*The Puddler - a Craftsman's Skill and the Spread of a New Technology in Belgium, France and Germany**

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"When a puddler dies, he becomes one of Satan's own furnacemen, and then he has it better than he ever did on earth."
The German Metal Workers' Association, 1912

Puddling is a refining process in which coal (instead of the previously common charcoal) was used to convert pig iron into a malleable form. The puddling process was employed by the European iron industry for over a hundred years. In Germany the first successful attempts at puddling were made in 1824.[1] And here the process enjoyed increasing popularity, reaching a peak production level by 1889, only to be supplanted by the new liquid steel processes (Bessemer, Thomas and open-hearth) more and more in the course of the 1890s. By 1913 it had ceased to be of any real importance.[2] Courtheoux sees the puddler's relatively short-lived heyday within the context of a transitional

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[1] L. Beck, "Die Einführung des englischen Flammofenfrischens in Deutschland durch Heinrich Wilhelm Remy & Co. auf dem Rasselstein bei Neuwied", in: C. Matschoß (ed.), *Beiträge zur Geschichte der Technik und Industrie*, Vol. 3 (1911), passim; R. Fremdling, *Technologischer Wandel und internationaler Handel im 18. und 19. Jahrhundert- Die Eisenindustrien in Großbritannien, Belgien, Frankreich und Deutschland* (Berlin: 1986), pp. 176-214.

[2] K. von Borries, *Das Puddelverfahren in Rheinland und Westfalen volkswirtschaftlich betrachtet* (Düsseldorf: 1929), pp. 26, 38, 55 ff; A. Paulinyi, *Das Puddeln - Ein Kapitel aus der Geschichte des Eisens in der Industriellen Revolution* (München: 1987), p. 154.

economy which was already beginning to industrialize but was still far from reaching maturity.[3] This sense of the "transitory" is reflected in the characteristics of puddling plants: Their dimensions could become quite impressive, when combined puddling and rolling mills grew to be major industrial complexes in which iron was mass-produced and given its final form by using machines. Puddling and rolling mills were admired as wonderous innovations because they were early examples of industrial mass-production.[4] The *industrial* character of these plants must, however, be attributed to the rolling mills.[5]

1. Puddling as a Craft

By entering into a union with rolling mills puddling allowed a "semi-industrial unit" [6] to develop, accompanying the industrial process of rolling as a short-lived transitional method during its decisive early phase, having made it possible in the first place. The puddling process was only able to keep step with the rapid expansion of rolling mills by virtue of increasing the number of furnaces and puddlers.[7] Thus puddling adapted to rolling mills as the ever more dominant branch of the industry by an extensive growth. After puddling had been supplanted by liquid steel processes, many former puddling and rolling mills continued to operate in the latter capacity.[8] Puddling in itself has no traits of

[3] J.-P. Courtheoux, "Privilèges et misères d'un métier sidérurgique au XIX^{e} siècle: Le puddleur", *Revue d'histoire économique et sociale*, 37 (1959), p. 181.

[4] v. Borries, p. 28.

[5] G. Plumpe, "Technischer Fortschritt, Innovationen und Wachstum in der deutschen Eisen und Stahlindustrie in der zweiten Hälfte des 19. Jahrhunderts", in: W.H. Schröder and R. Spree (eds.), *Historische Konjunkturforschung* (Stuttgart: 1981), p. 161.

[6] Plumpe, p. 162.

[7] In 1841 the Gutehoffnungshütte (forge) had ten puddling furnaces, in 1846 forty-six, in 1864 sixty, and in 1870 ninety-four (v. Borries, p. 43); G. Hardach, "Les problèmes de main-d'oeuvre à Decazeville", *Revue d'histoire de la sidérurgie*, 8 (1967), p. 55.

[8] v. Borries, p. 47.

industrial mass-production and can, therefore, be carried on independently. Hence for a long time in many regions of Belgium, France and Germany many economically successful small, old-fashioned forges started to puddle their customary charcoal pig iron and still hammered the refined iron into rods and bars. Those forges kept abreast of progress simply by building new puddling furnaces, while they remained firmly rooted in a craft tradition in all other respects.[9]

Because it played a role both in traditionally — operated forges and in industrially — operated rolling mills, puddling was very much a transitional process located somewhere between handicraft and industry, and could be integrated into either of these areas. Buth the puddler's task was influenced neither by the size of the mill, nor its degree of industrialization. Since the skill with which he performed the numerous manual tasks was of such decisive importance for the outcome, many authors have emphasized the "craft aspect" [10] of puddling. One can hardly speak of a technological understanding of the process, based on a sufficiently thorough knowledge of natural scientific processes.[11] On the contrary, puddling was seen as a highly mysterious art.[12] Even sober contemporaries emphasize time and again the uncertain theoretical relationships, the necessity of

[9] G.M. Roentgen, "Berigt van den toestand der ijzerwerken in de Waalsche provinciën, van de verbeteringen, waarvoor dezelve vatbaar zijn en de middelen, die aan te wenden zouden zijn om die verbeteringen op de spoedigste, zekerste en min kostbaarste wijze uit te voeren", in: M.G. De Boer (ed.), "Twee Memoriën over den toestand der Britsche en Zuid-Nederlandsche ijzerindustrie door G.M. Roentgen uit de jaren 1822 en 1823", *Economisch-Historisch Jaarboek*, 9 (1923), p. 134; L.H.W. Jacobi, *Das Berg-, Hütten- und Gewerbewesen des Regierungs-Bezirks Arnsberg in statistischer Darstellung* (Iserlohn: 1857), p. 147.

[10] v. Borries, p. 61; J.R. Harris, "Skills, Coal and British Industry in the Eighteenth Century", *History*, 61 (1976), pp. 177, 180; Paulinyi, pp. 115 ff.

[11] Plumpe, p. 161, n. 4.

[12] Birch paraphrases it as "the art and mystery of puddling and rolling" (A. Birch, *The Economic History of the British Iron and Steel Industry, 1784-1879* (London: 1967), p. 257).

trial and error, and the value of practical experience in performing the puddler's tasks.[13]

As one might expect, efforts were made to keep trade secrets from being aired.[14] Dobson, an Englishman, collected new information in his homeland sometime after 1808 in order to improve a puddling furnace in Dieppedale by Rouen and to try to explain "the remaining secrets of his art". He was rewarded for his efforts by being fined and put in prison for one year.[15] Measures prohibiting the emigration of British skilled workers, in effect until 1824, were another attempt to keep their skills in the country, i.e. out of the hands of others. But infringing upon this injunction was considered a mere peccadillo on the Continent: Although it was an offence punishable by imprisonment, many respectable people, such as the director of the Cockerill ironworks, Pastor, personally recruited various British craftsmen, including puddlers.[16] Efforts to keep this new technology secret for as long as possible were not confined to British state institutions. In France some British puddlers themselves refused to fulfill their obligation to train apprentices because they did not want to divulge trade secrets.[17] Yet in the end, no barrier, whether collective or individual, could hinder the spread of the puddling process. It was carried from country to country with the puddlers simply "doing" what only they knew how to do.

[13] B. VALERIUS, *Theoretisch-praktisches Handbuch der Stabeisen-Fabrikation nebst einer Darstellung der Verbesserungen, deren sie fähig ist, hauptsächlich in Belgien*, ed. and transl. by C. Hartmann (Freiberg: 1845), pp. 176 f. The period between August 24, 1824 and August 3, 1826 was described by the Remys as a phase of "ever continuing experiments" (Beck, "Einführung", pp. 122, 124).

[14] W. FISCHER, "Innerbetrieblicher und sozialer Status der frühen Fabrikarbeiterschaft", in: F. LÜTGE (ed.), *Die wirtschaftliche Situation in Deutschland und Österreich um die Wende vom 18. zum 19. Jahrhundert* (Stuttgart: 1964) p. 220.

[15] C. BALLOT, *L'introduction du machinisme dans l'industrie française* (Lille/Paris: 1923), p. 507.

[16] State Archives Liège, S.A. Cockerill 159, Cockerill Family, 4.6.1897.

[17] For reports on such cases at the Châtillon ironworks in 1822 see G. HARDACH, *Der soziale Status des Arbeiters in der Frühindustrialisierung. Eine Untersuchung über die Arbeitnehmer in der französischen eisenschaffenden Industrie zwischen 1800 und 1870* (Berlin: 1969), p. 84.

When reading contemporary descriptions of the puddling process, one is inclined to agree with Harris in his belief that the most essential, i.e. the practical "knacks" of the trade, were most certainly communicated on a non-verbal basis.[18] The "technical terminology" is utterly imprecise.

In describing the decisive moment at which a puddler should begin balling the iron to blooms, expressions like the following are used: "Gare trat ein" [19]; "it is coming round to nature" [20]; "il prend de la consistance" [21]; "pris nature".[22] The following expressions, used to characterize various qualities of iron, are no more exact: "sound, strong, tough" [23]; "schön" [24]; or having "body".[25] Therefore people resorted to comparisons in describing the clear impression that a colour or a state made on a puddler's well-trained eye: "wie geronnen Blut" [26] (like clotted blood); "comme une terre sèche" [27] (like dry earth); "als zaagsel" [28] (like sawdust). In particular, metaphors stemming from the baking trade are common in each of the languages mentioned here. Hence, expressions like: "teigige Masse"

[18] Harris, pp. 177, 179, 182.

[19] L. Beck, *Die Geschichte des Eisens in technischer und kulturgeschichtlicher Beziehung, Vierte Abteilung: Das 19. Jahrhundert von 1801-1860* (Braunschweig: 1899), p. 583.

