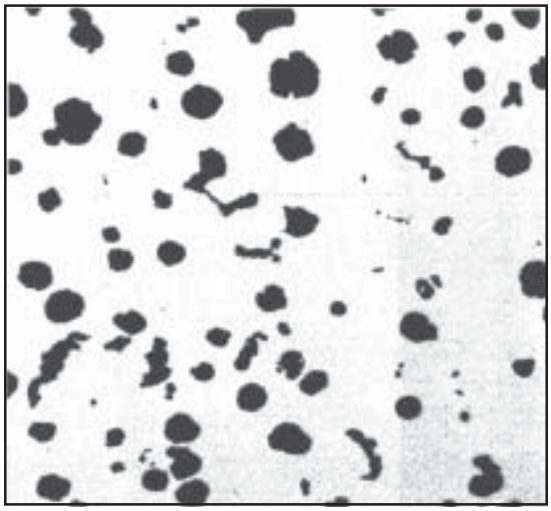
Degree of Nodularity



95%

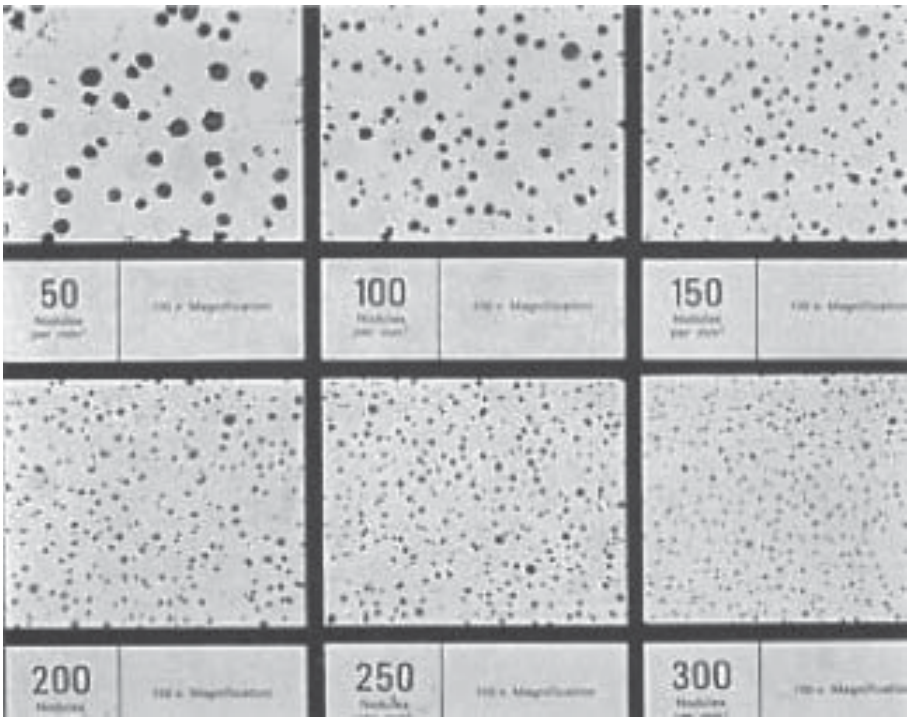


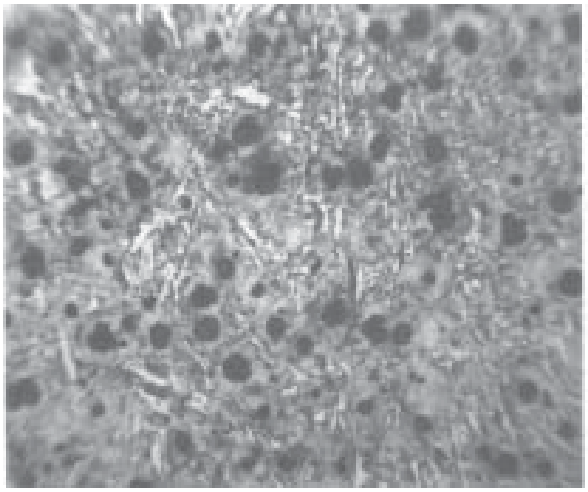
60%



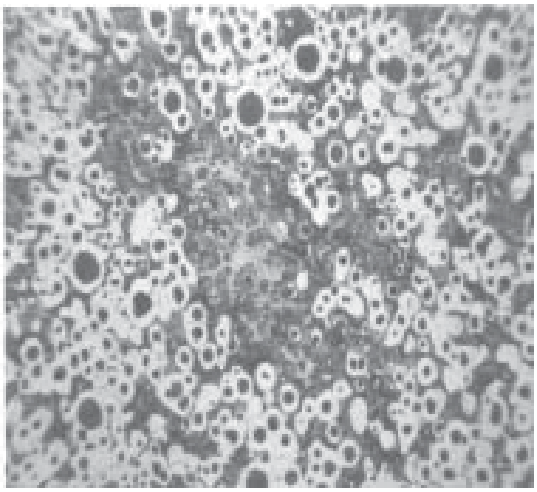
80%

Improvement in Nodule Count



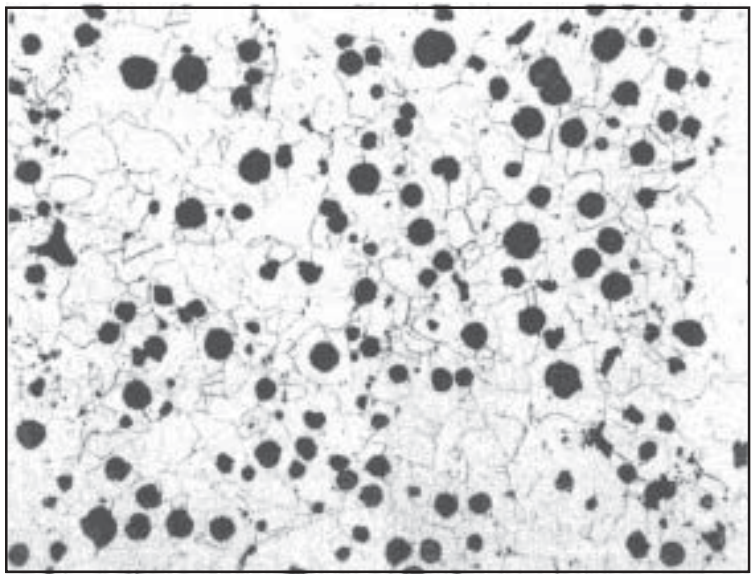


Prevention of Formation of Carbides Carbide in Ductile Iron



Inverse Chill

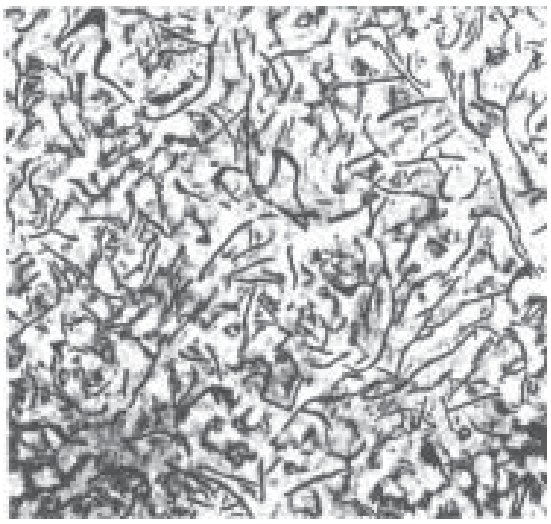
Increases Ferrite Content



Nil Pearlite - Completely Ferritic 100x-Etched

GREY IRON INOCULATION

Promote formation of type A graphite
Prevent formation of undercooled graphite
Prevent formation of Rosette graphite



4% Picral × 100

Stereoscan × 600

Effect of low % Sulphur on ductile iron microstructure

Material – ferritic ductile iron.

Grade – 420N/mm^2 minimum tensile strength, 12% minimum elongation.

Problem – low nodule count <100mm^2' 5% carbide, shrinkage porosity.

Cause – <0.005% S in base metal treated with 6% Mg, 1% TRE FeSiMg, 1.6% addition at 1500°C.

Inoculation – 0.5% addition FeSi 4% All in pouring ladle.

Remedy – increased % S to 0.010-0.015% in furnace.

Result – increased nodule count >100mm^2, no carbide, no porosity.

Inoculation at Low Temperatures

