The Cranage brothers and eighteenth-century forge technology

Richard Hayman

ABSTRACT: The patent awarded to Thomas and George Cranage in 1766 has long been considered an important precursor of the puddling process. This article re-assesses the evidence for the Cranage process and considers whether it had any influence on subsequent technological development. Questions are raised about the development of technology in the wrought iron industry and the way in which the evidence has been interpreted by historians and archaeologists. It argues that the reputation of the Cranage brothers has been enhanced by their association with the Darby and Reynolds families of Coalbrookdale. It goes on to caution against over-reliance on patents as an index of technological development, and to question whether technology derived from an environment of empirical skills can be said to have had a single inventor.

Introduction

Thomas and George Cranage were awarded a patent in 1766 for producing wrought iron in a reverberatory furnace. The patent was one of a number awarded after 1750 for the conversion of pig iron to wrought iron using mineral fuel instead of charcoal. It preceded the successful adoption of stamping and potting in Shropshire forges, a process covered by patents awarded to Charles and John Wood in 1761 and 1763, and modified by patents awarded to the West Bromwich ironmasters Wright and Jesson in 1773 and 1784. It also preceded the puddling and rolling process of Henry Cort, patented in 1783 and 1784. The Cranage method has long been regarded as an important precursor of puddling, and even as puddling by another name. In 1863 Samuel Smiles maintained that 'there can be no doubt as to the originality and the importance of their invention', which he termed puddling, a word never used by the Cranage brothers (Smiles 1863, 88). A year later John Percy called it 'without doubt the essence of the invention of puddling' and, despite conceding that there was no sustained production using the process, offered it as 'strong evidence against Cort's claim to priority in the invention of puddling' (Percy 1864, 636). Technological historians such as Morton and Mutton argued that the Cranage process contained the basic ideas of puddling and therefore fitted it into a model of linear progress that culminated with puddling and rolling (Morton and Mutton 1967, 724–5). Reginald Mott has been almost a lone voice championing the originality of Cort (Mott 1983). Cranage has become one of the established names in the technological revolution in the eighteenth-century iron industry.

The Cranage brothers' standing rests largely upon claims made by their employers at Coalbrookdale, the Darby and Reynolds families. It has been further sustained by historians who have adopted a marked tone of deference in talking of the Coalbrookdale ironmasters and their achievements. The Cranage process has been hailed as one of a series of Coalbrookdale 'firsts', including production of the first coke pig iron in 1709, the first coke pig iron suitable for the forge in the early 1750s, the first iron rails in 1767 and the first iron bridge in 1779 (Thomas 1999, 67). Arthur Raistrick's seminal study of the local iron trade assumed rather than demonstrated that the Cranage process was employed successfully at Coalbrookdale Company forges until puddling superseded it (Raistrick 1953, 86–7). It is now

well known that the Cranage method was not as successful as Raistrick believed. Nevertheless, ever since Henry Cort's men demonstrated his technique to Coalbrookdale workmen in 1785, an occasion on which puddling was dismissed as a derivative of a well-established Shropshire technique, the name Cranage has cast a shadow over Cort's reputation. This article makes a fresh re-assessment of the Cranage process based on all known sources, and considers what influence, if any, it had upon puddling. It then considers how the reputation of the Cranage brothers has persisted and what lessons their status offers to our general understanding of technological change in the wrought-iron industry.

The Cranage brothers and their patent process

Members of the Cranage family had worked at Cleobury Mortimer forge, Shropshire (Fig 1), in the seventeenth century (Goodman 1978, 205). George (b 1701) and Thomas (1711–80) were both born in the parish, the sons of John Cranage. George is said to have worked at the Middle Forge, Coalbrookdale, from 1722, and appears to have continued working for the Coalbrookdale partners throughout his career (IGMT E1977.85). The early career of Thomas Cranage is not known, but in the early 1760s he worked at Carron Ironworks in Stirlingshire. Carron had been built in 1759 and was established using expertise from other ironworking regions. However, neither Cranage nor his wife seem to have settled well in Scotland. His wife was accused of assuming 'an authority over the rest which is disagreeable to them', while her husband, a Methodist, became 'ill of a jaundice and dropsey the consequence of hard drinking' (Campbell 1961, 31, 52). Furthermore his technical expertise was criticised as being of 'little or no service'. During Cranage's time at Carron, Dr John Roebuck had been awarded a patent for manufacturing wrought iron using coal (Patent no 780, 1762). However, Roebuck used a conventional finery hearth, not a reverberatory furnace, and so had little influence on subsequent events in Shropshire.

