130 years of changing cast iron technology: John Harper & Company 1852-1982

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ABSTRACT: Developments in the iron foundry products and technology of John Harper & Co are reviewed, from its origins in the 1850s making white-heart malleable iron castings for locks and keys, grey iron castings for decorative hardware in the 1890s and for the electrical, typewriter and other industries in the 1920s and 30s, then Meehanite engineering castings in the 1940s and 50s and Spheroidal Graphite iron in the 1960s and '70s. The company was eventually taken over in 1974 and the foundry closed in 1982. Changes in metallurgical production processes are reviewed in relation to changing economics, management policies, markets, and technologies.

Historical background

John Harper and Company originated as a combination of several older businesses, of which the largest was Carpenter and Tildesley's Albion Works. In 1852 this was sold to John Harper and his cousin Matthew Tildesley. John Harper had managed it since 1846; he brought in some other smaller firms, and the new company took his name. In 1854 the partners moved to a new site, where the factory remained until 1950. The original business was lock-making, the major industry of Willenhall. The Albion Works had operated a foundry since 1846 (Tildesley 1971, 35), originally for making malleable iron lock components. By 1863, according to an article in The Ironmonger (Strauss et al 1863, 11), the company was also selling castings to outside customers, up to 28lbs in malleable, in brass, and in 'common iron' from 1 cwt to 'forty dozen to the pound.' In 1873 it advertised malleable castings, e.g. for telegraph line brackets (Griffiths 1873, 206 & xxii-xxv), and also coat hooks, pulleys and sash weights, which were probably made in grey iron, as well as locks and bolts.

In the 1870s the business survived trading difficulties, temporary bankruptcy and a dispute between the partners, and was eventually re-incorporated in 1888 as a private limited company owned by John Harper and his family (Tildesley 1971, 43). By then the finished product range had widened to include oil lamps, oil and gas stoves and other hardware, and the foundry was making intricate grey iron castings for these products and for the outside market (Fig 1).

In 1900 some 50 tons per week of castings were being made in five more or less separate foundries, and the proportion of castings for outside sale began to grow. After the first world war the demand for John Harper's grey iron increased, as new markets were developed for typewriter, electric cooker, and other castings, exploiting the skills which had developed to cast accurate and fine-finish decorative castings for the company's own products.

To expand capacity to meet this grey iron demand, malleable iron production was ended in 1925, and in 1928 a new foundry (Anon 1928, 261-2) was built on an adjacent site where the rest of the factory was progressively rebuilt over the next twenty years. This investment was financed by a public share issue, ending control by the Harper family.

Castings for some of the new markets, developed in the 1920s and 1930s, had demanding quality requirements, often beyond the ability of most competitors, and were consequently very profitable. On the other hand, castings for John Harper's own finished products were transferred from the foundry to the finishing departments at or below external market prices. Other low-price work was taken on to secure a consistent load for the new foundry, especially from Crompton Parkinson and F & A Parkinson, manufacturers of electric motors, whose castings were sold at an agreed low profit margin 'cost plus 8%' basis.

The need to make large volumes to recover the high fixed costs of new investment thus forced the company into more competitive markets. The same experience followed investments in foundry mechanisation in the 1950s and in SG Iron melting and heat treatment plant in the 1960s and 1970s.

Attempts to develop further profitable markets for engineering castings led to the adoption of the Meehanite process, for which a separate foundry was built in 1937, and which became very profitable. By 1940 the total output was about 150 tons/week. After 1945 the foundry was partly mechanized, and in the 1960s developed and expanded the production of Spheroidal Graphite (SG) iron. By 1965 production of grey iron, Meehanite and SG iron averaged about 260 tons per week.

Table 1 shows how new customers became important

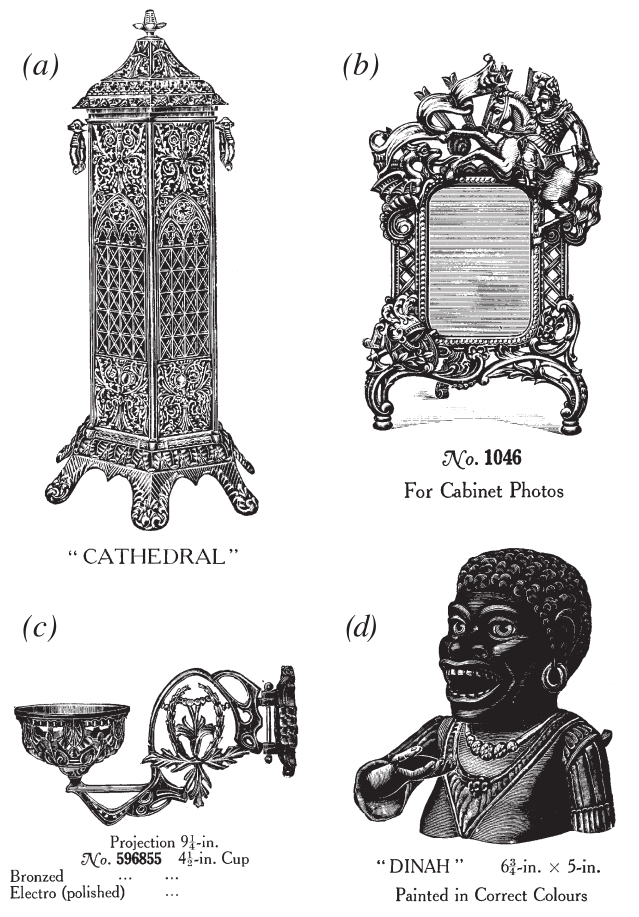

Figure 1: Typical grey cast iron products from the John Harper & Co Finished Products catalogue 1903-1924 and earlier (not to common scale): (a) 'Cathedral' paraffin stove, (b) decorative cabinet photograph frame, (c) wall bracket for oil lamp, (d) mechanical money box.

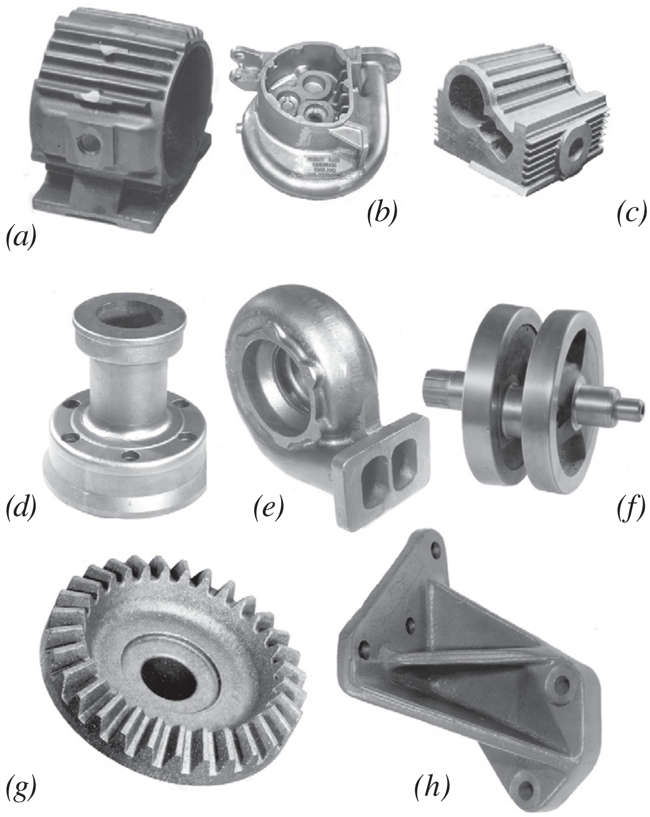

Figure 2: Typical castings produced in 1960s and 1970S (not to common scale): (a) electric motor stator body (grey iron) (b) irrigation pump body (Meehanite) (c) high-vacuum pump body (Meehanite) (d) dump truck wheel hub (SG Iron) (e) diesel engine turbocharger housing (SG iron) (f) motor cycle crankshaft (SG iron) (g) cast-to-form gear (SG Iron) (h) diesel engine mounting bracket (SG Iron)

as new products were introduced, and also how the company maintained its traditional types of business in parallel with new developments.