[20] T.E. Clarke, *A Guide to Merthyr-Tydvil, and the Traveler's Companion in Visiting the Iron Works, and the Various Interesting Localities of the Surrounding Neighbourhood; Containing a Concise History of the Rise and Progress of Merthyr-Tydvil, with Brief Notices of Glamorgan, and its Antiquities* (Merthyr-Tydvil: 1848, reprint with appendix, Merthyr-Tydvil: 1894), p. 31.

[21] L. Reybaud, *Le fer et la houille* (Paris: 1874), p. 19.

[22] Valerius, p. 167.

[23] Harris, p. 179.

[24] Beck, "Einführung", p. 101.

[25] Harris, p. 179.

[26] J.G.L. Blumhof (ed.), *Versuch einer Encyklopädie der Eisenhüttenkunde und der davon abhängenden Künste und Handwerke* (Gießen: 1819), p. 541.

[27] Reybaud, p. 19.

[28] G. M. Roentgen, "Schets van de toestand der ijzerwerken van Groot-Brittanniën in't jaar 1821, in: M.G. De Boer (ed.), "Twee Memoriën over den toestand der Britsche en Zuid-Nederlandsche ijzerindustrie door G.M. Roentgen uit de jaren 1822 en 1823", *Economisch-Historisch Jaarboek*, 9 (1923), p. 89.

(doughy mass)[29]; "gaar" or "mürbe" (tender, well-done)[30]; even "Kuchen" (cake)[31]; and "loaves of bread" (meaning blooms).[32] References are also made to a "masse laiteuse" (a milky mass)[33]; "pâte" (dough)[34]; and, in Dutch, to "dikke brei" (thick pap).[35]

Puddlers were probably only able to understand these "artificial technical terms" [36] because they were simultaneously confronted with practical illustrations. Only direct references on location facilitated the precise definition of an otherwise hopelessly vague terminology. Shade variations supplied experienced puddlers with information about the characteristics and temperature of the iron: Gray pig iron, for example, became whiter as it hardened, over-refined blooms were "röther" (redder), and blue flames emanating from them were a sign of insufficient decarburization.[37] Books were fully inadequate in conveying an understanding of this "empirical trade"[38]; puddling was a craft after all.

One might be inclined to attribute the puddlers' lack of a theoretical understanding to their dearth of education, and expect that contemporaries with an adequate academic training would have been able to comprehend the process well enough to learn and to teach puddling through a theoretical approach. Indeed, there were theoreticians who knew quite a lot about the process. They were not, however, capable of puddling, nor of

[29] Blumhof, p. 541.
[30] Valerius, pp. 174, 167.
[31] Blumhof, p. 541.
[32] Clarke, p. 32.
[33] M. VERRY, *Les laminoirs ardennais* (Paris: 1955), p. 28.
[34] Reybaud, p. 19.
[35] Roentgen, "Schets", p. 89.
[36] Blumhof, front page.
[37] Valerius, p. 179. "Based on experience, he is able to estimate the heat with his eyes", so G. D'AVENEL, *Le mécanisme de la vie moderne* (Paris: 1908), p. 136.
[38] Harris (p. 180) cites Keith Gale.
[39] Harris (ibid.) cites Keith Gale, who despite his extensive theoretical preparation was never, in his own estimation, capable of puddling on his own, nor of conveying the 'feel' of the process to others.

training others to do so.[39] Alone their manner of speaking differed too much from that of the workers they would have had to train.[40] The managers of some ironworks do not seem to have been impressed by the sciences which might have had a bearing anyhow. Instead they kept abreast of progress by recruiting modern workers from Britain. For these ironmasters attributed this country's lead exclusively to men of practice while they reproached scientific theory with restricting itself to merely noting the breakthroughs made by practice.[41]

Naturally, attempts to introduce puddling into other regions went beyond the practice of "importing" craftsmen from Britain. After studying the mainly Belgian, French and German technical literature,[42] many ironmasters and engineers made pilgrimages to the Mecca of the iron industry, Great Britain,[43] and then later to Belgium, in order to learn the newest techniques by seeing them in use. They were, undoubtedly, able to gather quite a bit of information, but they were not able to learn the really decisive "knacks" of the trade. Consequently, the most common result of these entrepreneurial expeditions abroad was the recruitment of foreign craftsmen.[44]

In 1826, Friedrich Remy made a fact-finding tour through the Rhineland to the Cockerill ironworks in Seraing. Despite his thorough preparation and incessant questioning of craftsmen (in which he wisely invested two bottles of wine), the practical benefits of his journey proved to be insufficient when he later tried to relate what he had seen to his brother. On Remy's second odyssey in industrial espionage the foreign craftsmen were methodically interviewed on the basis of a detailed questionaire

[40] Harris (p. 179) cites John Curr from about 1726.

[41] State Archives Liège, Cockerill 71, Conseil Général, 6.5.1844.

[42] Beck, *Geschichte 1801-1860*, pp. 381-389 presents the technical literature that was of importance in the period 1831-1850.

[43] R.R. Locke, *Les fonderies et forges d'Alais à l'époque des premiers chemins de fer 1829-1874* (Paris: 1978), p. 45.

[44] M. Schumacher, *Auslandsreisen deutscher Unternehmer 1750-1851 unter besonderer Berücksichtigung von Rheinland und Westfalen* (Köln: 1968), p. 232.

and a draughtsman was encouraged to keep his eyes open ("Gustav thue die Augen auf!"). By systematically sounding out the British craftsmen at Remy's ironworks at Rasselstein on the Rhine and carefully noting their answers as the Remys did, it seemed possible to save one's self the Channel crossing anyhow. Even after these Britons had long been employed in other Continental ironworks the Remys confronted them with a barrage of questions when the craftsmen occasionally visited Rasselstein.[45]

Importing machines and blueprints from Britain (something that was prohibited until 1843) also failed to effect the desired transfer of new technology without the specialized workers who went along with it.[46] Some draughtsman's plans for a hammer to shingle blooms (which John Cockerill had received from an Englishman, David Mushet, and in turn given to the Remys) illustrate the fact that even well-informed ironmasters could make little use of indirect theoretical information. It was only after two of their British puddlers had made a model of the hammer, according to the plans, out of pipe clay that the Remys were able to understand the drawing at all.[47]

Yet, training methods which (must) place the primary emphasis on practical experience, have distinct disadvantages. Without a sufficient knowledge of the theoretical background, that is without knowing the chemical and physical causes of the observed phenomena, many tasks stiffen into a "blind routine" on which new impulses have little effect thus debarring the process from any gradual change.[48] "The reason for this seems to lie mainly in the obstinacy and independence of the indigenous puddlers, who greeted innovations with hostility".[49] Symptoma-

[45] Beck, "Einführung", pp. 120, 118, 121, 117, 109.

[46] J.A.C. CHAPTAL, *De l'industrie française*, Vol. 2 (Paris: 1819), p. 430.

[47] Beck, "Einführung", p. 107.

[48] Hardach, *Status*, p. 83 ff.

[49] Scharf, "Bericht über eine im Herbst 1860 unternommene Bereisung der wichtigsten Eisenhüttenbezirke Englands und Schottlands", *Zeitschrift für das Berg-, Hüt-*

tically, it was not the traditionally trained refiners (puddling was, after all, a refining process) who adopted puddling when it was introduced.[50] But with puddling a new profession was created in which new people were employed. And the development and spread of the many variations of the process which nevertheless did come into use in different regions over the course of more than a century were inhibited if not blocked because puddlers were not willing or not able to retrain, to try innovations, or to employ improved methods.[51]

2. Sphere of Activity

Cort's puddling process dates back to 1783/84, but was continually improved as it spread first through Great Britain and from the 1820s on through Belgium, France and Germany as well. Around the middle of the nineteenth century wet puddling was considered the most modern version of the process. As at the outset, the puddler's skill remained the central factor in converting pig iron (or refinery metal) into a malleable form. Valerius [52] describes the (wet) puddling process as follows:[53]

The inside of a bricked-up puddling furnace consists of three parts: low walls separate (a) the smelting chamber from (b) the fire grate on the one side and from (c) the chimney on the other, thereby keeping the coal apart from the iron. Built only half high, these walls leave the cavern of the entire furnace open so that the hot firing gases pass over the pig iron in the smelting

ten- und Salinenwesen in dem preussischen Staate, 9 (1861), p. 291; Beck, "Einführung", p. 103.

[50] Hardach, *Status*, p. 84.

[51] "... only by hiring a whole new group of workers was it possible to introduce more rational puddling methods at some forges", Scharf, p. 291.

[52] Valerius, pp. 163 ff. - Concerning the various techniques which were introduced in the two decades before 1850 see Beck, *Geschichte 1801-1860*, pp. 559 ff.

[53] This supplanted the older sand hearth (C.J.B. KARSTEN, *Handbuch der Eisenhüttenkunde*, Vol. 4 (Berlin: 1841[3]), p. 224).

chamber, heating and smelting it, and then escape through the chimney.

