Inoculation of Cast Irons – An Overview

J.N. Harvey and G.A. Noble

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

G.A. Noble
Tennent Metallurgical Group Ltd,
Chesterfield,
United Kingdom
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.
Inoculation of cast Irons - an overview

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

Uninoculated Ductile Iron

Nodular Graphite

Stereoscan × 950
Degree of Nodularity

95%

60%

80%
Improve in Nodule Count

Prevention of Formation of Carbides

Inverse Chill

Carbide in Ductile Iron
GREY IRON INOCULATION

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

Nil Pearlite - Completely Ferritic 100x-Etched

4% Picral × 100

Stereoscan × 600

Inoculation of cast Irons - an overview
Effect of low % Sulphur on ductile iron microstructure

Material – ferritic ductile iron.
Grade – 420N/mm² minimum tensile strength, 12% minimum elongation.
Problem – low nodule count <100mm², 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% Al in pouring ladle.
Remedy – increased % S to 0.010-0.015% in furnace.
Result – increased nodule count >100mm², 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.
55th Indian Foundry Congress 2007

Undercooled Graphite

4% Picral \times 100 \quad \text{Stereoscan } \times 100

Rosette Flake Graphite

4% Picral \times 100 \quad \text{Stereoscan } \times 100

Inoculation of cast Irons - an overview
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 disadvantage-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.

Inoculation of cast irons - an overview
Fig. 9: In stream inoculation
Down Sprue

Runner Bar

Fig. 10: *In the mould inoculation.*

Pouring Basin

Fig. 11: *In the mould inoculation.*
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 + Al 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. Microshrinkage 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/mm² 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 autoupour furnace.
- 0.15% FeSi 4.5% into metal stream.
- 0.1% in the mould inoculant.

**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/mm².
  - 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/mm², 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.
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

Chunky Graphite, Etched in 4% Picral X100

Spiky Graphite, Stereoscan X530