In 1970 the finished goods department was closed after a period of losses. The foundry continued to grow, with output rising by 1978 to 330 tons/week, of which over 60% was SG iron. This contrasted with a continuing decline in the total national production of cast iron from 4.1 million tons in 1965, 3.8 million in 1970, 3 million in 1975, to 1.8 million in 1980 (Iron and Steel Industry Annual Statistics 1960-1980), a decline which was largely due to the collapse of previously important markets for heavy grey iron castings outside John Harper's range, for example steel works ingot moulds, whose use was being replaced by continuous casting.

In 1974 the company was taken over by the Duport Group, and in 1982 was amalgamated with Duport's own foundry in Tipton, when production at Willenhall ended, although the combined Duport-Harper foundry,

Table 1: Sales to ten largest customers 1937, 1958 and 1966

Full year 1937		October 1958		March 1966	
	£		£		£
GEC Birmingham	20,373	Brook Motors	10,550	Brook Motors	15,200
Imperial Typewriter	15,185	F & A Parkinson	7776	F & A Parkinson	8531
CAV Bosch	7000	Burtonwood Engng	3175	Addressograph	5434
GEC Witton	6627	Remington Rand	2575	Yale & Towne	5331
Siemens	5650	Rolls Royce Crewe	2313	National Cash Register	4673
Automatic Telephone	4920	Edwards High Vacuum	1894	Caterpillar Tractor	4641
Austin Motor	4885	Massey Harris	1872	Rotaprint	4471
Yale & Towne	4800	Borg & Beck	1799	General Engineering Radcliffe	4312
Standard Telephone	3236	Crompton Parkinson	1764	F Perkins	4274
Swift Scale	3100	Siemens Edison Swan	1640	(Dowty) Mining Engineering	3365

recently acquired by Grede Foundries of Milwaukee, still continues in Tipton. Table 2 summarizes this 130-year history.

Products

Malleable iron

John Harper & Co made whiteheart malleable by the Réaumur or European process, which although developed in 1722 was adopted rather slowly in Britain, (Gale 1969, 119). In the 1850s malleable had only recently come into Willenhall and the Albion Works was the first to make locks entirely of malleable iron (Tildesley 1971, 35, quoting Price 1856).

The whiteheart process starts with an iron containing about 3%C and 0.75%Si. It contains iron carbide when it solidifies, and is hard and brittle, becoming malleable only after prolonged annealing in an atmosphere which decarburizes thin sections and the outer layers of heavier castings, while the remaining carbon forms rounded graphite particles rather than the weakening graphite flakes formed when grey iron solidifies. Provided that other elements are correctly balanced, the annealed castings are ductile, and show a shiny 'white-heart' fracture below a black and softer decarburized outer layer.

In 1863 *The Ironmonger* (Strauss *et al* 1863, 9-10) stated that 'iron used for the best malleable castings consists of a mixture of best Spanish pig-iron and best lawn [*sic*, for Lorn] charcoal iron from Cumberland'. These pig irons were brought into the iron-producing area of south Staffordshire because of their much lower phosphorus, sulphur, and other impurity contents which could reduce strength or ductility. The article continued 'For fine malleable castings the metal is melted in the so-called pot furnace, in the common Stourbridge clay melting pots.' This crucible melting process avoided sulphur contamination from cupola coke. Lancashire pig iron, probably haematite from Barrow in Furness, is also mentioned, with the comment that Staffordshire iron was also used, 'more especially for wrought iron articles'. This may be a journalist's error: there is no other reference to wrought iron production at John Harper's, and probably Lancashire haematite pig iron was cupola melted for less 'fine' qualities of malleable, and Staffordshire pig iron was used for grey iron.

The malleable castings were annealed in ovens 6ft x 10ft x 5ft high, containing 40 cans, with 70 to 90 pounds of castings per can, packed with crushed haematite ore to support them and provide the decarburizing atmosphere: 'mixed with a rich red iron ore, by the aid of which carbon is extracted' (Strauss *et al* 1863, 11). Ten years later (Griffiths 1873, xxiii) the company

Table 2: Historical overview

Year	Foundry			Whole company		Events
	tonnage	sales (£, 000)	profits (£, 000)	sales (£, 000)	profits (£, 000)	
1852	-	-	-	-	-	company founded
1854	-	-	-	-	-	new site
1863	-	-	-	-	-	Ironmonger article
1874	-	-	-	-	-	bankruptcy, partnership disputes
1888	-	-	-	-	-	re-incorporation
1900	-	0.36	-	77.45	4.23	
1908	-	23.27	-	92.15	1.55	
1923	2348	90.4	13.8	205.6	21.84	(September quarter figures x 4)
1925	3400	-	-	-	24.9	malleable ended
1928	5000	-	-	-	26.3	new foundry, public company
1937	7396	280.9	33.7	-	56.99	Meehanite
1940	7841	271.9	35.6	452.9	-	Meehanite foundry extended
1945	7558	450.3	48.3	674.3	95.8	first mechanized moulding plant
1950	10006	665.2	92.1	1076.4	189.4	first SG iron experiments
1952	11349	956.2	163.4	-	226.0	Poole Foundry bought
1955	10861	962.1	102.0	-	180.9	basic cupola
1961	11956	1626.3	223.4	-	331.0	Meehanite company re-integrated
1965	12537	-	180.0	-	322.2	first SG melting plant
1970	13527	-	398.1	-	-	Finished Goods closed
1973	11686	-	217.8	-	-	second SG melting plant
1974	-	-	160.0	-	-	Duport take-over
1978	14400	7955.0	429.0	-	-	
1982	-	-	-	-	-	Willenhall foundry closed

Notes:
Sales and profit figures are shown in thousands of pounds (£, 000). Foundry tonnage, sales and profits include Meehanite and Poole Foundry data, although from 1951 to 1961 Meehanite figures have been added but not financially consolidated.

advertised 'Tildesley's Patent Compound, our newly discovered oxide for the annealing of Malleable Iron Castings'. It claimed that this compound was significantly cheaper than red haematite, had been used on its own in the company's ovens, and that other customers had used it either totally or in part to replace haematite. Whatever this material was, its use did not persist—a later review (Field 1926), and accounts from 1889 - 1908, refer only to annealing ore.

The ovens were coal fired and the cans were handled with a 'devil's toasting fork', presumably a suspended arm used to swing a can in or out of an oven. The annealing temperature was 'whitish red'; 950°C or more is essential for the process. The 1863 cycle time is not mentioned, but considering the heavy mass of castings, ore, cans and refractory to be heated, held at temperature, and slowly cooled, it was probably of the order of a week or ten days.