The puddler's assistant begins the process by preparing the bottom of the smelting chamber. Usually lumps of slag are distributed on a cast iron plate. This layer is melted, using a very hot fire, in five to six hours, and then levelled off carefully. Slowly cooled down with water the solidified mass forms a dished-out hearth bottom, which can be used for eight to fourteen days of puddling, although it often has to be repaired with a little slag after only a few uses.[54] After some weeks the slag base has to be renewed completely.[55] When this hearth bottom is ready, kindling and coal on the fire grate beside the hearth can be ignited. After four to six hours the furnace becomes red-hot and can be charged with 230 kg of broken pig iron [56] augmented by 25% hamer-scale. The furnace is then sealed and the lumps of pig iron begin to melt after thirty to forty minutes of intense heat,[57] during which time they have to be turned repeatedly by the puddler's assistant. At this point in the process the puddler has to stir the pool or puddle of molten iron for as long as fifty minutes without interruption. The iron tools, inserted through an opening in the furnace door for this purpose, have to be exchanged often because they become red-hot.[58] The puddler has to stoke again as soon as the white-hot, molten iron becomes covered with slag, and he continues stirring the bubbling, slag-

[54] Valerius, pp. 165 f.

[55] Karsten, p. 224.

[56] Figures for charge weights vary between 180 and 300 kg. Cf. *Reichs-Enquete für die Eisenindustrie 1878*, n.p. or d., pp. 4, 132; Beck, "Einführung", p. 106; Beck, *Geschichte 1801-1860*, p. 583; HARDACH, *Status*, p. 44. - Apparently the common charge weight increased over the years. At the beginning of the twentieth century, when the puddling process was already on its way out, charges of 300 to 500 kg were common in Upper Silesia. But I am not sure whether these figures do not possibly refer to double-furnaces. Cf. F. SYRUP, *Die soziale Lage der seßhaften Arbeiterschaft eines oberschlesischen Walzwerkes* (Munich: 1915), p. 194.

[57] Of course, the times vary according to charge weight and the sort of pig iron used. Cf. the time table for gray and white pig iron and for refinery metal in Valerius, p. 171.

[58] R. DELAVIGNETTE, *Birama* (Paris: 1955), p. 37.

swollen mass vigorously, with some relief from his assistant, until it becomes thicker, being at first pappy and then doughy.[59] After another fifteen to twenty minutes it comes to nature, the iron being fully refined when the slag sinks down on the solidifying mass. In the following fifteen to twenty minutes the master puddler alone has to ball the iron into blooms: he splits the heavy clump of iron into four to six portions from the bottom up, and forms these into round loaves by pressing, lifting and turning them. (In another method of forming blooms, snowballing, the puddler starts with a core of iron on his tool onto which more and more iron is rolled). Remaining scraps of iron have to be brought to white-heat again in order to fuse them together. The blooms are then left in the warm furnace ready for shingling. By squeezing, hammering and pressing them the shingler forces any remaining impurities out of the iron.[60] Slitting, faggoting and welding (or balling) are the follow-up procedures to prepare the iron for rolling. So much for a short description of the work involved.[61]

Of course, only men who were very strong, healthy and rather young made suitable puddlers. Tremendous masses of iron had to be lifted, turned and stirred by hand using a number of heavy tools.[62] Puddlers usually worked six twelve-hour shifts (day or night) per week.[63] Since puddling furnaces were in op-

[59] The melting point rises in relation to the decreasing carbon content, which means that the iron mass becomes thicker and finally dough-like at constant temperatures. Sometimes the slag flows off through the working door.

[60] At smaller forges in Belgium (Valerius, p. 65) and in England the puddlers often did the shingling themselves by squeezing the blooms under a press (Scharf, p. 288). The first of the Remys' puddlers initially did the rolling as well (Beck, "Einführung", p. 99).

[61] Since the puddling process originated in Britain and was carried from there to the Continent by British craftsmen, a description of the proceedings in one country will be, for the most part, valid for others as well.

[62] The puddler used four iron rods and rakes (one of which weighed 18 kg), four crowbars (also weighing about 18 kg) as well as hammers (5 kg) trowels, shovels, spits, tongs and hooks (Valerius, pp. 163 f.).

[63] In Seraing (Belgium) a shift lasted from 5 o'clock until 5 o'clock during which there were some breaks (*Enquête, Conseil Supérieur de l'Agriculture, du Commerce et*

eration continuosly, two teams of workers relieved each other at one furnace. On Sundays the puddling process was usually interrupted, but that provided a good opportunity to repair the furnace.[64] During a normal shift each team, a puddler and usually two underhands, completed five to eight heats, each taking from one and a half to two and a half hours. The variation in these figures results from the differences in the types and quality of the inputs and in the weight of the charge produced. Moreover, the expense of time apparently decreased in the course of years, i.e. puddlers became a bit more productive.[65] In conducting the process the puddler had to endure extremely high temperatures [66] which could drop suddenly because the working area was not completely enclosed.[67] In addition, there was the dazzling glare of the white-hot iron, the noise, smoke, gases, and a high risk of injury [68] (as a result of burns or even

de l'Industrie, 1 Paris: 1860, p. 650); Valerius (p. 66) mentions six o'clock as the time shifts changed in Couillet (Belgium) with two hours of meal breaks per shift. A six o'clock shift change is also documented for France. The change from day to night shift took place there every fortnight on a Sunday (Delavignette, pp. 32, 34), while a weekly shift change is reported for Germany (Syrup, p. 157).

[64] Hardach, *Status*, pp. 43 f., 60. Birch cites a commission report from Britain in which the night shifts and Sunday shifts are referred to as "the two main evils of the system" in the iron industry still after 1844 (Birch, p. 252). - Valerius considers the Couillet ironworks representative of conditions in Belgium around 1842. Here the furnaces were examined when puddling was completed on Saturday and repaired by masons, in the puddler's presence, on Sundays. Sunday evenings at ten o'clock the furnaces were heated for the shift that began Monday at six. Larger repairs proved necessary at least every two weeks, and the furnaces often needed slight repairs after one or two shifts (Valerius, p. 57 f., 67, 166, 376).

[65] Figures concerning the number of operations per shift vary from three to ten. Cf. Valerius, p. 171; Beck, *Geschichte 1801-1860*, pp. 583 f.; Hardach, *Status*, pp. 44, 108; *Enquête 1860*, p. 650; Birch, p. 251; Scharf, p. 292; Syrup, p. 195. - When comparing the productivity of different puddlers (weight of output or number of operations per shift) Valerius (p. 171) as well as Beck (*Geschichte 1801-1860*, p. 584) and Hardach (*Status*, p. 46) differentiate according to the quality of the pig iron used. Belgian and French ironmasters had done that as well (*Enquête 1860*, p. 650).

[66] Clarke, p. 31.

[67] Extremely fluctuating temperatures, particularly in the winter, caused infections, chronic illnesses affecting the respiratory system, and rheumatism (Birch, p. 250; Syrup, p. 169).

[68] Syrup, pp. 169 f.; Verry, p. 28; Clarke, pp. 31 f.

explosions).[69] Besides an immense permanent physical strength the various manual operations required the puddler's greatest concentration. He had, for example, to pay unflagging attention to the colour and consistency of the molten iron [70] and had to be careful not to apply too much heat while stirring lest the glowing slag might spill out of the furnace.[71] It was impossible to withstand such demanding work for very long under these conditions. Indeed, a number of authors testify to the fact that the physical wear and tear forced master puddlers to quit once they reached their forties.[72] If they were at all capable of working, they had to seek less strenuous employment, which was of course less lucrative.[73]

Puddling was real "man's work", but a few women and children were employed as helpers.[74] Every puddler had at least one

[69] The puddlers cooled the stirring rods in water and had to take great care that these were dry when put into the furnace again in the course of rapid exchange (Courtheoux, p. 179, n. 43).

[70] Harris, p. 175.

[71] Beck, *Geschichte 1801-1860*, p. 583.

[72] Birch, p. 250. Duveau cites Denis Poulot who claimed that in 1870 a metal worker in Paris was "déformé, usé... au bout de 20 ans" (G. DUVEAU, *La vie ouvrière en France sous le second empire* (Paris: 1946), p. 274). - "Because puddling is such hard work, one never sees a puddler over the age of forty-five. Once he is that old he is only able to work after having rested for a number of days" (Valerius, p. 378). But when the puddling furnaces at the Gleiwitz rolling mill were shut down in 1906, twenty-one of the forty-two workers were over fifty years old, and one was even over sixty (Syrup, p. 197). No mention, however, is made as to how many of the older workers had done the overstraining task of a *master* puddler. - On the other hand, Reif found out that railways engaged line-keepers who had formerly worked as puddlers for 35 years, 30 of which as master puddlers (H. REIF, "Soziale Lage und Erfahrungen des alternden Fabrikarbeiters in der Schwerindustrie des westfälischen Ruhrgebiets während der Hochindustrialisierung", in: *Archiv für Sozialgeschichte*, 22 (1982), p. 34).

[73] Courtheoux, p. 180; Syrup, p. 176. The fact that the workers themselves regarded a master puddler's task as extraordinarily wearing is documented by the following: Although master puddlers everywhere usually earned twice as much money as their underhands, there are a number of cases reported in which underhands refused to accept the promotion to a master position, and in which master puddlers voluntarily went back to working as mere underhands (Hardach, *Status*, pp. 99, 85).

[74] In 1864 three thousand children were employed as puddlers' and rollers' helpers in the 100 mills and forges of South Staffordshire (Birch, p. 251); often a young boy was the puddler's only helper (Scharf, p. 292).

regular underhand who performed a number of tasks independently (for example, firing the furnace, preparing the slag base on the hearth bottom, and turning the lumps of pig iron while they were melting). Otherwise the underhand relieved the master puddler during the performance of such long and exhausting tasks as stirring.[75] Accordingly, puddlers worked in regular teams consisting of from two to three workers, but usually three.[76]

Hardach cites these figures for France,[77] whereas Valerius only mentions groups of two at furnaces in Belgium. There were, however, always a number of day-labourers in every mill to whom the puddler could turn for assistance.[78] Both for France and for Seraing groups of three seemed a matter of course to the director of the Cockerill ironworks, Pastor, still in 1860.[79] But at that time Scharf usually saw teams of only two working the furnaces in Great Britain, a puddler and a boy.[80] And the Remys' first puddling teams, which were exclusively British, worked in pairs as well.[81] This, however, was not the case with German workers: Despite enticing offers, Upper Silesian puddlers were physically incapable of puddling in groups of only two still in the 1870s. Hence, the teams there consisted of three workers.[82]

The productivity of all the workers involved in follow-up procedures was, at least in smaller mills, almost completely dependent upon the puddler. Shinglers and rollers could, after all,

[75] Valerius, pp. 166 f. "The master puddler can always be recognized because he is the more active of the two" (*ibid.*, p. 378).