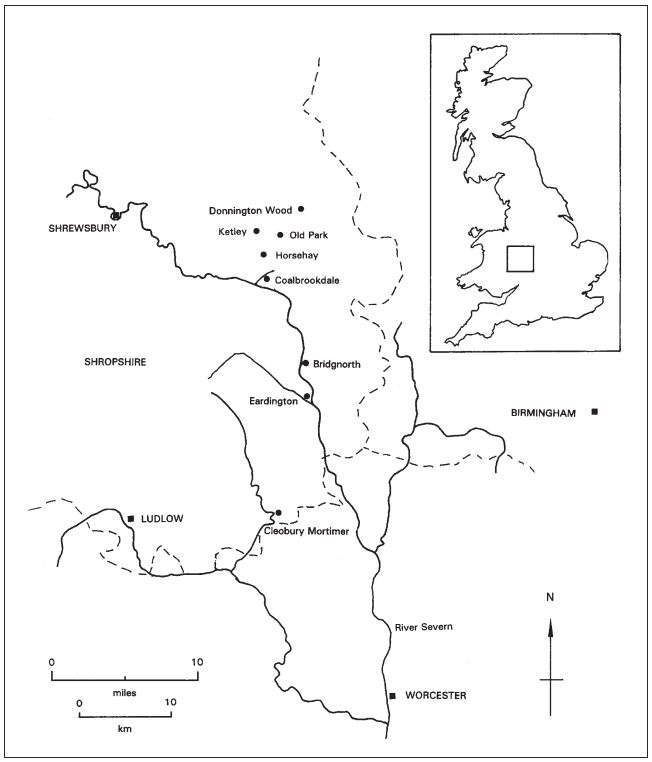

Figure 1: Shropshire forges mentioned in the text.

By 1766 Thomas Cranage was back in Shropshire, working at the Coalbrookdale Company's Bridgnorth Forge, where the Cranage process appears to have taken shape. The personal contribution made by the brothers to the patent that bears their name is, nevertheless, open to question. To use a common contemporary phrase, as two men 'bred up' in the trade, the authority and technical expertise of Thomas and George Cranage can hardly be doubted. However, aged 55 and 65 respectively when the patent was awarded, it is unlikely that either man was working as a finer on a regular basis, a strenuous job that few men continued to perform in their fifties. This raises the important issue of whether their process was really the product of experimentation and discussion among the workmen at Coalbrookdale and elsewhere, and therefore was not an invention with a single or dual inventors.

There are three important sources of evidence for the Cranage process: a letter written by Richard Reynolds, manager of the Coalbrookdale concerns, to his partner Thomas Goldney in April 1766, the patent specification of 1766 and a description of the process as witnessed by Alexander Chrisholm in 1768 (Smiles 1863, 87–8; patent 851, 1766; KUL 28405-39, ff 69–70). All of them repay close scrutiny. Reynolds stated that Thomas Cranage worked at Bridgnorth Forge, which Alexander Chrisholm stated had been established to draw out iron under the hammer ready for sale and therefore had a chafery but not a finery. In order for Cranage to develop his idea, however, there must have been a reverberatory furnace at Bridgnorth using coal. Such a furnace might have been built for re-working scrap iron, the significance of which is discussed below.

According to Richard Reynolds, a trial of the process was conducted at Coalbrookdale in 'Thomas Tilly's air furnace'. Favourable results then justified 'the erection of a small air furnace at the [Upper] Forge for the more