Casting – continuously cast bar.

Material – ductile iron ferritic and pearlitic.

Problem – depth of chill on surface of the bar excessive.

Inoculation – 0.6% FeSi, 4.5% Al at 1300°C into metal stream.

Remedy – change inoculant to FeSi + 5% Ba + 9% Mn 0.2 × 0.7mm.

Result – reduced chill depth on surface, greater consistency of nodule count and shape.

How to arrive at exact quantity of inoculant?

Ductile Irons – add minimum quantity to achieve:

- ❑ nodule count
- ❑ nodule shape
- ❑ carbide free
- ❑ fully ferritic.

Grey Iron **–** wedge test to give minimum chill in casting, microstructure type A graphite, cooling curve analysis – computer software programmes.

Over inoculation **–** eutectic cell count, shrinkage defects (sinks/draws).

Factors Affecting Fade Times

Type of melting furnace – cupola or induction melting?

Charge composition – % steel, % pig iron.

Type of recarburiser – graphite or synthetic.

Pouring temperature from furnace. Holding time before inoculation. Trace element contents.

Inoculation of Austenitic Ni-Resist

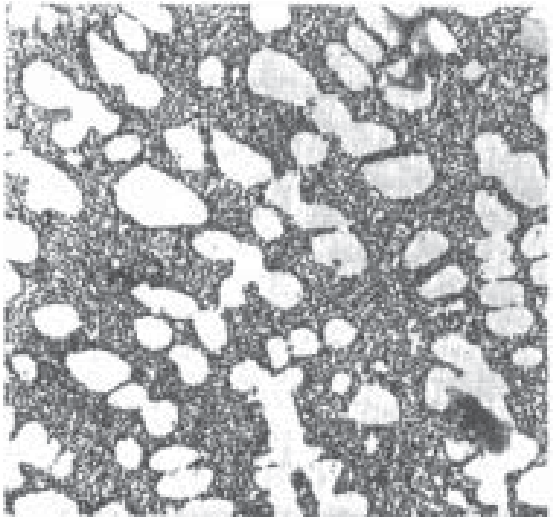
For Chromium containing Ni-Resist (D2, D2-B, D3, D3-A, D4, D5B and D5-S) inoculation is more critical.