As new finished products using grey iron, such as stoves and lamp brackets, began to replace locks, malleable iron output declined and was ended in 1925. A year later Herbert Field, Chief Metallurgist from 1913, reviewed the process in its final years (Field 1926). Crucible melted Lorn charcoal iron had proved too expensive, and recent malleable production had all been from cupola-melted haematite pig iron. The mechanical properties quoted, 24 tons/sq in ultimate tensile strength and 6 to 7% elongation, lie between the two grades of the later British Standard specification BSS 209. By the 1920s the ovens were equipped with temperature recorders, and the annealing temperature was given as 960-980°C, but Field comments that operators used temperature variations within the ovens to suit the needs of different castings. New and re-used annealing ore was mixed to control the proportions of the iron oxides Fe_3O_4 and Fe_2O_3, preventing an over-oxidized peeling defect.

Grey iron

The early grey iron was no doubt made from a local pig iron with a phosphorus content of up to about 1%, giving maximum liquid metal fluidity at a relatively low pouring temperature, allowing the production of thin castings with a fine skin finish. The cupola charge consisted of pig iron and foundry returns—runners, risers and scrap castings. Purchased scrap cast iron was not used until the 1950s.

From 1940 to 1952 quarterly records list pig iron stocks, purchases, consumption, and prices related to grey iron production. The average ratio of casting production to pig iron consumption was 91.3%. The remaining 8.7% must have included dirt, rust, melting and dressing losses, and spilt or other metal not recovered for re-melting. Pig iron was a major element in the cost of finished grey iron castings, *eg* amounting to 20% (£11.14s.0d out of £58.2s.0d) in 1949.

By the 1950s pig iron was being bought from many sources (Table 3).

From an early date some grey iron was annealed to improve machineability (Strauss et al 1863). Instead of ore, castings were packed in mixed sand and sawdust to 'prevent smelting' and 'give colour to the castings'. Metallurgically the treatment could have been shorter than that for malleable, but the thermal inertia of the ovens would still require a cycle of several days. In his 1930 retirement retrospect memorandum C Retallack, who was effectively technical director from the 1880s, comments on 'hard castings, and the annealing of the same in common iron ovens, coming out as hard as they went in sometimes, the mysteries of Mr Evans.' There is no other reference to this Mr Evans, maybe the annealing foreman, but in the early days the lack of temperature measurement or controlled metal composition would require no 'mysteries' to explain inconsistent results. But later, annealed grey iron became a major product, for applications requiring free machining or high magnetic permeability. In the 1920s John Harper had set up facilities, at the time unique, to measure the electromagnetic properties of iron castings, opening new markets for parts such as resistance grids and telephone exchange components.

By the 1950s two grey irons were made, with typical compositions shown in Table 4.

No. 1 iron, although originally not sold to specification, was equivalent to BSS 1452 Grade 12 or 14; by the 1960s, with closer metallurgical control, it was generally sold as Grade 14. After annealing, it was softer and more machineable than annealed No. 2 and was therefore used for typewriter castings—every UK typewriter producer used Harper castings. No. 1 iron

Table 4: Compositions of grey irons

Cast iron	wt% element				
	Total C	Si	P	Mn	S
No. 1	3.1-3.3	1.9-2.2	0.2-0.4	0.5-0.7	0.06-0.10
No. 2	3.0-3.35	2.9-3.3	0.8-1.2	0.5-0.7	0.06-0.10

Table 3: Pig-iron purchase records 1958-1959

High-P for grey iron		Low-P for grey iron and Meehanite		For SG iron experiments	
Clay Cross	£20.12s.5d	Barrow SP	£23.8s.6d	Barrow haematite	£27.16s.6d
Cransley	£20.15s.0d	GKN Britton Ferry	£23.2s.6d	Millom & Askham	£26.11s.0d
Manton	£21.7s.3d	GKB Haematite	£26.12s.0d	Warner SPH	£23.0s.0d
Renishaw	£19.10s.0d	Goldendale	£23.0s.0d	Bremanger SW	£30.7s.0d
Sheepbridge	£17.10s.3d	Lilleshall	£23.0s.0d	Bradley & Foster	£29.15s.0d
Staveley	£22.12s.6d	Scottish	£22.11s.3d		
Thornston	£21.7s.3d	Stanton	£23.0s.0d		
Shaw (for Poole)	£14.0s.0d	Workington	£26.1s.6d		
		Darwen	£27.6s.6d		
		Ford	£24.0s.0d		
High Si iron: Silky Kettering (4-5% Si) £22.14s.3d and Warner's Silvery (13% Si) £29.5s.0d					

was also used for larger electric motor castings, and for electric cooker hotplates with cast-in spiral grooves for the heating elements, a major product of the 1930s. No. 2 was a traditional phosphoric iron, for thin-section castings for such finished products as mincer bodies and stove feet, and for small electric motors and instrument cases.

While these two irons were made in the same foundry, metallurgical control was difficult because phosphorus from No. 2 iron contaminated No. 1, despite efforts to segregate the returns for re-melting. The use of differently designed containers, and white-wash marking the tops of solidified runners, were only partly successful.

In 1952, largely to make No. 2 iron castings for finished goods, the company bought a foundry in Poole, in Dorset, where labour was then more easily available, and whose separation eventually eliminated return scrap contamination. Poole Foundry became very efficient, making 600-700 tons of castings a year, mostly for finished goods, but also for local sale, including complex water-cooled cylinder bodies for British Seagull outboard motors.

Semi-steel and cylinder iron

The traditional grey iron practice, combining high-phosphorus iron with rather soft moulds, favoured a fine skin finish but was fundamentally unsuitable for pressure-tight engineering castings, where shrinkage porosity in heavier sections was a constant hazard.

This seems not to have been appreciated in the 1920s and 30s. In his otherwise rather boastful retirement memorandum, C Retallack speaks of the 'inevitable failure' of trying to make internally-sound compressor or engine cylinders. W H Harper, later Managing Director, writing years later, recalls a 'disastrous incursion into the motor trade' in the early 1920s 'when we attempted to supply cylinder blocks and heads using high phosphorus Northamptonshire pig iron, and which in our desperate attempts to make sound castings we plastered with chills.'

Table 5: Semi-steel compositions

Steel in cupola charge	wt% element		
	Total C	Si	P
10%	3.25	2.0	1.00
20%	3.40	1.8	0.85

During the early 1920s the foundry made 'semi-steel' (Field 1920), which was stronger than grey iron, and thought to be more suitable for engineering castings, although the name and the way it was produced were already being criticized (Moldenke 1917, 199-210) and were later replaced by better processes. Typical data from Field's paper are summarized in Table 5.

Field describes the increased tensile strength, and refers to problems with chilling and reduced fluidity, but makes no mention of shrinkage. It is also surprising that no attempt seems to have been made to use lower-phosphorus pig iron.

By the early 1930s semi steel had been discontinued. An advertisement refers to three types of grey iron:

'Soft Grey Iron for light castings
Annealed Iron for rapid machining
Cylinder Iron'

Microphotographs in the advertisement (Fig 3) show the 'soft grey iron' to be No. 2 iron, with inter-dendritic graphite in a ferrite-pearlite matrix, and phosphide inclusions. The annealed iron is essentially the same, ferritized by heat treatment. The cylinder iron microphotograph is too small and too highly magnified to interpret in detail but contains pearlite, graphite and phosphide.