[76] In Germany the third puddler was no longer classified as a puddler's helper at least since the 1870s, but rather as a common labourer and was, therefore, no longer detailed to one specific puddler or furnace (H. EHRENBERG, *Die Eisenhüttentechnik und der deutsche Hüttenarbeiter*, Stuttgart and Berlin: 1906, p. 95).

[77] Hardach, *Status*, p. 44.

[78] Valerius, pp. 167, 378.

[79] *Enquête 1860*, pp. 649 f.

[80] Scharf, p. 292.

[81] Beck, "Einführung", p. 105.

[82] *Reichs-Enquete*, pp. 347 f.

only work as much iron as the puddlers delivered. Mainly because of this pacemaker function puddling was considered the central operation in the production of wrought iron,[83] and the puddler served as the hub around which all the other tasks revolved.[84] The puddler quite literally had the entire refining process "in his hand".[85] Not only was the quality of the refined iron dependent upon his ability; the quantities of input and output were also directly related to his skill. Indeed, the productivity levels of individual puddlers differed noticeably, and even the productivity of one and the same puddler could vary from operation to operation [86] in the following points:

a) in the amount of coal used (If the fire was not stoked at just the right moment, the coal was not optimally utilized. If the coal was not distributed evenly on the grate, additional draughts were created and caused the furnace to cool down.);[87]

b) in the output of puddled iron in relation to the amount of pig iron used (The longer and the wider the working door, through which the puddler stirred, was kept open, the more iron was lost through oxidation. The same thing happened when the blooms, left in the furnace to keep warm, were placed too near the door. The waste of iron was also very great when the layer of coal on the grate was not thick enough and let too much draught through the gaps.);[88]

c) in the amount of time needed to perform one operation. A particularly fast-working puddler could complete one, or even two, additional heats in a twelve-hour shift.[89] (For example, a skilful puddler made sure that the chimney was not clogged with slag which would damage the chimney walls. If rem-

[83] Hardach, *Status*, p. 45. This will no longer hold good of the large ironworks in the 1860s and 1870s counting 50 to 100 puddling furnaces.

[84] Courtheoux (p. 167) cites Delavignette.

[85] v. Borries, pp. 61, 20.

[86] Hardach, *Status*, pp. 45 f.

[87] Valerius, pp. 170, 183.

[88] *Ibid.*, pp. 169, 183; Duveau, p. 149.

[89] Hardach, *Status*, pp. 108, 45 f.

nants of semi-refined iron ate into the hearth bottom these so-called "wolves" or "sows" ruined the batch of iron being refined, and made repairs of the entire furnace necessary.);[90]

d) in the quality of the puddled iron (If the temperature was not carefully regulated by opening and closing the damper, or if the molten mass was not stirred sufficiently, too many unrefined particles and slags were caught up in the rather heterogeneous puddled iron.);[91]

e) in the physical capabilities which determined whether two or three workers were necessary to build a puddling team.[92]

This description of a puddler's routine work applies to a forge with the furnaces already in operation. But when puddling was being established, the puddler's job was far more comprehensive. The minutes of puddling, which the Remy brothers kept from 30 August 1824 onwards document the British puddlers' rather generous definition of their responsibilities. At least in the early days, when the first successful puddling experiments of Germany were made at the Remys' Rasselstein ironworks at Neuwied, the puddlers there were also willing to shingle, ball and roll the blooms. First and foremost they had to make long-drawn experiments to find out the optimal dimensions of the first puddling furnace, which they thus helped to build from the ground up and which they modified and repaired afterwards. Hence, far from being common labourers, these all-round puddlers provided their employers with essential information and their advice was indispensable.[93]

3. Payment and Productivity

Ironworkers generally earned so much that even the unskilled labourers among them usually earned more, on the average,

[90] Valerius, pp. 184 f.

[91] G. Bremme, "Die Erfindung und das Prinzip des Stahlpuddelns", in: *Berg- und hüttenmännische Zeitung* No. 12, Vol. 24 (1865), p. 99.

[92] *Reichs-Enquete*, pp. 347 f.

[93] Beck, "Einführung", pp. 99 ff., 103 f., 106, 109, 114.

than other workers did.[94] The highest wages were paid in mills where the technologically most advanced processes were in use, and in these ironworks puddlers were among those at the top of the wage hierarchy,[95] surpassed only by rollers, ballers and shinglers.[96] The wage span in modern mills was relatively wide. In Alais, for example, rollers earned 12 francs per day, puddlers 6 francs and unskilled labourers only 1.25 francs in 1857.[97] Master puddlers usually earned three or four times as much as common workers in the metal industry, and twice as much as their underhands (second puddlers). According to French sources, a first puddler's average daily wage was 5.09 francs (with a minimum of 3.50 francs), and the underhand earned 2.43 francs between 1826 and 1868.[98] One finds similar ratios at various forges in several countries:

Using average wage figures reported by Reybaud and Duveau, Courtheoux calculated coefficients of 3.33 and 2.96 for the ratio between puddlers' wages and those of unskilled labourers in the years between 1846 and 1860.[99] British puddlers in South Wales earned between 3.0 and 4.4 times as much as their unskilled counterparts (presumably in the metal industry) between 1844 and 1850.[100] A coefficient of 3.2 indicates the ratio between the wages earned by puddlers and those earned by unskilled armanents workers [101] in Belgium between 1824 and 1842, and in 1860 master puddlers there earned 2.5 times as

[94] Hardach, *Status*, p. 117.

[95] v. Borries, p. 61.

[96] Hardach, *Status*, pp. 111, 105, 102. In some ironworks puddlers received the highest wages of all (*ibid.*, p. 106).

[97] *Ibid.*, p. 105 (1 franc = 0.80 shilling).

[98] *Ibid.*, pp. 98 f.

[99] Courtheoux, p. 174.

[100] Calculated on the basis of a table compiled by T. Mitchell which was published by Birch (p. 264). The wage series for puddlers and refiners which were probably transposed by Mitchell have been re-aligned here.

[101] Master puddler earned 4.80 francs, their underhands (second puddlers) earned 1.80 and armanents workers earned 1.50 francs per day (M. LÉVY-LEBOYER, *Les banques européennes et l'industrialisation internationale dans la première moitié du XIX^e siècle* (Paris: 1964) p. 333).

much as the third puddlers.[102] The Remys' first British puddlers earned a maximum wage guaranteed for one month which was 7.5 times higher than that of an unskilled labourer [103] and as late as 1881 the coefficient expressing this ratio was still 2.25 in Germany.[104] A systematic overview of the wages earned by various skilled workers in the period between 1869 and 1878 can be found in Kamp's and Kollmann's report to the German report on iron of 1878. These figures are summarized in Table 1 and particular note should be made of the relationship between the master puddlers' and the day labourers' wages.[105] At the Westphalian Union and the Upper Silesian Bismarck Forge this was usually no more than 2.0 to 2.5 and 2.5 to 3.0, respectively.[106] It seems therefore quite certain that iron workers' wages became less divergent in the course of time.[107]

Comparisons between different countries, regions or even mills are difficult because of the varying modes of payment. Further complications are caused by the fact that comparable figures referring to the same period are scarce or that the sources do not even mention the year in which the specified wages were paid. Puddlers usually did piece-work. Some ironworks paid only the master puddler by the job, because he determined the speed of all other operations, thereby drawing the workers who were paid by the hour in his wake. The puddler often func-

[102] Master puddlers earned 4.50 francs per day; underhands (second puddlers) got 2.60 francs; and third puddlers earned 1.80 francs per day (*Enquête 1860*, p. 649).

[103] Beck ("Einführung", pp. 105 f.) reports a daily wage of one shilling while a contract guaranteed the two British puddlers a maximum wage of 2.25 pounds per six-day-week, i.e. 7.5 shillings a day for one month.

[104] A puddler earned 4 of 5 marks per shift and a labourer 1.80 to 2.20 marks (v. Borries, p. 61).

[105] The sometimes quite remarkable variance between the three groups (puddlers, rollers and ballers) in different mills can be seen in Table 1. Additional wage tables are presented in Ehrenberg, pp. 148 f., 165 ff.

[106] Higher ratios can be found only for Lippstadt in 1869 and 1873. For Upper Silesia see *Reichs-Enquete*, p. 347.