Inoculation aims to minimise the quantity of Cr carbide, distribute evenly carbides in a fine form and improve nodule shape.

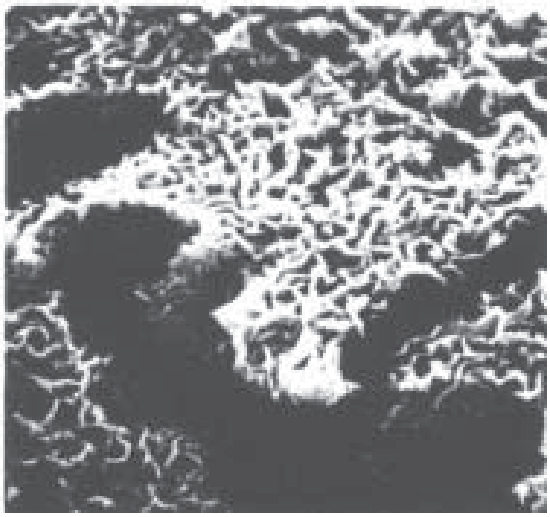
AFS recommends 0.5% Si addition, a FeSi 75 in ladle, 0.2% FeSi 75 in the base of the downsprue.

UK foundry making thin sectioned D5S add 0.3% of FeSi 4% Al or FeSi 1.5% Zr 2% Ca plus 0.1% "in the mould" inoculant.

Undercooled Graphite

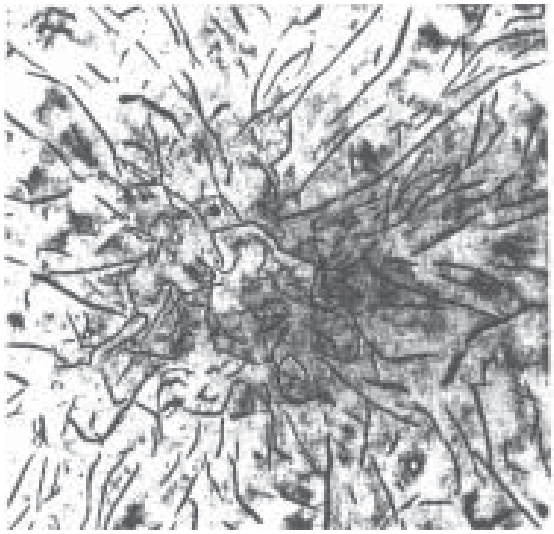


4% Picral × 100

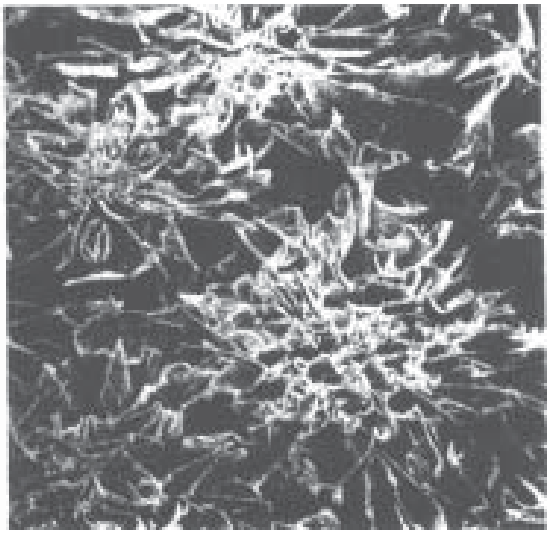


Stereoscan × 100

Rosette Flake Graphite



4% Picral × 100



Stereoscan × 100

Formation of Chill

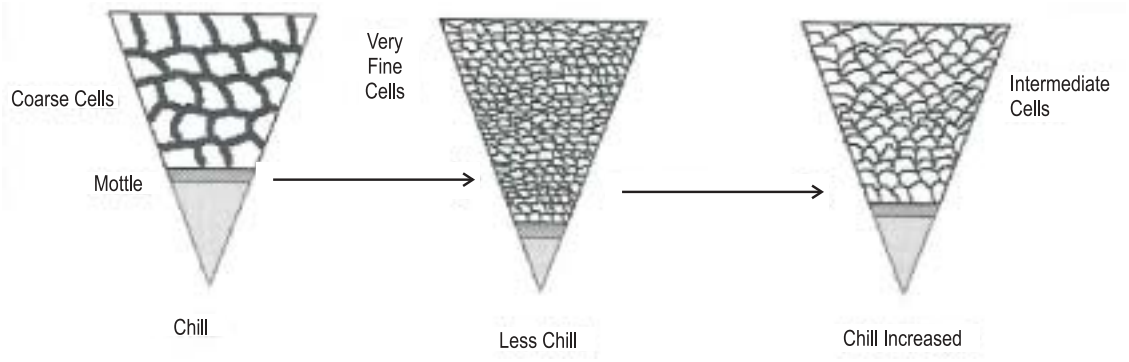


Fig. 6 : *Cross section of wedge.*

Magnesium Based Inoculant

There are no commercially available ladle or metal stream inoculants containing Mg. However, it is a necessary addition in the production of "in the mould" inoculant blocks utilising powder metallurgical techniques. Typically 0.7-1.7% addition.