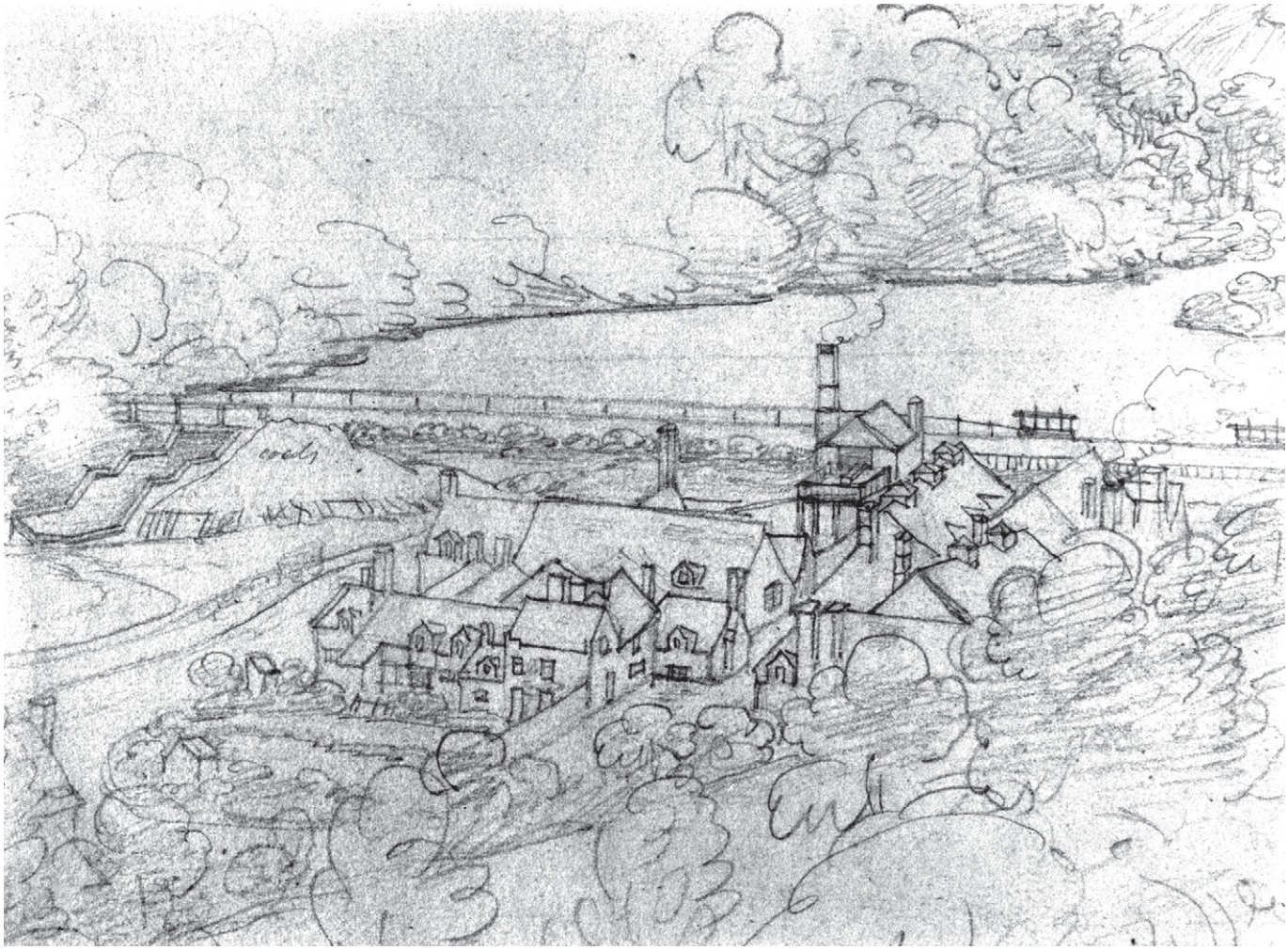

Figure 2: Detail of the Upper Forge from a pencil sketch of Coalbrookdale, drawn in 1789 by Joseph Farington. The Cranage brothers' trials were conducted in the central range of the block of forge buildings on the right of the picture. Reproduced courtesy of the Ironbridge Gorge Museum Trust.

perfectly ascertaining the merit of the invention' (Fig 2). An excited Reynolds described the second trial as 'one of the most important discoveries ever made', even though it was made using scrap rather than pig iron: 'The iron put into the furnace was old bushes [*ie* scrap], which thou knowest are always made of hard iron, and the iron drawn out is the toughest I ever saw'.

Reynolds expressed his intention of obtaining a patent which described the invention 'in a few words'. The description given in the letter was copied verbatim in the official patent specification, which shows that Reynolds rather than the Cranage brothers was in control. In any case, the official fees and stamp duties required to obtain a patent in the eighteenth century amounted to £70, excluding other gratuities payable, which was roughly equivalent to a year's wages for men of the status of the Cranages (MacLeod 1988, 76). In effect, therefore, the Cranages could not proceed without another source of capital behind them. The text of the patent disingenuously calls itself a 'full, true and perfect description of our said Invention'. It is nothing of the sort and is worth quoting in full to demonstrate the point:

> 'The pig or cast iron is put into a reverberatory or air furnace, built of a proper construction, and, without the aid of anything more than common raw pit coal, is converted into good malleable iron, and, being taken red hot from the reverberatory furnace to the forge hammer, is drawn into bars of various shapes and sizes, according to the will of the workmen.'