This cylinder iron was expensive because of its costly pig iron base. But it proved satisfactory for carburettor and fuel pump parts for Ford and for CAV under licence

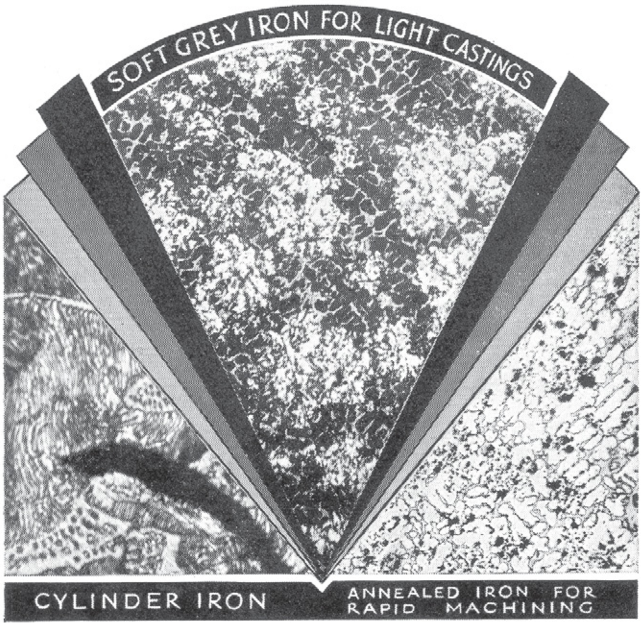

Figure 3: Cast iron microstructures from an advertisement

from Bosch in Stuttgart, who provided useful technical help. By then carburettor parts in USA were being made in permanent metal moulds by the Holly process, for which John Harper & Co had taken out a licence in 1927. However (allegedly through lack of tool-making skill) the trials were unsuccessful. In 1939 there was an offer to renew the licence for an improved process, but by then John Harper's was developing Meehanite and declined the offer. The licence went instead to Qualcast, who used it to build a successful and competitive foundry.

Meehanite

Although the cylinder iron gave better results on engineering castings, there were still porosity problems. One particular incident resulted in the loss of a valuable order to Cameron and Roberton in Scotland, who had recently taken a Meehanite licence. A paper by John Cameron (Cameron 1921) shows that this firm too had previously experimented with semi-steel. Meehanite, a registered name, was the commercialization of a process developed at the Ross-Meehan Foundry in Chattanooga, Tennessee, and was based on melting a low-phosphorus pig iron and steel scrap charge under standardized conditions, with calcium silicide inoculation at the furnace spout (Meehan 1924, quoted by Hughes 1985, 91). The controlled inoculation was a significant innovation, but otherwise Meehanite's success lay not so much in its technical details as in its systematic and rigidly applied process controls.

It was decided to take out a Meehanite licence. As thin-section grey iron production had to be maintained, the licence was operated by John Harper (Meehanite) & Co Ltd, a subsidiary company set up for the purpose. This makes interpretation of some of the surviving records difficult—it can be unclear whether later figures refer to the parent company, the Meehanite company, or to the consolidated whole. The acquisition of Poole Foundry in 1952 can further complicate this problem.

The Meehanite foundry opened in 1937 (the author, then aged 4, remembers pouring the first ceremonial mould, albeit with substantial adult assistance). The process was successful: Meehanite's greater consistency permitted the logical study of casting and mould design, so that skilled foundrymen could eliminate unexplained inconsistencies and minimize costly trial and error.

The timing was fortunate, as it coincided with growing demand for high-duty engineering castings directly and indirectly for the 1938 rearmament programme and from 1939 for the war effort. Meehanite was found suitable to replace steels for heavy-duty lathe spindles and other machine tool parts. Cast-to-form (or near to form) Meehanite dies replaced traditional press tools cut from alloy steel: by the end of 1938 the foundry had already made six tons of production dies for the new Spitfire wing panels, and after the war made the tools for the Ford Anglia dashboard moulding. Meehanite was also used for smaller munitions castings, notably the 'squid' anti-submarine detonator housing.

In 1937 the new company employed 21 people, but soon expanded, until by 1962 it employed 148 and covered 69,000 square feet. Demand grew rapidly, and John Harper (Meehanite) & Co became and remained very profitable, despite a hiatus after the war when new markets had to be developed in the printing, machine tool, vacuum pump, compressor, and other industries. This set the company on a growing and profitable course, which contrasted with the difficulties experienced by many other iron foundries as traditional markets contracted during this period (Church 1969, 200-1). By 1961 Meehanite production rose to 5,000 tons per year, with profits over £150,000, although these profits may have been partly artificial, since the allocation of overheads between the two companies was somewhat arbitrary.

In 1951 John Harper (Meehanite) & Co Ltd, which until then had been wholly owned by John Harper and Co. Ltd., was separately floated on the Stock Exchange (Lea Barham and Brooks 1951). Despite the official separation, in day-to-day operation under the same management and in adjacent buildings, the twin company structure became unrealistic and uneconomical (*eg* in the separate melting of Meehanite grade GE and the effectively identical grade 14, ex-No. 1, grey iron). In 1961 the Meehanite licence agreement was renegotiated at a lower royalty covering all the low phosphorus grey iron, and at the same time John Harper & Co repurchased all outstanding shares in John Harper (Meehanite) & Co, reintegrating the businesses financially to reflect the operational reality.

By the late 1950s the almost automatically high profitability of the conventional types of Meehanite was beginning to erode, as more competing foundries acquired licences or adopted similar technical standards, and the Board was looking for the next step forward to retain its profitable technical pre-eminence.

Alloy cast iron

One possibility was to expand the production of recently developed alloy cast irons (Hughes 1985). Small quantities of nickel alloyed non magnetic (NoMag) and corrosion resistant (NiResist) castings had been made under licence since 1928 and 1936 respectively. There was also some production of low-alloy grades of heat, wear, or corrosion resistant Meehanite, some of which had useful markets, for example for pressure die-casting machine melting pots and goosenecks. But none of these materials, nor some abrasion-resisting copper-chromium-nickel-manganese alloyed irons originally developed by the firm's own research department for shotblast parts, were ever marketed effectively or produced in any quantity.

SG iron

In 1947 the successful production of SG (Spheroidal Graphite), Nodular, or Ductile Iron was announced by Morrogh at the British Cast Iron Research Association (BCIRA) using cerium, and by Gagnebin and Millis at International Nickel (Inco) in USA using magnesium (Hughes 1985, 94).

SG Iron eventually became the company's major product. Its high strength and ductility results from its microstructure, in particular its round graphite inclusions, which, like the graphite particles formed on annealing malleable iron, weaken the metal less than the graphite flakes formed in solidifying grey iron. Although 'Cast iron with Elongation' was an item on John Harper & Co's 1945 internal research programme (the results were negative), memoranda from H Field in 1949 and 1953 were cautious; he pointed out that although he foresaw that eventually SG would revolutionize iron foundry production and markets, there were still no reliable production processes, and no existing market, so that all applications would have to be new and individually sold to, and developed with, customer engineers. There were also patent and royalty issues: it was not clear how far Inco's nickel-magnesium alloy process, already the subject of a law suit with Ford in USA, would be in conflict with BCIRA's cerium process or some later Meehanite processes.

John Harper's development work started in 1950 with a Meehanite process, adding ferro-silicon-magnesium and copper-magnesium alloy to cupola-melted metal. Good test bar results were obtained, but the high-sulphur metal needed so much alloy that after treatment it was too cold to make saleable castings. In 1952 ladle injection desulphurizing and magnesium metal plunging were tried, again giving good test bars but no castings. In 1953 BCIRA trials at Willenhall with nickel-cerium-magnesium produced both good metallurgical results and the first saleable Harper SG castings, for Self Change Gears Ltd., replacing previously forged steel components.