Impact of Size and Shape on Inoculation

In the mould inoculation.
Pressed and sintered block.
Powder metallurgical techniques.
Size, shape, weight - tailor to foundry needs.
Cost saving.
Ductile Iron 0.1% addition.
Grey Iron 0.05% addition.
Promtes uniforms structure in various sections.

A disvantage-increases tendency to unsoundness.

HOW DO WE INOCULATE IRONS?

ADDITION RATES FOR GREY & DUCTILE IRON

Ladle inoculation – up to 1.0%, typically 1-6mm.

In stream inoculation – 0.05 to 0.2%, typically 0.2-0.7mm.

In the mould inoculation – 0.05 to 0.12%.

Electric melted irons – require up to 50% higher addition than cupola melted irons.

CHOICE OF INOCULANTS FOR GREY AND DUCTILE IRON

Introduction

Majority of inoculants are FeSi based. Si level 75% or 45% content. FeSi as a pure material has no inoculation effect. A combination of active elements e.g. Al, Ca, Ba, Mn, Zr, Sr, Bi when added to FeSi will inoculate. Ba, Zr, Sr, Bi are more

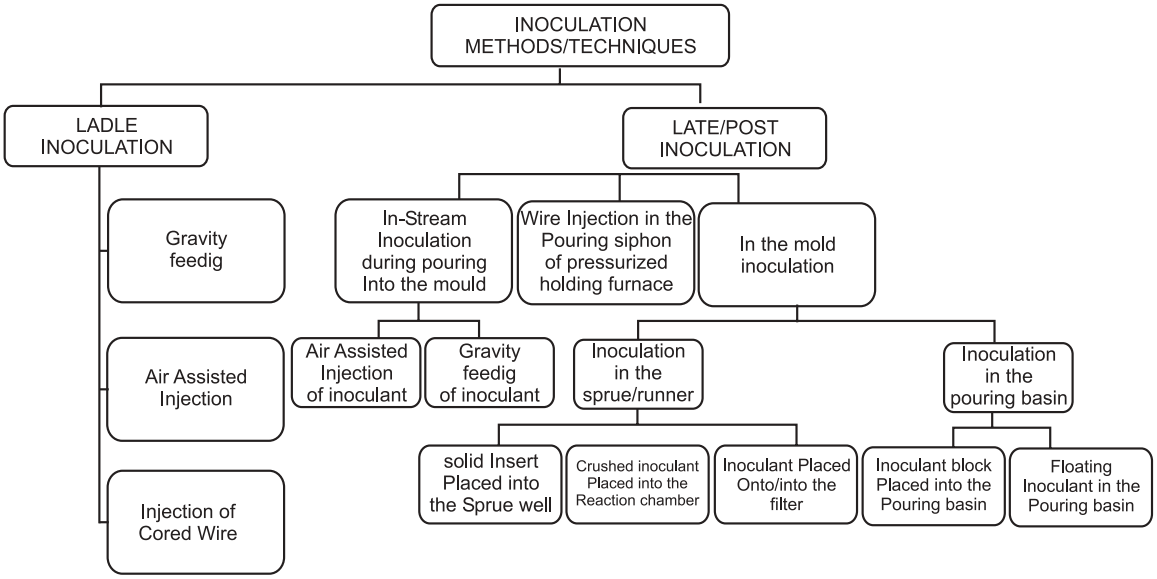


Fig. 7 : *Schematic of inoculation methods.*

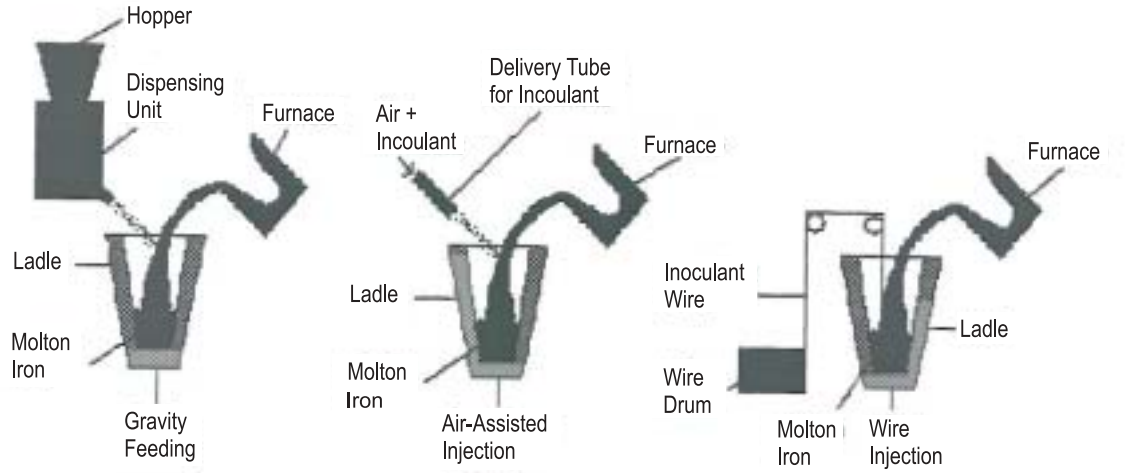


Fig. 8 : *Ladle inoculation.*

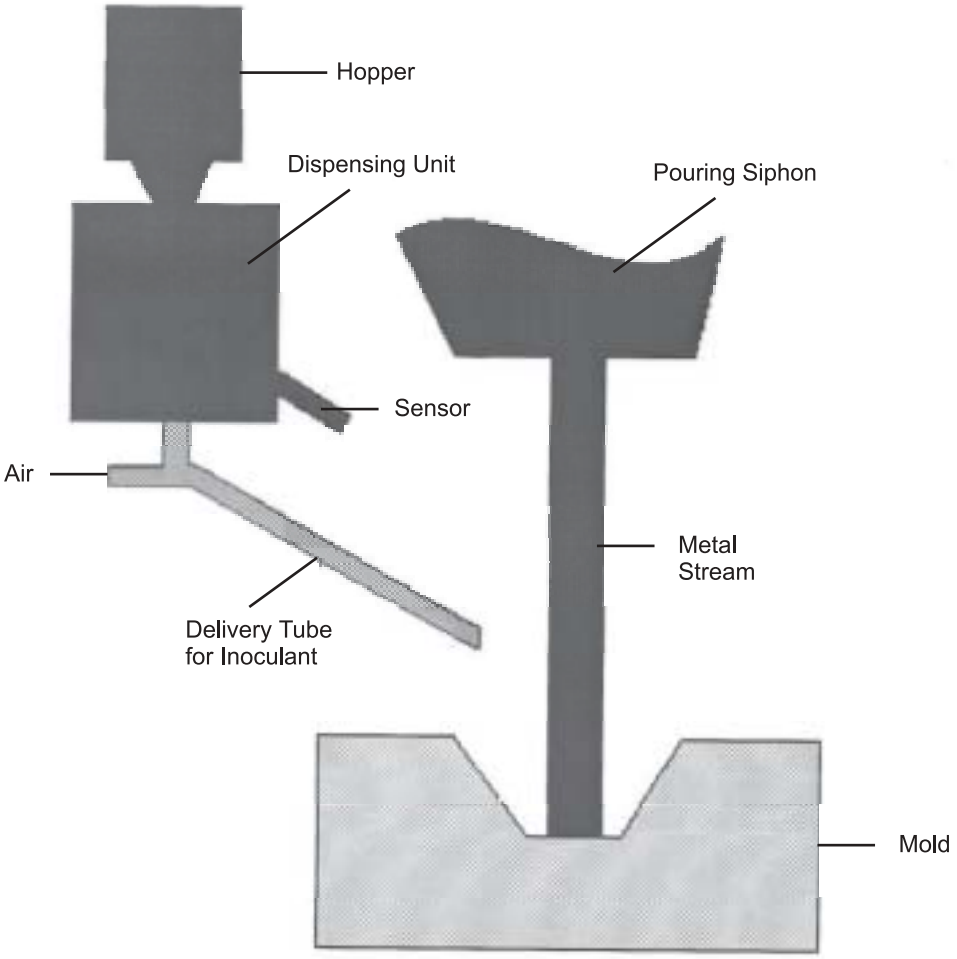
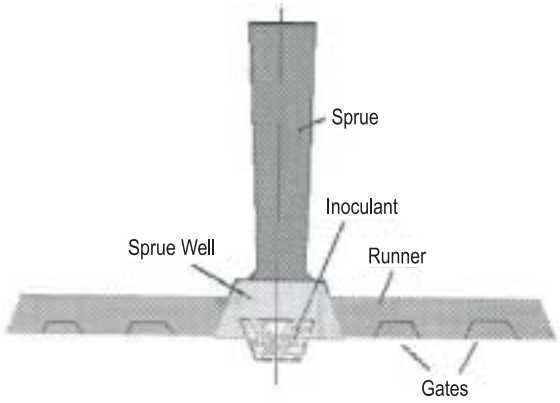