The vagueness of the description was not unusual for a patent awarded in the middle of the eighteenth century. The accuracy and fullness of a specification remained largely at the discretion of the patentee, and its purpose was mainly to allow law officers to discriminate between superficially similar inventions (MacLeod 1988, 48–51). That full disclosure was not essential meant that a patent could be obtained before an invention was perfected. Furthermore, the English patent system was essentially one of registration, and differed from the

French system where the authenticity of every invention was examined before a patent was awarded. The Cranage process, as it is given in the specification, is not a process at all and the award of a patent does not imply that the process was ever perfected. The specification has an obvious flaw, arising from the ironmaster's careless use of language: Iron was taken from a furnace at white heat, not red heat, an elementary error that shows that the Cranages were not party to the wording. Iron could not be placed in a furnace and taken out when ready, as if it was just heated in an oven. All techniques of refining iron required the finer to stir the iron in the hearth to ensure consistent decarburization, but the description does not indicate how this was to be achieved. The specification merely sets out the idea of refining iron in a reverberatory furnace and its deliberate vagueness can therefore be interpreted in two ways. The patent could have been taken out hastily, before sustained trials had taken place. This is exactly how it was later seen in the trade (SRO D695/1/12/36). Alternatively, a vague specification allowed the Coalbrookdale partners to argue that any similar future techniques infringed the Cranage copyright. The patenting of an idea rather than a technique was at the root of the Coalbrookdale workmen's future hostility to Henry Cort.

Subsequently money was invested in developing the process and a detailed account of it was written in 1768 by Alexander Chrisholm. There were two reverberatory furnaces at the Coalbrookdale Upper Forge, where a mixture of pig and scrap cast iron were heated three times.

> 'In the first reverberatory, they melt imperfectly, just run together irregular rugged masses; and become less fusible. The workmen say that little or no cinder separates; nor was any cinder to be seen about or near the furnace. During the time we staid [sic] there, not less than a quarter of an hour, the metal continued of a moderate glowing red heat, and was seldom if at all stirred.'

The second heat was stronger:

> 'Cinder melts out in abundance and looks bright like quicksilver. The unmelted iron is continually moved and turned, with straight and crooked ringards, that it may sweat equally. At length it is taken out in one large rugged mass, thrown on the floor, and beaten with sledge hammers, to unite it a little and flatten the protuberances.'

The third heat was similar to the earlier chafery and later balling furnaces: 'It is then put in the furnace again among the fluid cinder, after a little time taken out and carried under the great hammer, where it is beaten gently, and for a much longer time than in the charcoal forges.'

This description points up the misleading nature of the patent specification. Of greater significance is that the most authoritative assessment of the process was given to Chrisholm not by Richard Reynolds or the Cranages, but by the workmen, whose arcane vocabulary is sometimes difficult for the outsider to interpret:

> 'The workmen say that if the metal has been equally sweated [presumably meaning even exposure to the oxidising effect of air], it proves as tough as any iron can be, and fit for wire, otherwise very brittle; insomuch that in one bar there shall be 8 or 9 inches so tough that it cannot be broke, and other parts as brittle as glass – it is forged chiefly into flat bars for tyres, and for rolling into plates: they do not make wire of it – it seemed to work stiffer and harder under the great hammer than any other sorts of iron I have seen, and throws out much less cinder than that of the charcoal fineries: the Master said, that the more of the cinder was retained in it, the mellower [more ductile?] the iron – Their boiling pans are made of plates of this iron, except the bottoms which are brass.'

The quality of the iron was inconsistent and the process was wasteful. Chrisholm was told that up to one half of the iron was lost in the working. The process was given up shortly afterwards, the problem being essentially one of technique rather than technology, that of how to ensure that 'the metal has been equally sweated'. Subsequently the Coalbrookdale Company paid the Cranages £30 for the patent rights, a not inconsiderable sum to the workmen, but poor compensation for their loss of regular earnings while they concentrated upon perfecting the process. Thomas and George only stood to prosper by a share in any future profits, which did not materialise (SML MS 371/3, f 153).