From 1955 the basic cupola melting process (see below) opened the way to commercial SG production from low sulphur iron, initially with Meehanite's newly developed 'Procally' addition alloys. In 1956 the market started to grow—crankshafts for Royal Enfield motor cycles, 'explosion-proof' stators for GEC electric motors, levers, gear blanks, and other parts, often replacing steel. Sales growth continued throughout 1956, but graphite structures were inconsistent, and management began to fear that Inco licensees were making better progress, both in Great Britain and in USA. By then the company had taken an Inco licence, initially as a legal precaution against the still unresolved patent questions, and in 1957 nickel-magnesium was tried. Metallurgical consistency and results improved immediately, and the process was soon adopted in production. Later, when improved melting processes permitted, nickel-magnesium was replaced by ferrosilicon-magnesium-cerium alloy, used with the 'sandwich' process in which a little steel scrap was placed over the alloy in the ladle to cool it locally.

Post-inoculation, originally immediately after magnesium treatment but later at the time of pouring, was with ferrosilicon, in the 1970s with controlled calcium, strontium, and aluminium content to improve effectiveness.

By 1961, SG iron output was about ten tons/week, still less than 5% of the total, but despite established competition SG was becoming increasingly profitable and starting to fulfil the Board's hopes that it represented the next step after Meehanite. Many problems remained to be solved, for example with quality control, heat treatment, and production logistics. The author toured a number of American foundries in 1962 and somewhat arrogantly reported that although there were some useful ideas, in general there was little which even the larger American producers could teach John Harper & Co.

Unlike many of its competitors John Harper & Co melted a standard base metal, using a low-cost steel scrap furnace charge, and produced the different specifications: ferritic, pearlitic, or harder martensitic grades, by heat treatment. Some competitors used high-purity pig iron, melted electrically to avoid contamination, making castings which could often be used without heat treatment. The economic and technical pros and cons of the alternative approaches were often reviewed, both on paper and in foundry trials. Calculation suggested that neither route was significantly cheaper, although it was argued that heat treatment gave more consistent mechanical properties. Furthermore, foundry sales policy had always been to make high-quality, technically-demanding castings, even if ordered in small quantities. So despite a growing tonnage of high volume ferritic SG castings, eg for Perkins diesel engines and Ford tractors, there was always the need for smaller batches in pearlitic and other grades, for which separate melting or alloying would have posed serious logistic and quality control problems.

So the company invested in heat treatment furnaces to make the different specifications from one base metal. In 1959 a two-ton-capacity Birlec electric pit-type furnace was installed, and as production grew additional larger furnaces were added, including eventually a combined gas and electric continuous pusher hearth furnace and a lift-off furnace for larger castings. To reduce scaling and consequent distortion from second shotblast cleaning, nitrogen was piped into each furnace. Electricity consumption averaged 400-420 kWh/ton in the pit furnaces, less than 250kWh in the larger lift-off furnace, and an equivalent of about 150kWh (including gas and electricity) in the continuous furnace.

As each 800lb ladle of SG was separately treated, magnesium content and microstructure varied from ladle to ladle, and from mould to mould due to magnesium loss during pouring. The implications were dramatized in the early 1960s when one of a batch of castings for locking pre-stressing cables in concrete structures at a new hydroelectric plant in Wales failed under load. As these castings were made two per mould it was realized that at least one other defective piece had been delivered. By then all had been part embedded in concrete and were scheduled to be stressed on the following Monday. So management and laboratory staff spent a muddy cold weekend with emery paper, a portable microscope, and a Poldi hardness tester on a Welsh mountain side. The faulty casting was found and replaced, and forthwith a fail-safe inspection procedure was devised, based on a microscope examination of a sample from the last drop of metal from each ladle. Until this had been passed by the control metallurgist, the moulds poured from that ladle were not released for shake-out. Eventually over 300 specimens had to be polished and examined daily. Ultrasonic and other test procedures were tried and never found to be sufficiently reliable, so the company became experts in mass production metallography, but there were no further rejects for microstructure defects.

Processes

Melting

In 1863 the highest quality malleable iron was melted in coke fired crucibles (Strauss *et al* 1863, 9-10). The purchase of crucibles is mentioned in the 1890 to 1903 accounts, but not from 1904 onwards, so crucible melting may have ended at that time. But H. Field, who joined the company in 1913, refers to his experience with ‘pot’ melting (Field 1926), so perhaps it continued on a small scale. *The Ironmonger* (Strauss *et al* 1863, 10) notes that the company made its own gas ‘using the light coke obtained in the process for fine or pot castings, which reduces the cost of gas to almost nil’. Derbyshire coke was also purchased, presumably for the cupolas, although in later years cupola coke was bought from South Wales. On the other hand Tildesley suggests that the main purpose of the gas plant was to make special quality coke for the cupolas, and that gas was the by-product (Tildesley 1971, 35-6). Local Staffordshire coal was used elsewhere to make blast furnace coke (Gale 1966, 43-4), and although cupola coke needs to be larger and stronger it is not impossible that the company did at one time make its own. But it is unlikely that it would have been made in the gas plant: in the 1880s by-product oven coke was considered too small and ‘unfitted for most metallurgical requirements’ (Greenwood 1885, 43). In 1899 John Harper’s had a complete gas plant (Anon 1899, 24), which had six retorts according to an 1897 inventory (unfortunately now lost, but quoted by Field 1950, 22), but there is no mention of hearths or ovens for furnace coke.

Cupolas were probably always used for grey iron. The furnace described in the Ironmonger article (Strauss *et al* 1863, 10) had a solid bottom, and was thirteen feet high and ‘three feet wide in the clear’, lined with six inches of fire brick and four inches of a rammed ‘somewhat argillaceous sand’ from Gornal, which glazed over and required replacing only once per week (Gornal gannister was still in use over 100 years later). The resulting internal diameter would thus have been only sixteen inches. The pig iron was broken into four-

Table 6: Melting data calculated from surviving accounts for the financial years 1899-1908 and the September quarter 1923

	Year											
	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1923 grey	1923 mall
Pig iron value (£)	*5994*	*9077*	*7846*	*7039*	*6740*	*5588*	*5477*	*6931*	*8615*	*8846*	*3058*	*401*
Price (£/ton)	*3.13*	*3.30*	*2.44*	*2.60*	*2.32*	*2.32*	*2.58*	*2.85*	*2.90*	*3.15*	*5.30*	*5.80*
Hence tons pig iron	1916	2751	3214	2707	2902	2409	2124	2429	2972	2806	577	69
Steel scrap value (£)	0	0	0	0	0	0	0	0	0	0	45	0
Price (£/ton)	-	-	-	-	-	-	-	-	-	-	1.3	-
Hence tons steel scrap	0	0	0	0	0	0	0	0	0	0	35	0
Total raw material (tons)	1916	2751	3214	2707	2902	2409	2124	2429	2972	2806	612	69
Tons charged to furnace	2903	4168	4870	4102	4397	3650	3218	3680	4503	4252	929	106
Coke value (£)	*1833*	*1982*	*1504*	*1406*	*1236*	*1049*	*954*	*864*	*975*	*1189*	*294*	*58*
Price (£/ton)	*1.35*	*1.25*	*1.33*	*1.00*	*1.25*	*1.25*	*1.23*	*1.15*	*1.50*	*1.15*	*2.25*	*2.25*
Hence tons of coke	1358	1586	1131	1406	989	839	776	741	650	1034	131	26
Coke % of charge	46.8	38.1	23.2	34.2	22.5	22.9	24.1	20.1	14.4	24.3	14.1	24.5
Tons of castings	1742	2501	2922	2461	2638	2190	1931	2208	2702	2551	557	64
Tons of castings recorded	-	-	-	-	-	-	-	-	-	-	*533*	*63*