Fig. 9 : *In stream inoculation*

Down Sprue



Runner Bar

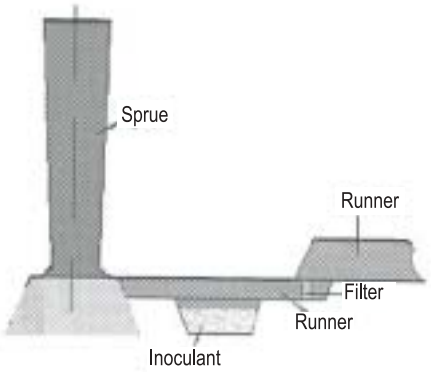
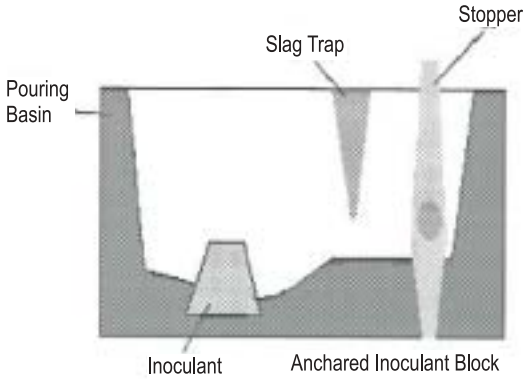


Fig. 10 : *In the mould inoculation.*

Pouring Basin



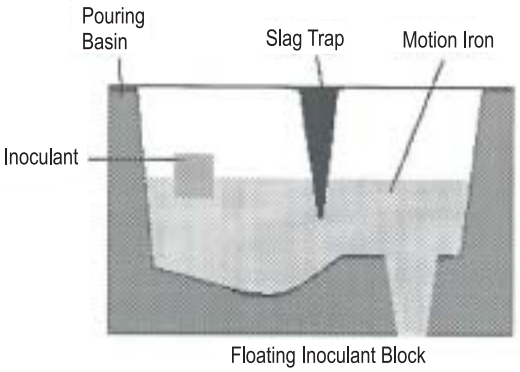


Fig. 11 : *In the mould inoculation.*

Pressed and Sintered Inoculant Blocks.

powerful active elements than Al and Ca in FeSi based inoculants. This results in lower addition rates.

Active Elements

Aluminium

Typical 0.5-4.5%.
Danger of pinholing in green sand grey iron production if Al>0.015%.

Calcium

Typical 0.5-2.0%.
Ca + AI total of 2.5%.
Known as inoculating grade FeSi.
First commercially used FeSi inoculant,

Manganese

Typical 3-10%.
Used in combination with other elements, typically Ba, Zr.
Forms lower melting point phases.

Zirconium

Typical 1.5-4.5%.
Aids fade resistance in combination with other inoculants.
Ties up N2 from melting process.

Barium

Typical 1.0-11.0%.
Minimises chill formation in combination with other elements.
Good fade resistance.

Rare Earths

Typical up to 10%.
Combinations of Ce/La.
Effective in low S content grey iron.

Bismuth

Typical up to 1.5%.

Combination with 0.5% RE.
Effective in thin section ductile iron.

Strontium

Typical 0.6-1.0%.
Combination with 0.1% Ca and 0.5% Al maximum.
Good chill reduction
Lower shrinkage tendencies.
Low S grey irons and ductile irons treated with high RE FSM reduce effectiveness.

CHOICE OF INOCULANTS - OUR ADVICE

Grey iron – ladle -1 % Sr or 2% Ba.
Grey iron – ladle -1 % Sr or 4% Zr/4% Mn.
Ductile iron – ladle -1% Bi/0.5% RE for thin section.
Ductile iron – ladle - 2% Ba or 2% Zr for thicker section.
Ductile iron – late - 4% Al or 4% Zr/4% Mn.
Fade times – 8 to 10 minutes.

CASE STUDIES

"In the Mould" Inoculation

Casting – steering knuckle - 7kgs.
Material – ductile Iron grade 400/15 impact properties of minimum 60J at minus 30°C unnotched bar.
Problem – failure to meet impact values.
Cause – 5% pearlite in test piece microstructures. Micro-shrinkage in test piece.
Inoculation –0.6% addition of 1.5% Al, 1% Ca FeSi in pouring ladle.

Remedy

- 0.3% addition of ladle inoculant FeSi + 1.5% Al + 1%Ca.
- 0.1% in the mould block - 70% Si, 4% Al, 1% Ca Result - typically 80-100J at minus 30°C impact values.

Effect of High Mg Treatment on Inoculation

Casting – Automotive Manifold.
Material – grade 450N/mm^2 minimum tensile strength, 10% minimum elongation.
Problem – changed from a cored wire containing 70% Mg, 30% FeSi to 98% Mg wire resulting in carbide problems.
Inoculation –0.1% in the mould inoculant FeSi 4.5% Al.

Remedy

- 0.25% FeSi 4.5% Al into autopour furnace.
- 0.15% FeSi 4.5% into metal stream.
- 0.1% in the mould inoculant.

Result - elimination of carbide.

"Pre-Conditioning"

Material – ductile iron - ferritic

Grade-420/12.

Problem – the last metal taken from a 2MT induction furnace exhibited:

- poor nodularity <85%.
- poor nodule count <100/mm^2.
- 10% pearlite.

Cause – up to 1.5 hours to treat 8 × 250kg treatments. Resulted in loss of nucleation in the furnace metal.

Remedy – pre-conditioning addition of 0.1% of a 75% FeSi/25% graphite mixture every 20 minutes to the furnace.