News of the Cranage patent spread quickly. One of the first people to comment upon it was Charles Wood, patentee of stamping and potting, who at that time was superintending the erection of a new ironworks at Cyfarthfa in Merthyr Tydfil (Gross 2001, 72–3). In his diary Wood noted that the process sounded similar to one patented in 1724 by Roger Woodhouse which, despite early optimism, was abandoned because it was wasteful of iron. Wood presumed that the Cranage brothers had made significant improvements and was prepared to adopt their process, abandoning the expense and trouble of heating iron in pots, if it proved succ-

essful. One of the problems of using a reverberatory furnace, as opposed to a finery where the iron was placed on a bed of charcoal, was what material should be used to line the bottom of the furnace. The Cranage brothers were apparently using a sand bottom, but Wood's own experiments with the same had not been successful, and for that reason he sounded cautious. The momentum towards cheaper and quicker means of refining pig iron using mineral fuel was, however, not doubted. Wood acknowledged that this climate of development was such that one man's invention would prompt another man's improvement, to the extent that technological change would be achieved not by isolated inventions but through the combined efforts of the trade.

It is difficult to argue that the Cranage process had any long-term influence on forge techniques, partly because the available evidence is so limited. It was not successfully employed at Coalbrookdale, unlike stamping and potting. The earlier efforts of Roger Woodhouse, and the implication that Charles Wood had made similar experiments, suggest that, although the use of a reverberatory furnace was relatively new in the iron industry, there was little in the Cranage process that had not been tried before. It is likewise difficult to show that the Cranage process contributed to a cumulative and universal knowledge bank that was consulted and improved by Cort. The other context in which the Cranages might be of significance is in connection with contemporary techniques of re-working scrap iron, an important but under-rated aspect of the eighteenth-century forge.

Related techniques of re-working scrap iron

In 1812, a Parliamentary enquiry was held into the validity of Cort's patents. Samuel Homfray, of the Penydarren Ironworks in Merthyr Tydfil, told the committee that puddling was just another name for 'buzzing', a process that was previously employed at Coalbrookdale and Eardington in Shropshire (Percy 1864, 633–4). The earliest known reference to a buzzing furnace is in 1789, made by Thomas Botfield when he was preparing to build the Old Park Ironworks in the East Shropshire coalfield. Botfield thought that 'bussing' would yield 12cwt (610kg) of bar from a ton (1.02 tonnes) of pig iron (BOT 1/8). However, there is no evidence that pig iron was ever refined in this way at Old Park, where puddling began in 1794. In all other references, buzzing refers to working scrap wrought iron. The word, and presumably therefore the technique, appears to have had a wider Midland context and its later form, recorded by Keith Gale in the 1950s, was known as bustling or bushelling (Gale 1971, 34). Buzzing clearly bore some resemblance to the Cranage and puddling processes because the iron was stirred in a reverberatory furnace. Buzzing and the Cranage process came out of the same workmen's environment in the second half of the eighteenth century and therefore either could have influenced the other. That buzzing was widely practised in Shropshire is implied by the existence of reverberatory furnaces at rural forges that did not adopt stamping and potting. Bridgnorth forge, built by the Coalbrookdale Company in 1760, probably had such a furnace, or else Thomas Cranage would not have been able to work on his new process there. Evidence sugg–ests that working scrap iron in a reverberatory furnace was a significant part of the forgeman's repertoire in the second half of the eighteenth century. No one ever claimed to have invented a technique for working scrap iron in this way, presumably because there was no perceived commercial advantage in doing so.

Stamping and potting, the Cranage process and puddling were all related in some degree to the re-working of scrap iron, a subject that has been almost entirely overlooked by historians of eighteenth-century technology. However, it is arguable that different techniques of refining pig iron were all developed from techniques of re-working scrap. The use of clay pots is a good example. In 1753 Reinhold Angerstein visited Charles Wood's Low Mill forge in Cumberland where he was told that large quantities of wrought-iron scrap were imported from France, the Netherlands and Germany. The iron was cleaned in a scouring barrel, granulated and heated in clay pots (Berg 2001, 287-8). This was nearly a decade before a patent for stamping and potting was awarded. Cort's 1783 patent also specifies how scrap iron could be re-worked, which appears to have been the context in which he discovered the value of the rolling mill.