[107] The French ironworks Le Creusot and Terrenoire reduced the highest wages paid to foreign puddlers as early as 1828 (*Ministère du Commerce et des Manufactures, Enquête sur les fers* (Paris: 1829), pp. 71, 144).

tioned as a subcontractor and paid his underhand a share of what he earned, usually splitting 2:1. Piece-work wages were related to the amount of iron puddled, but rates could vary according to the type of pig iron used (i.e. refinery metal, coke- or charcoal- pig iron).[108] As a rule this piece-work wage was calculated monthly with a share paid in advance every week or fortnight, but it often only served as a base wage. Puddlers could augment their weekly income by as much as half a day's wage by earning bonuses. Bonuses were usually paid when less than norm amounts of coal or pig iron were used, or, seen from another perspective, when more iron was puddled using set amounts of raw materials. By the same token, deductions could be made for a too high use of raw material, or for a too low production.[109]

In addition to base wages (at a piece-work or hourly rate) and bonuses, some mills also paid "play wages", i.e. reduced or full wage payment when the furnace was inoperative.[110] A few ironworks also provided their employees with free housing and heating,[111] partial or full wage payment when ill or after

[108] Hardach, *Status*, pp. 96 f., 99; Beck, "Einführung", p. 105. The director of the Cockerill ironworks, Pastor, likewise refers to piece-work wages for his puddlers in 1860, (*Enquête 1860*, p. 648). And in Germany piece-work wages for puddlers seem to have been common practice as well; at Harkort's forge as early as 1825 (C. Matschoß, "Friedrich Harkort, Der große deutsche Industriebegründer und Volkserzieher", in: C. Matschoß (ed.), *Beiträge zur Geschichte der Technik und Industrie*. Jahrbuch des Vereins deutscher Ingenieure, Vol. 10 (1920), p. 17). However, when puddlers found themselves in a good bargaining position they seem to have been able to negotiate a high hourly wage or an advantageous minimum wage; for example, the Remys' first British puddlers refused to accept piece-work wages for puddling water iron (Beck, "Einführung", p. 105). This strong bargaining position may explain the special treatment that British craftsmen, who were in high demand, were able to negotiate in the period in which puddling was first introduced: In Fourchambault, for example, they received ten-year contracts and guaranteed minimum weekly wages; in St. Julien puddlers were put on piece-work wages only at a later date (Hardach, *Status*, p. 95).

[109] Hardach, *Status*, p. 107 f.

[110] Beck, "Einführung", p. 106.

[111] Hardach, *Status*, pp. 118, 131; Delavignette, p. 30.

Table 1a

PRODUCTIVITY AND EARNINGS AT THE WESTPHALIAN UNION FORGE 1869, 1873 AND 1878

In Hamm	Rolled Iron						Rolled Wire					
	Productivity per shift metric tons			Earnings per shift marks			Productivity per shift metric tons			Earnings per shift marks		
	1869	1873	1878	1869	1873	1878	1869	1873	1878	1869	1873	1878
1st Puddler	1.50	1.50	1.59	4.80	5.55	4.50	1.15	1.15	1.33	4.15	4.85	4.30
2nd Puddler	1.50	1.50	1.59	3.60	4.20	3.40	1.15	1.15	1.33	3.22	3.45	3.25
1st Baller	4.40	4.50	5.00	4.40	5.40	5.00	5.00	5.50	9.00	5.25	6.60	8.10
2nd Baller	4.40	4.50	5.00	2.40	3.15	3.30	5.00	5.50	9.00	2.90	3.60	4.85
3rd Baller	4.40	4.50	5.00	2.00	2.50	1.85	5.00	5.50	9.00	2.50	3.05	2.25
Rollmaster	4.40	4.50	5.00	4.40	5.40	3.85	5.00	5.50	9.00	4.50	5.50	6.75
Rougher	4.40	4.50	5.00	2.80	3.60	2.45	5.00	5.50	9.00	3.15	3.85	4.75
Catcher	4.40	4.50	5.00	2.40	2.90	1.95	5.00	5.50	9.00	2.00	2.75	3.60
1st shingler	9.50	9.50	12.00	3.80	4.30	4.20	5.00	5.50	9.00	—	—	—
2nd shingler	—	—	12.00	1.70	2.00	1.90	—	—	—	—	—	—
Mechanic	—	—	—	2.00	2.60	2.35	—	—	—	—	—	—
Turner	—	—	—	2.00	2.60	2.35	—	—	—	—	—	—
Smith	—	—	—	2.00	2.60	2.35	—	—	—	—	—	—
Day Labourer	—	—	—	1.80	2.20	1.90	—	—	—	—	—	—
Carpenter & Cabinetmaker	—	—	—	1.90	2.60	2.30	—	—	—	—	—	—
Former	—	—	—	2.10	2.40	2.30	—	—	—	—	—	—

Table 1b
PRODUCTIVITY AND EARNINGS AT THE WESTPHALIAN UNION FORGE 1869, 1873 AND 1878

	In Nachrodt				In Lippstadt						In Werdohl					
	Productivity per shift metric tons		Earnings per shift marks		Productivity per shift metric tons			Earnings per shift marks			Productivity per shift metric tons			Earnings per shift marks		
	1873	1878	1873	1878	1869	1873	1878	1869	1873	1878	1869	1873	1878	1869	1873	1878
1st Puddler	1.20	1.30	5.52	4.20	1.40	1.50	1.50	4.90	6.00	4.35	1.00	0.8–0.9	1.2–1.3	4.00	4.10	4.50
2nd Puddler	1.20	1.30	4.08	3.46	1.40	1.50	1.50	2.24	3.15	2.85	1.00	0.8–0.9	1.2–1.3	2.20	2.60	3.36
1st Baller	3.50	6.20	6.65	5.00	7.00	7.50	11.00	5.60	6.75	6.60	6.0–7.0	7.00	9.00	8.00	9.50	9.00
2nd Baller	3.50	6.20	4.60	3.70	7.00	7.50	11.00	4.20	5.25	4.84	6.0–7.0	7.00	9.00	4.00	5.60	5.80
3rd Baller	—	—	—	—	7.00	7.50	11.00	2.80	3.75	3.30	6.0–7.0	7.00	9.00	2.50	2.80	3.10
Rollmaster	3.50	6.20	6.47	5.60	7.00	7.50	11.00	3.50	4.50	5.28	6.0–7.0	7.00	9.00	7.80	9.10	7.60
Rougher	3.50	6.20	4.70	3.60	7.00	7.50	11.00	3.85	4.88	4.40	6.0–7.0	7.00	9.00	3.00	5.00	5.40
Catcher	3.50	6.20	3.85	2.60	5.00	5.00	5.00	2.50	2.75	2.30	6.0–7.0	7.00	9.00	2.60	4.20	5.00
1st shingler	—	—	4.00	3.20	8.40	12.00	13.50	4.20	7.20	5.40	6.0–7.0	7.00	9.00	3.60	4.00	4.50
2nd shingler	—	—	2.00	1.60	8.40	12.00	13.50	2.18	3.60	2.97	6.0–7.0	7.00	9.00	1.70	1.90	2.30
Mechanic	—	—	3.75	2.80	—	—	—	2.00	3.00	2.50	—	—	—	2.0–2.5	2.4–3.5	2.80
Turner	—	—	4.80	3.10	—	—	—	2.00	3.00	2.50	—	—	—	2.0–2.5	2.2–2.6	3.00
Smith	—	—	4.30	2.50	—	—	—	1.80	2.80	2.25	—	—	—	2.50	2.7–3.0	3.00
Day Labourer	—	—	2.50	1.80	—	—	—	1.25	2.00	1.70	—	—	—	1.70	2.00	2.00

Source and Explanations:
Protokolle der Reichs-Enquete für die Eisenindustrie 1878, n.p. or d., pp. 160 f. The figures were reported by Heinrich Kamp the director of the Westphalian Union Forge. The four ironworks in Westphalia had thirty puddling furnaces in Hamm, twelve in Lippstadt, twenty-two in Nachrodt and sixteen in Werdohl. They produced 30,000 tons of rolled wire and 14,000 tons of bar iron (*ibid.*, p. 125). The workers first mentioned, from puddlers through to shinglers, were paid piece-work wages. Wages hit an overall low in 1878.

retirement,[112] and various other forms of social security.[113] Besides at least some mills paid puddlers for training at the outset of puddling; for the Remys' first British puddler demanded the "usual price of 12 Louis d'Or training fees" [114] for six to twelve months of training German workers. Puddlers and their families were generally refunded their removal expenses and they were paid a bonus for signing the contract of employment.[115]

The high wages on the Continent had attracted British puddlers even while the act prohibiting the emigration of special skilled workers was still in effect, i.e. before 1824. In 1821 British puddlers were reported to have earned 10, 11 or even 14 francs (8, 8.8 or 11.2 shillings) on the Continent. In 1833 British skilled workers in Belgium demanded 9.50 francs per day (7.6 shillings) while indigenous workers (in this case nail makers) received only 1 to 2 francs (0.8 - 1.6 shillings).[116] Still in the 1830s British puddlers were recruited from Staffordshire to Belgium where they were paid 3 instead of 2 pounds per week (60 shillings instead of 40).[117]

In all three countries, Belgium, France and Germany, the wages given above were paid with a differential between domestic and foreign (namely British) [118] puddlers from the 1820s

[112] Hardach, *Status*, pp. 131 f.

[113] Social security was provided for in different ways in each of the countries considered. But everywhere the traditional iron industry with its tight bonds to agriculture tended to be patriarchal (Hardach, *Status*, p. 131), while the nascent modern large enterprises relied on more formalized methods of assistance to which employees also contributed (*ibid.*, p. 141). Minute references to social security can only be found for (forge) workers in general, but not specifically for puddlers. Thus the various approaches to providing social security are rather a reflection of the country in question than on puddlers as a particular group of workers. Consequently, this complex won't be considered here. For information on Germany see Ehrenberg, pp. 69 ff.

[114] Beck, "Einführung", p. 104.

[115] Decazeville paid a group of five British workers a joint bonus of 25 pounds (Archives Nationales Paris (A.N.) 84 AQ II.4.7.1831).