Result – 85% minimum nodularity, 150 nodules/mm^2, fully ferritic structure.

Effect of Strontium on Shrinkage Characteristics of Grey Iron

Casting – brake drum.

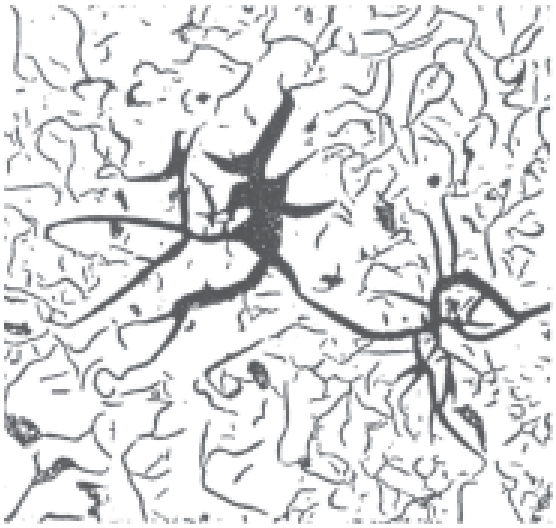
Material – grey iron grade 220.

Problem – microshrinkage.

Inoculation – 75% Si, 1% Al, 4% Mn "in the mould" block 0.05% addition.

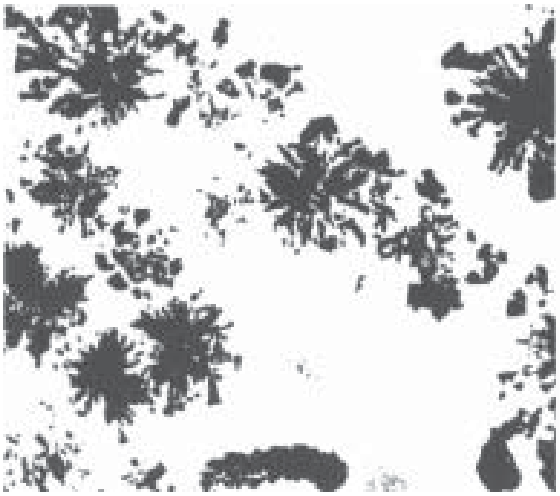
Remedy – in the mould block containing 75% Si 0.6% Sr 0.05% addition.

Result – elimination of microshrinkage.