Puddling

Henry Cort was awarded patents in 1783 and 1784. It is worth looking at the specified details of his techniques, because they can be compared with what is known of the Cranage process. His first patent was partly concerned with the working up of scrap or bad iron that had already been refined. As shown above, this was already a common practice in contemporary forges. The patent covered three processes: the working up of semi-finished or scrap wrought iron in a reverberatory furnace rather than a common finery, the working up of

'scull iron' (i.e. iron spoiled by burning in the finery) in a reverberatory furnace, and the working up of cast iron in a common finery using mineral fuel. The radical element, and where he differed from Wood and the Cranage brothers, was to claim that by passing the iron through a rolling mill a superior quality of bar could be produced. According to Cort, 'mooring-chain links, ships' knees, and other iron decayed or eaten by rust, being cut into proper lengths, duly heated and passed through the rollers, will produce exceedingly good iron without any other process' (Mott 1983, 97). The rolling mill produced a consistent size and shape of bar, but also aided the removal of slag, which had hitherto been achieved by forgemen entirely under the shingling hammer.

The principal element of the second patent was the conversion of pig iron in a reverberatory furnace using coal. During the heating and stirring of the pig iron it was found efficacious to add small amounts of fragmented scull or scrap iron. Once the iron had become fused it was removed from the furnace. It could then be stamped and heated again in pots or piles, exactly as in the stamping and potting process. Cort's preferred technique, however, was to return the iron to the furnace and bring it to a white heat. Subsequently the iron was shingled into half blooms or slabs. From this point the iron could be heated in a common chafery, but the best results were obtained when the blooms were heated again in another or the same reverberatory furnace, and were then passed at a white heat through the rollers, the effect of which was that the iron 'will be discharged of the impurities and foreign matter which adheres to them when manufactured in the methods commonly practised'.

Like the Cranage method, Cort used coal and the reverberatory furnace, but whereas the Cranage patent specification offered no account of how the iron was worked in the furnace, Cort provided a detailed description. The difference in the wording of these specifications was determined by changing practice in the award of patents between 1766 and 1784. It did not signify a desire to enlighten or mystify on the part of either party. This has provided difficulties for historians of technology and has proved favourable to the long-term reputation of the Cranage brothers.

Was the Cranage process really the 'process now technically called puddling', as Hannah Mary Rathbone, Richard Reynolds' granddaughter, claimed in 1852 (Rathbone 1852, 27)? What little is known of the Cranage process does not suggest any compelling link with puddling. The account written by Alexander Chrisholm in 1768 offers the best evidence for comparing the two techniques (KUL 28405-39). After a preliminary stage, the Cranage method was similar to the specification of Cort's puddling process, except that no use was made of a rolling mill. What cannot be known is what induced the workmen at Coalbrookdale to judge that the iron was ready to be shingled. In Cort's specification a blue flame signalled that decarburisation was taking place, which was accompanied by a more vigorous stirring of the metal. The Cranage method was not used outside Coalbrookdale and was discontinued soon after 1768, well before Cort took a practical interest in forge techniques. So far as is known, he was unacquainted with the Cranage brothers and had no known connection with Shropshire, while the Cranage patent specification offered him no useful information. Their similarity is that they were derived from the same environment of accumulated manual skills.

Essential characteristics of the two processes were their reliance on manual dexterity and the close association they had with re-working scrap iron. They were techniques, not technology. Although puddling is commonly referred to as technology, and can be justified by the fact that it brought the reverberatory furnace into universal use in the forge, the definition is not wholly satisfactory. Previous experiments with reverberatory furnaces, like those of the Cranage brothers, demonstrate that furnace type was less crucial than the technique of manipulating the iron in the furnace. Emphasis on manual dexterity distinguishes innovations in the refining sector from those of the smelting sector. Blast furnace management depended primarily upon the correct application of raw materials, although like the puddling furnace it relied upon expert judgement to yield iron of suitable quality. Emphasis on manual skill also distinguishes puddling from other contemporary technology like the steam engine. Whereas an engine's motion was predictable and repeatable, the product of a puddling furnace varied according to a host of factors, not least the competence of the workman.

Puddling in Shropshire

Cort sought to persuade ironmasters to take up the process and on 15 December 1784 his men demonstrated puddling at the Coalbrookdale Company's Ketley Ironworks. An anonymous note concerning the Ketley trials recorded that just over 27 tons 12 cwt (28.1 tonnes) of pig made 20 tons (20.4 tonnes) of half blooms, which compared favourably with the Cranage process where 40 cwt (2.03 tonnes) of pig made only 20 cwt (1.02 tonnes) of blooms (SRO D695/1/12/36). The