[116] Lévy-Leboyer, pp. 333, 360.

[117] Birch, p. 262.

[118] Puddlers who were trained in Seraing received wages almost as high as the British workers in Germany already in the 1840s (T.C. Banfield, *Industry of the*

through the 1840s. Even when the Britons had trained domestic workers to the point where the latter could puddle independently and were likewise employed as master puddlers, the foreign puddlers generally earned 1.4 times as much.[119]

Direct comparisons of the wages earned by foreign and indigenous puddlers employed in the same position can be found for several French ironworks: Fourchambault paid his ten British puddlers a piece-work wage of 13 francs (10.4 shillings) per ton of puddled iron until 1828, and French puddlers only 9 francs (7.2 shillings) for the same amount. At that time the payment ratio at Le Creusot was 14:10 francs.[120] In Decazeville the British earned 7 to 10.5 francs (depending upon the sort of pig iron used) and the French 5 to 6 francs in 1838.[121] In Terrenoire at the outset of puddling, the British even earned twice as much as the French, and after 1828 one third more than their native counterparts.[122] In 1848 Banfield noted that foreign puddlers in Sterkrade (Belgian and French besides the British) earned 5 to 6 shillings per day,[123] but he did not mention any comparable figures for German puddlers.

The higher wages paid British puddlers was fully justified according to management reports: Those that worked at Fourchambault in 1828 used less fuel and pig iron [124] and — as is documented for Le Creusot — had a far higher daily output than indigenous puddlers.[125] And in Belgium, too, the Britons

Rhine (London: 1848; reprint 1969), p. 237). In the Aachen area there were not many British anyhow, but rather Belgian and French workers among the leading skilled workers (*ibid.*, p. 236).

[119] *Enquête 1829*, pp. 62, 71.

[120] *Ibid.*

[121] Hardach, *Status*, p. 99.

[122] *Enquête 1829*, p. 143.

[123] Banfield, p. 41. These earnings were as high as in England (*ibid.*). - Scharf (p. 292) reports a piece-work wage of 7 to 9 shillings per ton for Scottish forges in 1860.

[124] *Enquête 1829*, p. 62.

[125] In one twelve-hour shift the British puddler produced 800 kg of puddled iron and his French counterpart only 700 kg who, over and above this, used 1/12 more pig iron (*Enquête 1829, p. 71*).

exploited raw materials more effectively and puddled iron of a better quality in the 1830s. That is why they earned much more than indigenous puddlers did and 50% more than puddlers in England.[126] In 1860 Scharf compared ironworkers from his native Upper Silesia with their British counterparts and exuberantly praised the latter as a "gritty and intelligent race of workers". His eulogy takes on pragmatic dimension when he describes how puddlers in England performed a variety of additional tasks (for example, shingling) and that the furnaces were manned by teams of only two, with one of these often being just a boy. And these small teams produced eight to ten batches per shift, each weighing 180 to almost 220 kg. Even more: "The figures on output and coal consumption are almost unbelievable". In short, Scharf praised the British puddlers for losing only a minimum of iron through waste while using very little coal.[127]

In 1878 a vivid comparison of German and foreign puddlers (in this case workers in neighbouring Belgium) was made by the director of the Bismarck Forge in Upper Silesia, himself a former puddler having worked in Middlesbrough and Belgium: "I simply was not able to have only two people work the furnaces. I promised the two workers I intended to put on the puddling team the same money I would have paid three, and they were good men, but they just could not manage. Such an extremely big and strong Walloon from the district of Liège, or a worker of Cockerill can turn blooms weighing 2 to 3 Ctr. (100 to 150 kg) with one hand. Our workers just are not capable of that".[128] Director Kamp from Hamm made a comparison of Belgian and German workers' productivity based on concrete figures: The Belgians produced eight or nine 220 kg batches per day, while puddlers in Aachen had an output of only seven batches at 240 kg each. Moreover, the Belgians used less material (less coal and

[126] Birch, p. 262.
[127] Scharf, pp. 289, 292.
[128] *Reichs-Enquete*, pp. 347 f.

twenty kg less pig iron per ton of puddled iron), that means less waste.[129]

Even if the varying forms of payment and fringe benefits render precise comparisons difficult, the relative earnings documented for a number of ironworks where all the workers were presumably subject to similar conditions consistently show puddlers among those at the top of the wage hierarchy. In considering these high daily and weekly wages, however, one must not forget that puddlers were not always employed year round [130] and that "play wages", paid when a furnace was occasionally inoperative, were generally lower.[131] Perhaps of even greater importance was the fact that a puddler's span of employment during his lifetime was shortened by the very exhausting job he had to perform, while many others, in lower-paying jobs, were able to earn their living over a longer period of time. One should take overall lifetime earnings into account, as figures regarding momentary income give a distorted impression of the puddlers' long-term economic situation. Moreover, mere wage figures alone do not even allow an adequate analysis of the puddler's economic situation during his working years. For this his cost of living has to be taken into consideration. Hardach compiled sample budgets for the families of various workers at a French ironmill. His figures indicate a number of steps in a nutritional hierarchy between puddlers and unskilled workers. Those with higher incomes spent more, in real terms, on food, which is not surprising when one considers how many calories puddlers must have burnt up. And their food was of higher

[129] *Ibid.*, pp. 131 ff.

[130] Syrup (p. 185) considers the commonly cited figure of 300 working days per year to be exaggerated, even for the beginning of the twentieth century. In the report on iron of 1878 Director Kollmann reliably states that puddlers in Upper Silesia worked 256 shifts (i.e. 'days') per year while ordinary day-labourers worked between 275 and 280 shifts per year (*Reichs-Enquete*, p. 347).

[131] The first of the Remy's puddlers were dissatisfied when they had to accept play wages because of flooding (Beck, "Einführung", p. 106). Ehrenberg (p. 83) equates these play wages roughly with a boarding or food allowance.

quality and more expensive: Puddlers, for example, ate more meat and less bread than other workers did.[132]

The puddlers' expenditures for (alcoholic) beverages, which are clearly documented here (31% of their wage for wine) were viewed by their contemporaries with either secret awe or unconcealed disdain. Friedrich Harkort condemned the British puddlers' "boisterousness and gluttony";[133] Remy noted that two of his puddlers had "been drinking all night (nineteen bottles of wine) with both of them getting completely drunk, but (the one) still holding himself up as a true John Bull, whereas (the other) simply behaved boorishly".[134] Owen, on the other hand, seems almost reverent in his recognition of the British puddlers' ability to consume "gallons of beer" without becoming intoxicated. He also exhibits more understanding for their predisposition to drink considering the amount they sweat while puddling.[135] Delavignette concludes, laconically, that the heat of the furnace wakes more of a thirst for wine rather than for milk.[136]

4. Status

The mere fact that at least the first (British) puddlers of almost every Continental ironworks were known by name indicates how much they differed in the eyes of their contemporaries from the rest of the labouring masses.[137] This holds good both of their fellow-workers and of the ironmasters who, after

[132] Hardach, *Status*, p. 126, 142.

[133] F. Harkort, *Geschichte des Dorfs, der Burg und der Freiheit Wetter als Beitrag zur Geschichte der Grafschaft Mark* (Hagen: 1856), p. 39.

[134] Beck, "Einführung", p. 106. "John Bull" was a nickname for the English, first used for Saint-John Bolingbroke.

[135] J.A. Owen, *The History of the Dowlais Ironworks, 1759-1970* (Risca Newport Gwent: 1977), p. 73.

[136] Delavignette, p. 49.

[137] F. Redlich, *History of American Business Leaders*, Ann Arbor 1940, p. 41; cf. W.O. Henderson, *Britain and Industrial Europe 1750-1870* (Leicester: 1972), p. 154, n. 64.

all, recorded the puddlers' names which have been handed down to the present. Many contemporaries were so fascinated by this "athlète du puddlage",[138] this superman, that they described him in superlatives.[139] Some puddlers were even celebrated as international stars: One of the Remys' British puddlers admired a fellow-worker of his as "the great", being "the most famous puddler in England".[140] A newspaper report from 1883 refers to "a puddler known of in Dowlais, who 'filled the whole chapel with his presence and alone and unaided he made a greater flutter as he swaggered down the aisle than did the minister and his family' ".[141] Hence this "aristocrat of the workingmen" was admired as a sort of Hercules, but the "seigneur" was also maligned for his propensity to drink, his lack of discipline and his arrogance.[142]

Foreign puddlers (and other craftsmen) repeatedly aroused the animosity of the local population.[143] The (British) puddlers were not at all inclined to make themselves agreeable to their surroundings. "They came to Germany as masters of a craft and were fully conscious of their worth. Their pay was many times that of other workers" and they were not willing to learn the local language.[144] They rationalized their demanding higher wages on the grounds that they had special rights and special claims as foreigners: "...no Englishman could live on that!" [145] It is therefore not surprising that very few German workers' families, in whose quarters the British gentlemen were supposed

[138] Delavignette, p. 37.

[139] Reybaud, p. 19; D'Avenel, p. 136.

[140] Beck, "Einführung", p. 112.

[141] J.A. Owen, *The History of the Dowlais Ironworks, 1795-1936* (Merthyr Tydvil: 1972), p. 48.

[142] Courtheoux, pp. 167, 176.

[143] Hardach, *Status*, p. 167; Locke, p. 57; Duveau, p. 44.

[144] Matschoß, "Harkort", p. 14. On the contrary, at the Remys' mill the ironmasters had to learn the English expressions "whereby a sort of gibberish... resulted" (Beck, "Einführung", pp. 107, 101).