Note: Contemporary data from surviving accounts and from prices published in contemporary issues of *The Foundry Trade Journal* are shown in italics. Other figures are calculated assuming that: (i) the average material loss was 6% of the weight charged to the furnace, (ii) the yield of castings was on average 60% of the weight charged to the furnace, (iii) there were no significant changes in inventory (the 1923 material data are based on consumption, but the other data are based on purchases), (iv) the raw materials used cost on average the prices quoted for the corresponding periods in *The Foundry Trade Journal* (No. 3 Foundry pig, Barrow haematite, steel scrap and Foundry coke as appropriate). These assumptions cannot be correct in detail so the calculated results can only be indicative. In particular unrecorded changes in raw material stocks probably account for many of the anomalous year-to-year variations, eg coke consumption. The calculated coke consumption includes the coke charged with the melt, the additional coke used for the starting bed for each melt, and the loss by breakage into breeze in handling.

inch lengths, no doubt to avoid scaffolding. The coke charge and melting rate are not recorded, but such a small furnace, with coke rates of over 20% as suggested by the later 1889-1908 accounts, would probably have melted less than one ton per hour, at a temperature below 1300°C, despite the enthusiasm of the article's authors for the 'dazzling white heat' and the consequent need for beer, which seems to have been indulged despite the principles of John Harper, who was a leading temperance campaigner.

In 1863 the cupola blower was driven by a 25 horse power steam engine which also powered the rest of the plant, including a Nasmyth's steam hammer for forging bolts (Strauss *et al* 1863, 12). By 1874, when the company finances were at a low ebb, John Harper was negotiating for the purchase of another, second-hand, boiler plant. By 1897 (Field 1950) there were five steam engines, including a disused beam engine which may have been brought from the original Albion Works site in 1855 (Tildesley 1971).

By the end of the century (Anon 1899, 24) there were five cupolas. Surviving annual accounts from 1899-1908, and for the September quarter 1923 (when the grey iron included semi-steel), are used in Table 6 to estimate some melting and production data.

A 1925 photograph (Fig 4) shows a solid bottom cupola standing on a brick plinth, about four feet external diameter, with a spout about 18 inches from the floor for filling hand-held pouring ladles. The blast main comes into the windbelt from underground. This may have been the cupola used for semi-steel (Field 1920), although Field states that this was fitted with a blast volume recorder which is not visible in the picture; in any case it was probably in use when the 1923 figures quoted above were compiled.

When the 1928 foundry was built, there was prolonged debate about whether or not the new cupola should allow for separate short melts in morning and afternoon, as was the practice in the old works. Finally it was decided to have one daily melt, in a ten-ton/hour Whiting 48in internal diameter drop bottom cupola. Later a 38in diameter furnace was added. They were mechanically charged from bottom opening buckets with a four-ton capacity telpher crane. This plant was used daily until the foundry closed, although it was modified from time to time, *eg* by fitting the company's internal vertical pipe segment water cooling system (Dews 1953), modifying the windbelt, and adding improved dust arresters, initially as an ARP black-out requirement in 1939. In 1937 a separate cupola plant was built for the Meehanite foundry, to Meehanite specifications, including a balanced-blast windbelt and manual charging to give better charge distribution. This plant was later expanded to include four cupolas of different sizes, all of which were later water cooled.

In 1952 a pair of 24in cupolas was installed to provide continuous metal to a new mechanized moulding plant which had no mould storage capacity. These were also water cooled (Dews 1953). As the thin grey iron castings being made on this plant needed hot metal, and as competitive costs required that pig iron be replaced as far as possible with cheaper cast iron scrap, the cupola was fitted with a hot blast system to increase temperature and carbon pick-up and minimize silicon loss. A counte-current Schack recuperator, with a radiant combustion section and (as a later addition) a tubular second stage (Evans 1953) was supplied by Metallurgical Engineers. It was never easy to maintain the specified 500°C blast temperature: at one time the melting staff complained that the cupolas were being operated to generate hot blast rather than to melt iron.