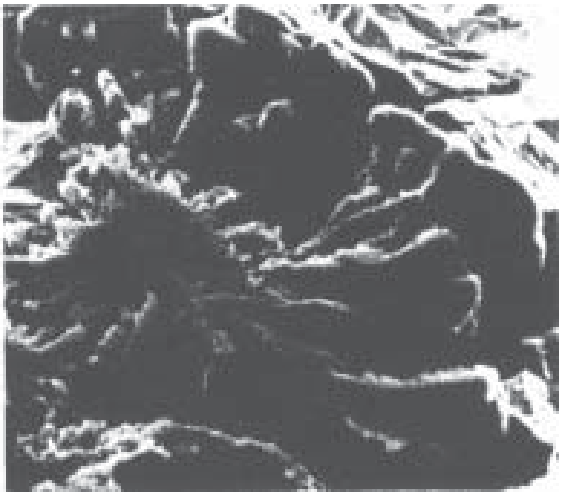


Kish Graphite, Star-Shaped Clusters 4% Picral X300

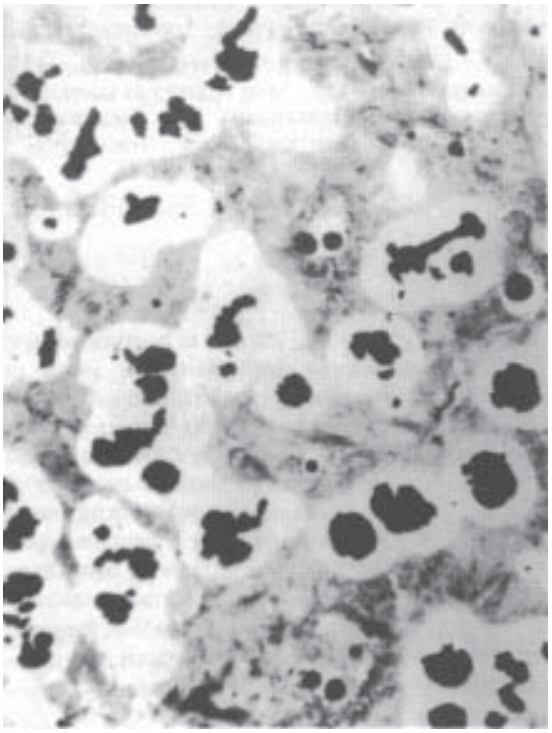
Stereoscan X450



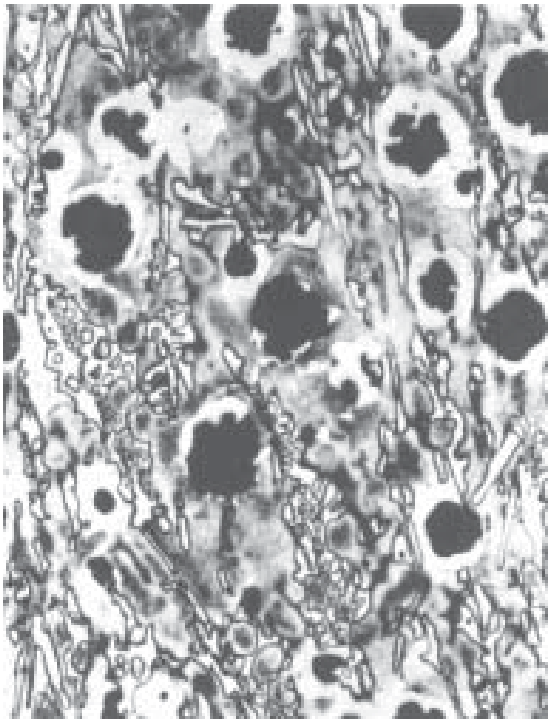
Exploded Graphite Nodules Unetched X300



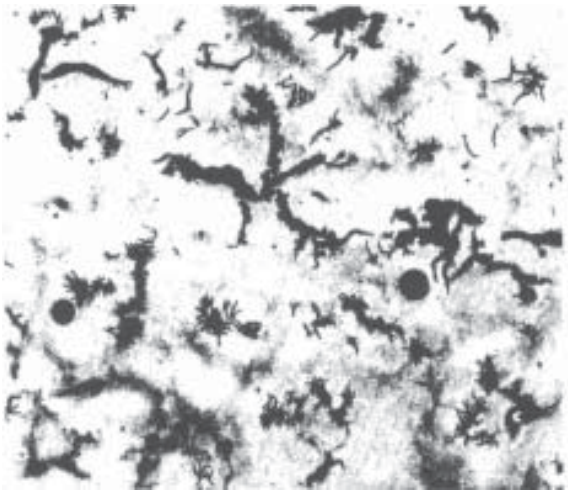
Exploded Graphite Nodules Stereoscan X320



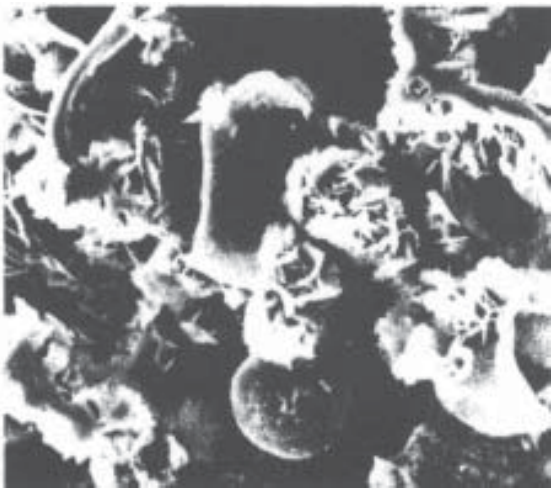
Inoculated- 20 mins later



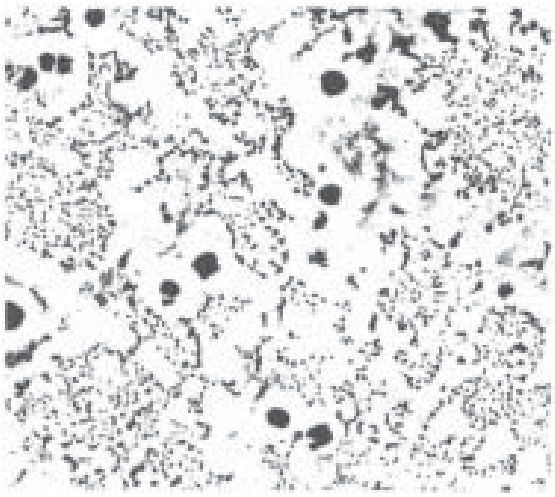
Underinoculated ductile iron 100 etched

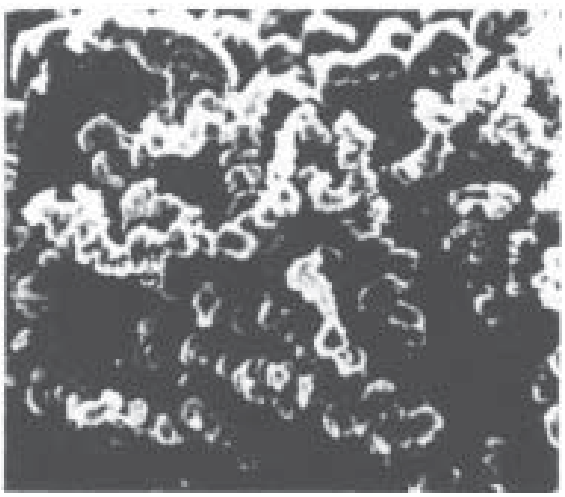


Spiky Graphite, Etched in 4% Picral X100



Spiky Graphite, Stereoscan X530





Chunky Graphite, Etched in 4% Picral X100