Ketley workmen were, however, unimpressed. Cort required written confirmation that his men had divulged his technique, which was signed by Thomas Jones and Thomas Cranage, 'hammermen to Messrs Reynolds & Co at Coalbrookdale' (SML MS 371/3, f 205). Thomas Cranage (b 1751) was the son of the patentee George Cranage, while in 1780 Thomas Jones had been one of the executors of the will of the patentee Thomas Cranage (IGMT E1977.85). The Cranage brothers and Cort's men had both been working iron in a reverberatory furnace. For Cort's men to achieve a superior bar iron from Ketley pig iron could only mean that Cort had developed a superior technique. As forgemen with an obvious loyalty to the Cranage brothers, Cranage and Jones are unlikely to have conceded the point. In fact the evidence of his trials at Ketley and elsewhere suggests that Cort was unable to persuade workmen bred up in the iron trade that he, a relative newcomer, could work iron with more dexterity and economy than they. In an often repeated anecdote said to have derived from Richard Reynolds' younger son Joseph, Thomas Cranage bested Henry Cort by proving that his technique was nothing new to Coalbrookdale workmen: apparently, 'Cranage put in some white iron – cold-blast mine iron – and soon brought out a ball of puddled iron' (Percy 1864, 636). Such evidence, probably apocryphal, demonstrates that the workmen's defiance influenced their judgement of the possible commercial advantage of puddling.

Cort failed to licence his process to any Shropshire ironworks. The Coalbrookdale partners had, a few months previously, invested capital in a new stamping and potting forge at Horsehay with a Boulton & Watt hammer engine, and had already introduced stamping and potting to Coalbrookdale. Further investment in stamping and potting at other forges controlled by the Darby and Reynolds families – at Coalbrookdale, Donnington Wood and Ketley – came after Cort's trials.

The Coalbrookdale Company claimed that Cort's process was derivative and taught its workmen nothing new. As noted above, Samuel Homfray told the 1812 Parliamentary enquiry that puddling had long been practised by the Coalbrookdale Company (Percy 1864, 633-4). If that was the case, there should have been a smooth transition to the new process in the 1790s, when the industry adopted puddling following its successful introduction at Cyfarthfa and Penydarren in Merthyr Tydfil. Evidence contained in the Horsehay wages book tells a different story (SA 245/145). It charts the introduction of puddling at the company's Horsehay forge from June 1797 to September 1798. Experimentation with puddling began in June 1797 when Samuel Purcell, one of the two principal finers, was sent to Ketley to learn about the preliminary refining stage, the running-out fire. Other forgemen experimented with puddling but no puddled iron was produced commercially until a mere 23 tons in December 1797, compared with 28 tons by the existing stamping-and-potting process. This was a month after the company had employed Joseph Williams to superintend the conversion to the new process. Williams had previously superintended the Old Park forge, built in 1790 and where puddling was introduced from 1794 (BOT 1/8). Samuel Purcell continued as a finer in addition to work at the running-out fire. James Skelton, the other principal finer in the stamping-and-potting forge, left the company early in 1798. Throughout the first half of 1798 other Horsehay forgemen continued to be taught the process, which can be distinguished from commercial production in the wages accounts because the men were paid a day rate rather than a piece rate. However, more than a year after experiments with puddling began none of the Horsehay forgemen can be shown to have become puddlers. Joseph Williams was paid for all the puddled iron produced, suggesting that he had been given the authority and freedom to hire or sub-contract as he pleased. The root of the difficulties appears to have been the development of new skills among the men already working there. Contrary to the claims made for Coalbrookdale Company workmen, they did not have the wherewithal to adapt to puddling without calling upon outside expertise. As a technique, puddling was new to Horsehay forgemen when it was introduced in the 1790s (Hayman 2003, 97–100).

Conclusion

The air of authority surrounding the award of a patent convinced historians for over a century that the Cranage brothers had achieved a serious technological breakthrough. Although the list of patents is the only reliable guide to technological innovations in the eighteenth century and cannot therefore be ignored, it should not be taken innocently as merely an index of inventions. Patenting was also a strategy used by businessmen for their own ends. Furthermore, their association with the Darby and Reynolds families invested the Cranage brothers with an authority in the historical development of the wrought-iron industry that they might not have enjoyed had they been associated with other Shropshire or Midland ironmasters. The Coalbrookdale partners, and to a lesser extent the East Shropshire Coalfield, enjoyed a reputation for technical supremacy in the

eighteenth century, largely due to the adoption of coke for smelting and the building of the Iron Bridge across the River Severn, both of which were associated with cast rather than wrought iron. Some of this reputation rubbed off on the Cranage brothers.