[145] *Ibid.*, p. 105.

to find their lodgings, wanted these fastidious and costly boarders.[146]

Hence contemporaries outside of the ironworks developed a rather ambivalent attitude toward the "gentleman puddler", whose position within the ironworks is outlined in the following. Because puddlers were paid piece-work wages as well as bonuses, exact records of inputs and outputs had to be kept. Often the puddlers maintained their own ledgers.[147] Management was, of course, not inclined to place too much faith in these. On the contrary, they had storemen strictly monitor the amount of coal and pig iron used, as well as the weight of the refined iron produced.[148] This was necessary because the widespread system of piece-work and bonus payment led puddlers, likewise widespread, to adopt larcenous techniques in order to increase their wages: If the bonus system placed negative sanctions on the use of too much pig iron or coal, they were simply stolen.[149] These tricks became obvious, at the latest, when the weight of the puddled iron equalled, or even exceeded the weight of the pig iron which had reportedly been used.[150] In

[146] Matschoß, "Harkort", p. 15. In fact, only the first generation of puddlers was British. French ironmasters tried to replace the Britons as early as the late 1820s (Hardach, *Status*, p. 73; Locke, p. 100). And not a single English name can be found any more on a list drawn up of the Harkort puddlers in 1831/32 (Westfälisches Wirtschaftsarchiv. Harkort/Kamp, Dep. Demag, F1.259. Betrieb der Puddelöfen und Hammerwerksetats 1831-1832). It is possible, however, that the Germanized forms of the English names used in colloquial speech at Harkort's ironworks (changing MacMullen into Max Müller) were written down in the books as well. On the practice of Germanizing names see C. Matschoß, *Ein Jahrhundert deutscher Maschinenbau. Von der mechanischen Werkstätte zur Deutschen Maschinenbaufabrik 1819-1919*, Berlin 1922², p. 35.

[147] Owen, 1972, p. 48.

[148] Valerius (p. 54 ff.) cites the regulations for the rolling mill at Couillet in Belgium. There they used emission receipts and material ledgers as a means of double checking.

[149] Birch, p. 191.

[150] "... by the last heat, which produced 300 pounds, they admitted in a rather non-committal manner to having thrown in more than 300 pounds" (Beck, "Einführung", p. 105).

order to counteract such practices the ironmasters had to hire day and night watchmen whose job it was to keep the puddlers from stealing.[151] There were company regulations according to which thieves were severely punished.[152] Yet for as long as this system of payment was in effect, countermeasures were never fully successful.

The end product of the puddling process could be quantitatively and qualitatively controlled. Often puddlers were simply not paid for poorly refined blooms. These could be recognized by their colour and consistency and by the colour of the flames they emitted, but convincing proof was provided either by the squeezer or the helve, under which imperfectly fused blooms broke asunder. Assuming Scharf is right in alleging that obsolete hammers and helves remained in use in England deliberately because poorly refined blooms crumbled under them immediately, this would indeed provide a clever method of directly checking the quality of a puddler's work.[153] This form of control was possible because each bloom could be put down to the puddler making every master, quite like a craftsman, individually responsible for his product. The puddler conducted a clearly defined production process from its beginning to its end, i.e. he made blooms out of pig iron working largely autonomously at his furnace.[154] During his shift the furnace became his own and as the "master of his furnace" [155] he alone held the reins. He allowed no one to interfere with his art,[156] something no one was really capable of doing in the early days anyway.

Within his direct sphere of activity the master puddler was close to being almighty. The widespread system of

[151] Hardach, *Status*, p. 162; Valerius, p. 58.

[152] Delavignette, p. 66; Valerius, pp. 66 ff.

[153] Scharf, pp. 288 f. "...the men... stood or fell by the quality of their iron once it reached the helve... or hammer" (Harris, p. 177).

[154] Courtheoux, p. 177.

[155] Owen, 1972, p. 48.

[156] Birch, p. 191.

subcontracting [157] made him a quasi-entrepreneur. He hired his underhands (or recommended the ones he wanted to management) [158] and paid them as well. Management negotiated the piece-work rates, bonuses and other details concerning the group's pay with the master puddler. This, in turn, resulted in his being assigned some of the entrepreneurial risk, responsibility, supervision and, of course, power.[159] Apparently there were master puddlers who abused this power. In France, as well as in England, there were complaints that the subcontracting system led to the enslavement of the underhands and other helpers.[160] The master puddler often paid his subordinates in a pub, and did it incorrectly there. Plans to abolish this system of payment were drawn up in Dowlais already in 1841, and in 1852 the payment of each worker individually became common practice.[161] A number of French ironworks also did away with the subcontracting system in the 1860s.[162] Whether the subordinate members of a puddling team received a percentage of the puddler's piece-work earnings, or whether they were paid an hourly wage, which was also lower than the puddler's piece wage, in any case the powerful master puddler embodied all the authority of the ironworks to his team. The "puddler was looked up to as one standing somewhat higher in the social scale than almost anybody in his own department of the Works".[163]

The power delegated to the puddler within the ironworks, as well as his consciousness of the fact that he belonged to a tech-

[157] Birch (p. 257) wrote on British ironworks in the period around 1850 that "the system of sub-contracting was almost universal".

[158] Beck, "Einführung", p. 104. The superior inspectoral staff were responsible for the final decision, though (Valerius, p. 68).

[159] Hardach, *Status*, pp. 96, 99; Valerius, p. 68. Harkort wanted to let as much work as possible by contract already in 1825 "so that supervision will cause less trouble" (Matschoß, "Harkort", p. 17).

[160] Duveau, p. 264.

[161] Owen, 1977, p. 35.

[162] Hardach, *Status*, p. 152.

[163] Own, 1972, p. 48.

nological avant-garde, led him almost inevitably to adopt an elitist conception of his personal worth which was often taken for arrogance. The fact that these elite workers "stooped" to strikes at a very early date may seem at first surprising. Did they not cloud the division which Thompson, for example, sees so clearly between skilled and common (unskilled) labourers in industrialization's youngest phase? [164] Although strike behaviour and strike motives cannot be reconstructed here for each of the countries in question, a number of individual occurrences support Hardach's following evaluation (and at the same time Thompson's hypothesis that skilled labourers distinctly distanced themselves from the unskilled): "Most of the conflicts that we documented for the iron industry demonstrate... not the solidarity of all workers but rather the exclusivism of certain privileged groups".[165] The puddlers are a classic example of this, puddlers (only) took part in nine out of forty-five strikes in the French iron industry between 1815 and 1870.[166] They usually demanded higher wages, but only for their own group of workers. Cases in which puddlers went on strike demanding that puddler wages be increased are likewise documented for South Wales from 1816 on.[167] In business records references to strikes by puddlers sometimes coincide with entries on the fact that these craftsmen were in short supply.[168] This coincidence intimates that puddlers viewed strikes as a means of promoting their specific interests, rather than as an opportunity for demonstrating their solidarity with other workers.

[164] E.P. THOMPSON, *The Making of the English Working Class* (New York: 1966), p. 244.

[165] Hardach (*Status*, p. 178) refers to the industrial conflicts in French ironworks from about 1815 to 1870.

[166] Hardach, *Status*, pp. 174, 178.

[167] M.J. DAUNTON, "The Dowlais Iron Company in the Iron Industry. 1800-1850", *Welsh History Review*, 6 (1972), pp. 37 f.

[168] Archives Nationales Paris, A.N. Decazeville 84 AQ II, 24.5.1831. On January 29, 1833 (A.N. AQ II) entries were made both on the facts that British puddlers had stopped working for six and a half hours and that it was difficult to find British workers at that time.

During the period in question puddlers, along with other workers, seem to have placed the emphasis on the first word when regarding themselves as "elite workers." This was not necessarily the case with the ironmasters. Particularly in the early days of puddling, in Great Britain, as well as on the Continent, the ironmasters were indeed compelled to make numerous concessions to their puddlers, and to treat them very carefully, because puddlers were difficult to replace. With only a few short interruptions, the ironworks carried on a more or less open struggle for puddlers. The latter profited the more when the competing mills lay in close vicinity. Then they were enticed with particularly high wages, bonuses, recruitment payments, and housing etc.[169] As soon as the puddling process was introduced in the Merthyr Tydvil area, around 1800, local ironworks began vying for each other's puddlers. The puddlers could best exploit the fact that they were in such great demand when they knew exactly what the competitors were willing to pay. Hence their desire for information on working conditions in neighbouring firms became strong enough for them to provide sufficient grounds for a strike: In 1816 the Dowlais puddlers cited their demand for precise information on measures agreed upon at Cyfarthfa as one of their strike motives.[170] A little later, in the 1830s and partly still in the 1840s, French ironmasters engaged in a similar recruitment struggle.[171]

Although the ironmasters were willing to take great pains to attract puddlers to their mills, almost courting them, they were interested solely in the *scarce workman*. At times when puddlers were not in such short supply, or when a puddler was not (any longer) able to stand at his furnace, then his privileges and prestige over common labourers began to slip away.[172] In considering the close connection between the puddler's function and his

[169] State Archives Liège, Cockerill 71, Conseil Général, 17.4.1846.
[170] Dowlais, Cyfarthfa, Penydarren, Plymouth (Daunton, pp. 33 ff., 37 f.).
[171] Hardach, "Decazeville", pp. 59 ff., 64f.
[172] Delavignette, p. 70.