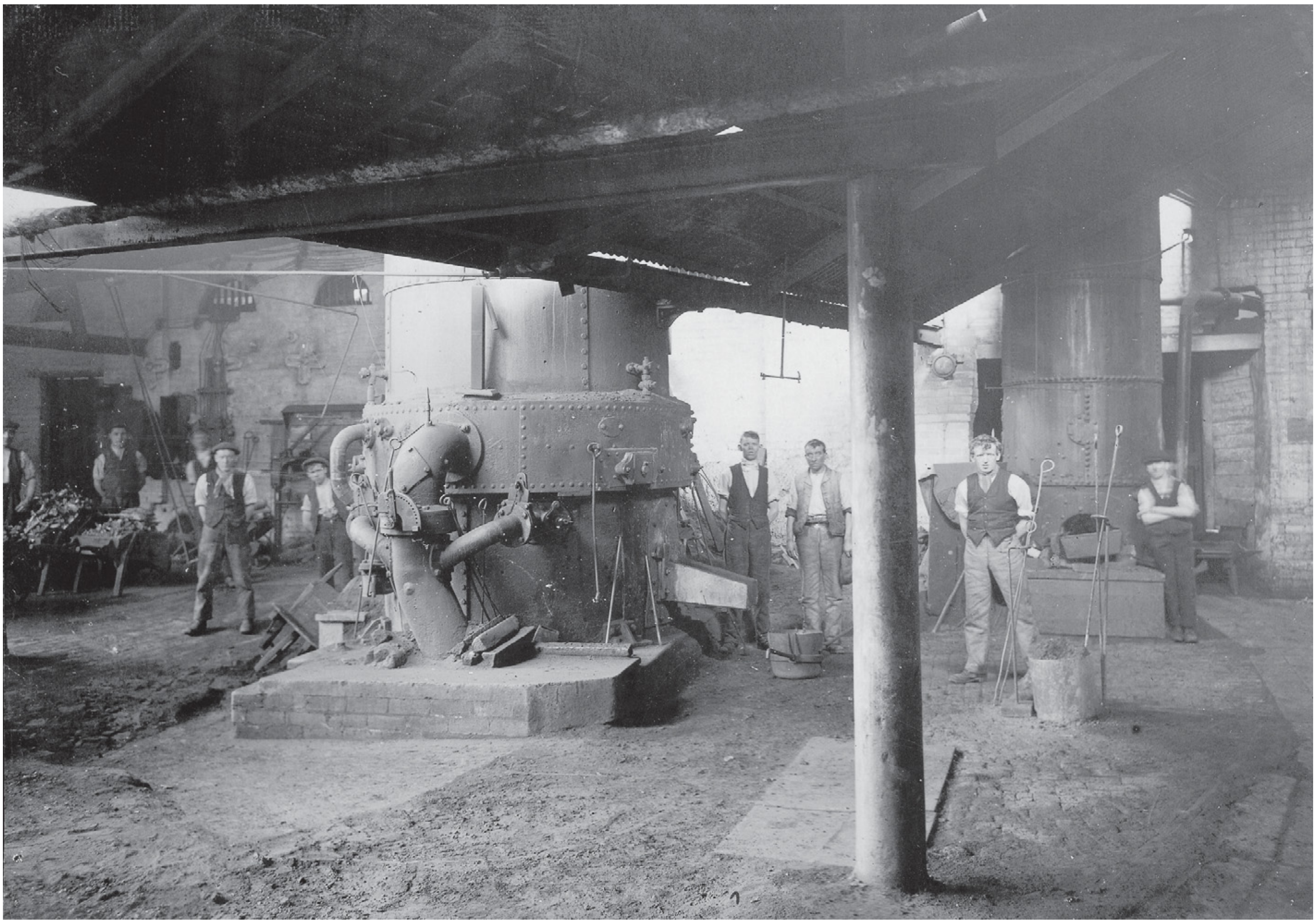

Figure 4: Cupola furnaces in 1925; note the manual regulator on the blast main coming from below, the tapping spout to the right, and wheelbarrows of return scrap to the left.

But it was eventually possible to replace 37.5% of pig iron at £20.6s.0d/ton with purchased scrap at £11.0s.0d. After allowing for a slightly higher coke charge and ferro-silicon addition there was a calculated saving of £2.6s.8d per ton of iron melted. This resulted in arguments between the metallurgists and the cost accountants, since a simultaneous increase in yield (because of hotter metal) provided fewer returns to re-melt so that more money had to be spent on raw materials per ton melted. But as less money was spent per ton of product the economics were finally agreed.

This scrap-based hot-blast grey iron practice was generally successful, but was subject to occasional problems—outbreaks of hard or chilled castings, sometimes attributed to 'trace element' contamination of the purchased scrap, for example when a high proportion was vitreous enamelled, or outbreaks of 'drawing': localized surface shrinkage defects. BCIRA studies of this problem at Willenhall contributed to the understanding of the interrelated effects of pouring temperature, composition, and degree of inoculation.

SG melting made a breakthrough in 1955 when a dolomite lining was installed in a Meehanite cupola by an Italian Meehanite engineer. This allowed a low cost steel scrap charge to be melted under a highly basic 'falling' slag, producing hot, low sulphur metal, as described by the author (Harper 1967). As SG output grew, two more cupolas were converted to basic lining. But the duplicated plant and labour, high coke consumption, expensive refractories, and occasional problems from inconsistent slag reactivity became costly, and so in 1965 a completely new SG melting plant was built, costing about £150,000 (Anon 1967, Harper 1972). Melting was in two acid-lined, externally-water-cooled, twin-wind-belt, continuously-tapped six-ton/hour cupolas (Fig 5). The metal was desulphurized and recarburized in the ladle with nitrogen agitation through a porous plug, mixing the iron with calcium carbide and graphite, a process developed by BCIRA. The slag was removed, and the metal was reheated in six-ton capacity mains-frequency coreless electric induction furnaces. This plant provided a major cost reduction, of some £11 per ton at 1972 prices, partly because consistent desulphurization and metal temperature allowed expensive nickel-magnesium to be replaced by ferrosilicon-magnesium.

SG iron production continued to increase, and eventually the six-ton induction furnaces became a bottleneck and were replaced by a 40-ton Ajax drum type channel induction holding furnace (Harper 1972), shown in Figure 6. This was the first part of a new plant which eventually comprised two of these furnaces, fed from two larger FTL cupolas with oxygen blast

Table 7: Melting cost data for the month of January, 1978

	SG iron	Grey iron and Meehanite
Total melt (tons)	1820	729
Good castings produced (tons)	811	431
Scrap castings	9.5%	7.2%
Thus total castings (tons)	896	455
Yield on melt	49%	62%
Coke used (tons & price)	245, £79/ton	146, £79/ton
Coke to melt (%)	13.5%	20%
Electric furnace (energy/ton & price)	26kWh, 10.8p/kWh	nil
Pig iron (tons, % & price)	nil	155, 21%, £118/ton
Steel scrap (tons, % & price)	977, 54%, £42/ton	187, 26%, £42/ton
Grey iron & Meehanite returns (tons, % & price)	nil	273, 37%, £74/ton
Ferrosilicon (tons, price)	5.67, £385/ton	5.92, £385/ton
Total metal charge cost (£/ton)	43.0	74.0
Coke cost (£/ton melt)	10.6	15.8
Electricity cost (£/ton melt)	2.8	nil
Labour & overheads cost (£/ton melt)	12.0	10.3
Desulphurizing & magnesium (£/ton melt)	20.4	nil
Total cost (£/ton melt)	90.0	104.0

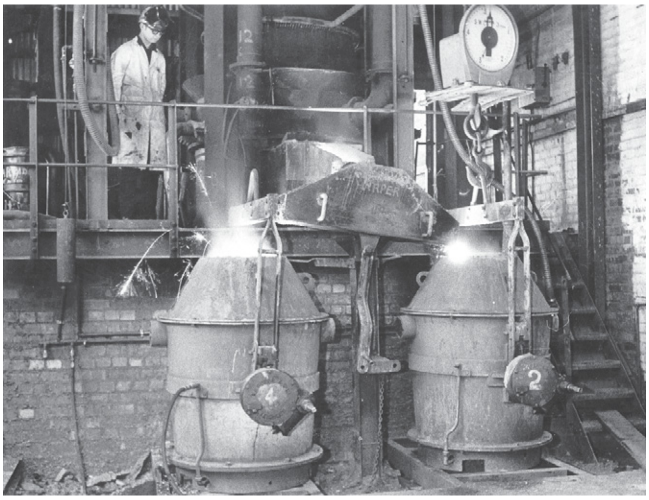

Figure 5: 1965 melting plant; continuous tapping cupola spout with tilting launder filling porous plug ladles in which the metal is treated with calcium carbide and graphite before being transferred to the electric furnace.

enrichment, on which coke consumption was held at 13.5% despite the high steel charge. It included a Canadian (Don Barnes) designed fume collection plant with multicyclone dust cleaning—environmental pressures had by then to be taken seriously. Another environmental issue was the foul smell of the used desulphurizing slag: calcium carbide was replaced with a lime-fluorspar mixture for a time, but this was never consistently effective.

The whole plant cost over £250,000 and was not completed until late 1976, after the company's independent existence had ended. Table 7 shows the operating costs of this plant and of the remaining grey iron and Meehanite cupolas in 1978.

Moulding

A smooth cast surface was important for keys, locks and hardware castings, and became so for outside sales: advertisements often featured the 'Harper Skin'. The *Ironmonger* article (Strauss *et al* 1863, 11) states that 'Red Staffordshire loam sand is used for moulds for common castings, best Mansfield sand for fine castings'. Local red sand, from the company's own quarry or purchased outside, remained the basis of the company's moulding for many years. This fine-grained natural sand has a clay content which gives a wide range of optimum moisture content, and when milled with 6-7% coal dust is ideal for thin-section castings, poured at relatively low temperature, and moulded by hand or on simple squeeze hydraulic or pneumatic jolt moulding machines. But its permeability is too low to allow it to be rammed hard enough to make rigid moulds with high pressure moulding machines, or for larger castings, without risking blowhole defects. Big moulds were stove-dried, but this was too cumbersome for volume production. Although it may not have been realized at the time, the porosity problems in the 1920s and 1930s with semi-steel and cylinder iron were undoubtedly worsened by the lack of mould rigidity.