Previous studies of technological change have stressed the importance of individuals. Within the context of the history of the industrial revolution, there is a well-defined tradition of the heroic inventor (MacLeod 1998). However, a forge was essentially a collaborative culture and all the forge technology that has been discussed here was based on manual operation. That any individual can claim to have 'invented' any of the techniques seems less certain when placed under close scrutiny. The advanced ages of the Cranage brothers have already been mentioned and cast doubt as to whether they were the sole originators of their patent process. Henry Cort and his men at Fontley perfected a technique – Cort never claimed to have invented the working of iron in a reverberatory furnace. Much of the technological change in the wrought-iron industry was achieved by forgemen whose names have not been recorded. The long-term reputation of the Cranage brothers was secured by Smiles and Percy in the 1860s, beginning a period in which historians have written the history of the industry as a sequence of inventions by individuals. A case study of one of those inventions has suggested that the importance of collective knowledge has been underestimated. The names who appear on the list of patents were men who could distil collective knowledge into a specific process, in the expectation that they would reap commercial rewards from it.

Acknowledgements

The subject matter of this article is drawn from a thesis submitted to the University of Birmingham. Its examiners kindly suggested that material from it was worthy of publication in a revised form. Dr Barrie Trinder expertly supervised the thesis and was kind enough to comment upon an earlier draft of this article.

Bibliography

Manuscript sources

Ironbridge Gorge Museum Trust (IGMT) E1977.85, Miscellaneous papers relating to the Cranage family.

John Rylands University Library, Manchester University, Botfield Collection (BOT) 1/8, Botfield Memorandum Book, 1788–91.

Keele University Library, Wedgwood MSS (KUL) 28405-39, W Lewis and A Chrisholm, 'Specimens & Observations in a Journey thro' some parts of England, July 21 to August 6 inclusive – 1768'.

Science Museum Library (SML) MS 371/3, J Weale, 'An historical account of the iron and steel manufactures', c1791–1804.

Shropshire Archives (SA) 245/145, Horsehay Ironworks wages book, 1796–8.

Staffordshire Record Office (SRO) D695/1/12/36, Note concerning trials of Cort's puddling process in Shropshire, 1784.

Unpublished theses

Goodman KWG 1978, Hammerman's Hill: The Land, People and Industry of the Titterstone Clee Hill Area of Shropshire from the Sixteenth to the Eighteenth Centuries, PhD thesis, University of Keele.

Hayman R 2003, The Shropshire Wrought-Iron Industry, c1600–1900; A study of technological change, PhD thesis, University of Birmingham.

Printed sources

Berg T & P (eds) 2001, *RR Angerstein's Illustrated Travel Diary, 1753–1755: Industry in England and Wales from a Swedish Perspective*. London: Science Museum.

Campbell RH 1961, *The Carron Company*. Edinburgh: Oliver & Boyd.

Gale WKV 1971, *The Iron and Steel Industry: A Dictionary of Terms*. Newton Abbot: David & Charles.

Gross J (ed) 2001, *The Diary of Charles Wood of Cyfarthfa Ironworks in Merthyr Tydfil, 1766–7*. Cardiff: Merton Priory Press.

MacLeod C 1988, *Inventing the Industrial Revolution: the English patent system, 1660–1800*. Cambridge: Cambridge University Press.

MacLeod C 1998, 'James Watt, heroic invention and the idea of the industrial revolution', in M Berg and K Bruland (eds), *Technological Revolutions in Europe*, 96–116. Cheltenham: Edward Elgar.

Morton CR and Mutton N 1967, 'The Transition to Cort's Puddling Process', *Journal of the Iron and Steel Institute* 205, 722–8.

Mott R 1983, *Henry Cort: The Great Finer*. London: The Metals Society.

Percy J 1864, *Metallurgy, Section 1: Iron and Steel*. London: John Murray.

Raistrick A 1953, *Dynasty of Ironfounders*. London: Longmans, Green & Co.

Rathbone H 1852, *Letters of Richard Reynolds with a Memoir of his Life*. London: Charles Gilpin.

Smiles S 1863, *Industrial Biography: Ironworkers and Toolmakers*. London: John Murray.

Thomas E 1999, *Coalbrookdale and the Darbys*. York: Sessions Book Trust.

The author

Richard Hayman is a consultant archaeologist who has worked on the archaeology of the iron industry over many years, notably at Ironbridge, Blaenavon and Merthyr Tydfil.

Address: Ty Wen, Falstaff Street, Shrewsbury SY1 2QN, UK.