social prestige, which was independent of his person,[173] one must admit that in the long run puddlers did not really occupy a prominent position: They were working men, "tough, rough; uneducated and not at all out of the top drawer".[174] The fact that the number of puddling furnaces and of puddlers in larger ironworks increased to fifty or even one hundred in the 1860s depreciated the master puddler's position drastically. Often he was even no longer referred to as a master puddler, but simply as the first puddler and the difference between his wage and that of the second puddler shrank.[175]

5. Training, Career and Mobility

Conceptions of an apprenticeship orientated towards inexperienced school leavers must lead astray when considering an age in which children were brought up in their future working environment and grew into their occupational field by way of child labour. A puddler's training was still based on this traditional method of preparing workers for the iron trades, since prospective puddlers were recruited among ironworkers. One can hardly overestimate the impact of this sort of vocational training. In 1828, a Fourchambault manager saw the still high superiority of the English puddlers to their French counterparts explained by the fact that "the English workers were brought up in ironworks (where modern puddling methods were practised) and had thus acquired their excellent abilities with the greatest of ease".[176] The environment in which prospective ironworkers were trained had been defined by centuries of tradition in the countries under consideration here, but in Great Britain alone the use of coal had long been an integral part of this sphere. So every puddler there grew up taking part in this collective experi-

[173] Courtheoux, pp. 179, 181.
[174] Harris (p. 177) quotes Keith Gale.
[175] Ehrenberg, p. 96.
[176] *Enquête 1829*, p. 65.

ence. In all four countries (Great Britain, Belgium, France and Germany) puddlers began their careers "in earnest, the hard way, by doing, not talking".[177]

Arrow forces the behaviouristic view that any learning is based on experience and happens solely "by doing" in a mathematically formulated model. He defines the process of learning within the sphere of production rather narrowly when he argues that the labourers find out the shortcomings of the equipment while working with it. Their thus acquired knowledge is converted into newly-made improved equipment which initiates a new process of learning through handling the new devices. Technical progress is hence embodied exclusively in the new capital stock. Well aware of the fact that learning within the production process equally increases the workers' skills and thus their productivity, Arrow himself suggests a broadening of his model at the end of his article, which is considered a standard study. The extended model should include the effect learning by doing exerts on human capital. Very often the term is anyhow used in the sense that labourers learn their job by doing it, and thus becomes synonymous with "on-the-job training". Although linguistic reasons might suggest this equation it neglects the principal meaning applying the term of "learning by doing" to improvements on the equipment induced by handling it.[178]

After having long been familiar with the ironworks where, often, he had begun labouring as a child, the aspiring puddler had to carry blooms for at least three months. When he was fourteen or fifteen (sometimes even younger) he began his "apprenticeship" (as third puddler) by doing odd jobs around the furnace. After he had become somewhat stronger, he was promoted to the rank of puddler's underhand (second puddler).

[177] Harris (p. 177) quotes Keith Gale. Cf. further *ibid.*, pp. 175, 179.

[178] KENNETH J. ARROW, "The Economic Implications of Learning by Doing", in: *Review of Economic Studies*, 29 (1962), p. 155-173.

If and when he was allowed to assume the largely autonomous position of a master puddler was determined neither by his going through a set period of apprenticeship nor by his passing an examination, but alone by the master puddler's and management's estimation of the aspirant's ability to puddle on his own. Often the decisive factor was not the underhand's ability, but rather the relative demand for puddlers in a given economic situation: When there was a shortage, poorly trained underhands were quickly promoted to master puddlers if, however, there were too many master puddlers an excellent underhand could be barred from advancement.[179]

One is undoubtedly justified in viewing the position of a master puddler as the highest rung on a puddler's career ladder, even if there were isolated instances in which master puddlers entered managerial positions and became the director of the ironworks.[180] The number of puddlers who managed to make the move from among the rank of workers into positions as foremen, supervisors, department heads or even production managers [181] was so small that more advanced career steps need not be pursued. On the contrary, many master puddlers were not even able to remain in this rank for long. In the early days of puddling, master puddlers at forty or forty-five were too old and infirm to be physically capable of puddling anyhow, and had to take a step down. And many puddlers never did become masters of the trade, or abandoned the capacity after only a short time.[182]

But it was possible for puddlers to advance, at least financially, by migrating to developing areas where they introduced the modern puddling method as highly paid craftsmen and instructors. At first this sort of migration took place within Great Bri-

[179] Hardach, *Status*, pp. 81 f., 85.

[180] The director of the Bismarck Forge in Upper Silesia had been a puddler in Middlesbrough and in Belgium (*Reichs-Enquete*, p. 345).

[181] Hardach, *Status*, pp. 150 f.

[182] Hardach, "Decazeville", pp. 66 f.

tain: puddlers who had been trained by Crawshay in South Wales, for example, were attracted by high wages paid in parts of Britain where the new process was as yet unknown and puddlers, therefore, scarce. Until well after the middle of the century, areas such as Wales continually gave away skilled workers who often settled down in the North and the West of the country.[183]

With the sort of practical training the skilled workers had gone through, the puddling and rolling process could only be transferred to other ironworks, regions or countries in a short time when whole groups of various craftsmen were willing to migrate. Puddlers had learned only their particular skills on the job and were hardly able to imagine that someone with a different sort of training might find doubtful or incomprehensible what they simply took for granted.[184] Since there were no instructors to impart a basic knowledge of all the relevant aspects of the new trade upon the prospective puddlers and rollers, groups of highly specialized different craftsmen set out on their travels, each passing on his particular practical skill. Many British puddlers continued to make these journeys in groups, even when more and more of them crossed the national borders after 1824.[185]

The emigration of special craftsmen from Great Britain was prohibited until 1824, but even before the repeal many puddlers had nevertheless been attracted by the high wages offered abroad. "They were usually birds of passage *(Wandervögel)* who went wherever the money was best".[186] The first teams of craftsmen who set out in order to teach the Belgians, French and Germans the puddling and rolling process were exclusively British. However, the forges on the Continent did not always hire

[183] A. Redford, *Labour Migration in England, 1800-1850* (Manchester: 1926), pp. 152, 157.
[184] Harris, p. 179.
[185] Redford, p. 154.
[186] Beck, "Einführung", p. 99.

an entire team of British craftsmen at once; they often employed merely one or two puddlers and then, some months later, possibly a roller. As a result, groups were temporarily split up, yet the international elite of craftsmen maintained close ties with each other. When establishing new puddling and rolling mills, many ironmasters relied on the craftsmen they had already hired to recruit other specialists. This method worked indeed, which can be seen in the first generation of puddlers at the Remys' ironworks (see table 2). During the period of almost a year from August 1824 to July 1825, the Remys employed at most four puddlers simultaneously. And each of these British puddlers was hired either on the recommendation of a countryman already working for the Remys, or had "tried his luck" [187] by joining a puddler on his way to the Remys' ironworks where he knew an old friend or relative to be already under contract.

The diffusion of the newest and best-fitted methods of puddling must have been accelerated powerfully by the way in which these teams were formed and formed anew. If the teams had moved from one ironworks to the next in static formation they would have been able to pass on only one and the same method everywhere they went. As it turned out, puddlers contributed what they had learned through their manifold experience in different ironworks, regions and countries to every new group they helped to form. "The ironmasters used the (puddlers') experience for their new equipment" [188] and quickly got an overview on all the various methods used in the most important European ironworks.

Because all continental ironworks endeavoured to hire the expensive foreign elite craftsmen (after a while Frenchmen and Belgians had also begun to migrate to Germany) for only the shortest possible time, most of these itinerant groups broke up around the middle of the century, and many of the puddlers

[187] *Ibid.*, p. 105.
[188] *Ibid.*, p. 99. That is exactly "learning by doing" in Arrow's understanding.

Table 2

MIGRATION OF PUDDLERS EMPLOYED BY THE REMYS IN 1824/25

Name:	1. W. Wills	2. R. Wills	3. J. Lewis	4. D. Jones	5. W. Reece	6. J. Davis	7. D. Hirens	8. Thomas
Remarks:	1 & 2 brothers			3, 4, 5 & 6 related		6 was a roller		
Previously in:								
Plymouth (GB)	X	X	X	X	X	X	—	—
Fourchambault (F)	X	—	X	X	X	—	—	—
Châtillon (F)	X	X	—	—	—	—	—	—
Orban (BELG.)	—	X	—	—	X	—	—	—
Cockerill (BELG.)	X?	—	—	—	—	X	X	—
Hoesch (GER.)	—	—	X	X	—	—	—	X
Departed for:		?					?	
France	—	—	X	—	—	—	—	—
Decazeville (F)	—	—	—	—	—	X	—	—
Orban (BELG.)	—	—	—	—	X	—	—	—
Hoesch (GER.)	X	—	—	X	—	—	—	X

Source: Beck, "Einführung", pp. 99, 104 ff., 108, 112, 114, 117f., 121.

sought employment in their native countries. Once puddling had become common practice with a sufficient number of indigenous puddlers having been trained,[189] the former instructors, the very masters of the trade, were no longer in demand and hence could not earn any more abroad than at home. Puddling began to decline towards the end of the nineteenth century and its final knell was sounded at the beginning of the twentieth century when this craft-orientated form of refining iron was supplanted by more efficient processes of industrial steel production. For about forty years both processes had been in use simultaneously, so that the puddlers had not yet decreased in number until the 1880s, while the number of liquid steel workers had increased steadily. Between 1895 and 1900 the boom even allowed puddling to enjoy a short-lived revival,[190] but in the following period ironworks definitely closed down their puddling furnaces, employed their former puddlers with different tasks,[191] and did not have any new ones trained.

[189] Hardach, "Decazeville", p. 59.
[190] Ehrenberg, pp. 97, 129.
[191] Syrup, p. 176.