More permeable 'synthetic' sand, based on washed silica sand bonded with added clay, gave an inferior skin finish and its narrow range of optimum moisture content proved awkward in the foundry.

The eventual solution was the CO_2 process, using a clay-free silica sand with water-glass hardened by carbon dioxide. This made a hard rigid mould, with a good skin finish, sometimes surface coated for heavier castings, and although expensive, it allowed the production of relatively large Meehanite and SG iron castings, and so was essential to the market growth of the 1960s and 70s into components for fork lift trucks, tractors and excavators.

John Harper & Co had used moulding machines from the 1880s or before, initially home-made hydraulic squeeze machines, and later larger pneumatic machines bought from British, French, German, Swiss, and American manufacturers. After 1945 the shortage of foundry labour was a principal motive for mechanizing sand and mould handling, as well as mould making, and eventually five separate mechanized plants were built, for different mould size ranges. Each of these plants was installed with the basic intention of increasing output without a simultaneous increase in labour requirements, but each had high overhead costs, and required high volume production to be economically viable, thus forcing the company into high volume competitive and thus lower-priced markets, in both grey iron and SG iron.

But the company never abandoned hand-moulded or small batch quantities of castings sold at higher prices. In the 1950s, when total output was about 250 tons/week, it included castings from more than 900 different patterns, weighing from 1 ton to a few ounces each. The product mix was no less varied in the late 1970s when output reached 330 tons/week. The variation in mould production and casting size was compounded by the complexity of the use of different types of iron—at one time two grades of grey iron, three or more grades of Meehanite, and one basic grade of SG iron. The resulting logistic difficulties were a constant management

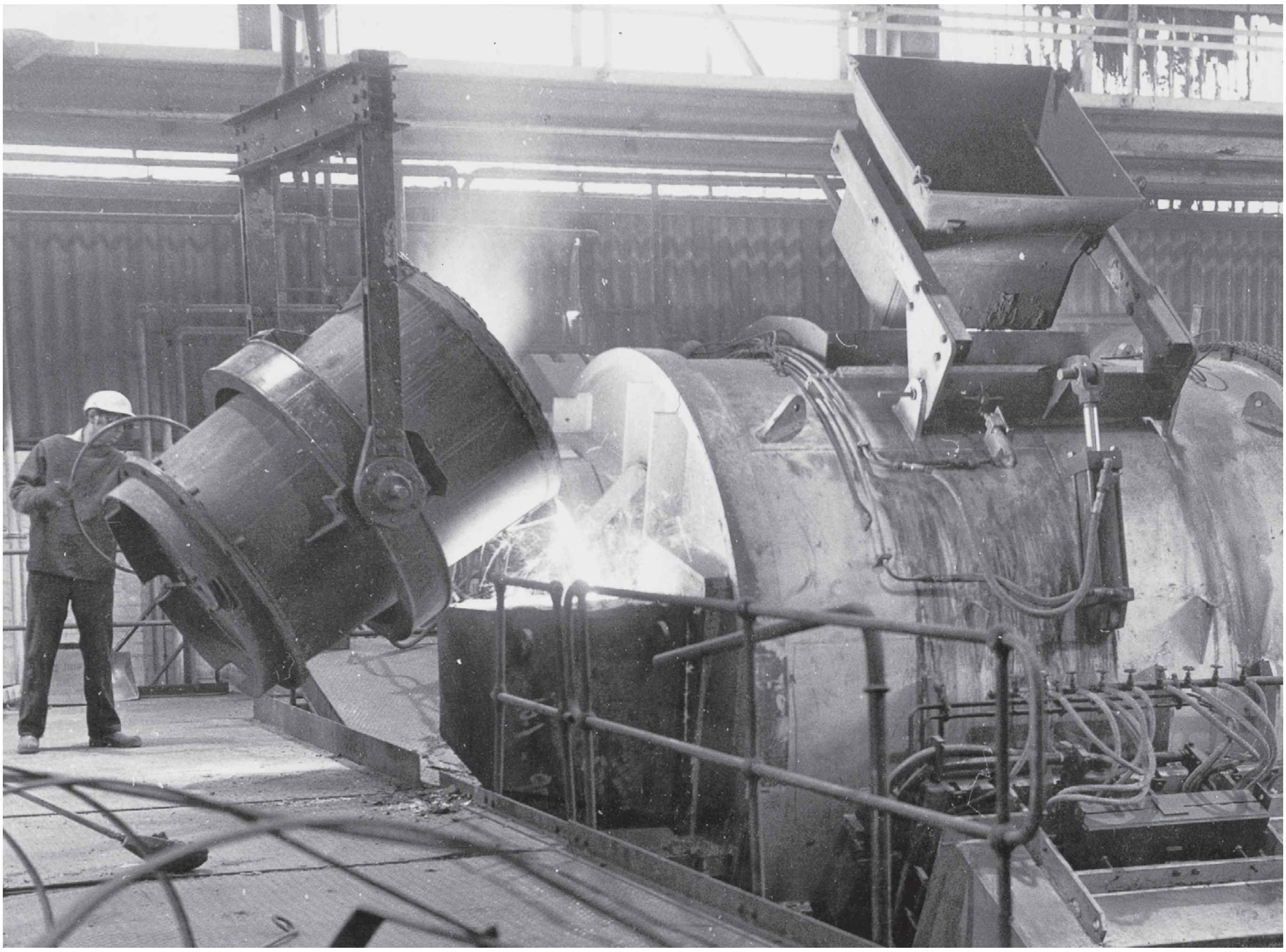

Figure 6: 1972 SG melting plant; desuphurized and recarburized iron being poured from the porous plug treatment ladle into the 40-ton capacity drum-type channel induction holding furnace.

preoccupation, and by the 1970s a rationalization programme was being developed, which would have created separate, generally self-contained production units, exploiting the flexibility of electric melting and modern resin-bonded sand moulding processes. This was never implemented after the takeover in 1974.

Conclusion

It is impossible to summarize this history in a few words. The firm did not follow consistent policies or goals throughout its 130 years, and its long term development was no more directed or logical than that of most other business, reacting to opportunities and to problems in changing circumstances, and adapting technology accordingly. It was at least no less financially successful than many of its contemporaries, and was often, if not always, justified in its claims of technical superiority. Its independent history did not end because of any major technical or market disaster, and the takeover has to be seen as part of the 1970s fashion for business mergers and acquisitions, coinciding with a depressed share price due to the recent closure of the finished goods division.

If there is a common theme it may be in how the business reacted to two internal conflicts from the early years of the twentieth century onwards. One was the conflict between the need to supply castings for the company's finished goods and simultaneously to develop profitable external casting markets. The other conflict was between a business tradition of earning high profits from small batches of difficult castings, and the need to rationalize markets and mechanize production to improve efficiency. This conflict most severely affected the development of mechanized moulding, where efficiency was reduced by the need to make many individual casting orders. Investment in bulk processes like melting or heat treatment was always easier to justify. The technical history of the foundries reflects how far the compromises reached in these conflicts were successful.

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Other material used in the preparation of this article is unpublished, from a collection of account books, internal memoranda, reports, minutes of meetings, letters, publicity material, *etc* concerning John Harper and Company and the Harper family, currently in the possession of the author.

The author

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