Steel

Americans made many attempts at steelmaking from 1655 onward.¹ Although they experimented with all the different processes used by Europeans, for two hundred years no one succeeded in consistently producing good quality steel. Steelmakers in Sheffield, England, dominated the American market for all except the cheapest grades until the last third of the nineteenth century.²

PROBLEMS WITH AMERICAN STEEL

Legends depict colonial or early American smiths as skilled, independent craftsmen making quality products. Artifacts show us, however, that smiths often had to use low-grade steel and sometimes did their work poorly. John Light and Henry Unglik found the remains of twenty axes in their archaeological study of a blacksmith shop used between 1796 and 1812 at Fort St. Joseph, Ontario. Smiths there had folded and welded wrought iron plates to make axe bodies and had then welded-in steel bits. They had made the bits too small and placed them badly. The steel had a variable carbon content and abundant slag inclusions. In none of the blades had the smiths properly hardened the bits.³ They made poor quality tools that would not have satisfied a demanding user.

In the first years of the republic, the United States had a substantial iron industry and little manufacturing capability.⁴ After entrepreneurs like Simeon North (who later became famous as one of the first makers of firearms with interchangeable parts) equipped themselves with tilt hammers in the 1790s to manu-
facture edge tools, Americans gradually captured a large share of the world market for axes and scythes with factory-made tools. In the following decades American manufacturers such as Collins (making edge tools), Colt (small arms), and Ames (machine tools) not only satisfied the home demand but also displaced some established English makers from their dominance of world markets. They succeeded by selling to customers willing to pay for well-made tools. Firms such as Collins and Douglas stamped their names into axes deeply enough to remain visible throughout the life of the tool. They depended on the uniformly good quality of their products to build their reputations and could ill afford to sell badly made tools prominently marked with their names.

Yet the artisans making the Collins axe, the Colt revolver, and Ames machinery used steel imported from Sheffield that they shaped with Sheffield-made files. Americans had not yet been able to match their successes in manufacturing and ironmaking with corresponding accomplishments in steel metallurgy. Axe-works proprietor Samuel Collins observed, “A poor article of cotton goods will do some service and may give tolerable satisfaction, but a poor axe though showing a good polish and looking pretty well in the hands of the merchant most generally proves to be of little value in the hands of the chopper—I never knew a chopper who preferred cheap axes.” Collins soon learned that he needed to find a reliable source of steel:

The quality of our steel, that is really the most important question we have to deal with except paying our debts as they mature, and that only takes precedence because to neglect it would close up the business instanter, and to neglect the other will close it by a slow process... If we could have been supplied regularly with a uniform quality of superior steel, we could have beat the world on Edge Tools and secured a demand for all we could make at 20 per cent advance above the usual market price for other tools.

Early American attempts at steelmaking generally failed to produce the uniform, reliable product needed by the new manufacturing industries. Manufacturers frequently tried samples of American-made cast steel and found them wanting in uniformity. Colt’s armory bought imported steel in the 1860s in spite of the 30 percent duty. Colt managers thought “that in fabricating steel, and its mother, iron, young America has made more haste than good speed.” Manufacturers wanted uniform steel so that artisans could harden parts without having to readjust temperatures and quenching rates for each lot of metal they bought. Sheffield steelmakers retained the American market by offering quality products, and encouraged and rewarded customer loyalty through gifts, such as a cast steel bell presented to the Collins Company. To build sales some Sheffield makers of crucible steel sent technically knowledgeable agents to their
customers' works to help solve metallurgical problems. Thomas Pearson, agent for Naylor, Hutchinson, Vickers, and Company, visited the Collins works in Connecticut to discuss why the smiths couldn't get uniform hardness in their steel axe bits. In 1831 he supplied Collins with plans for the hardening and tempering furnaces used at Naylor's in Sheffield, along with full instructions for their use. With the aid of services such as these, Sheffield steelmakers retained their American market at the same time as Collins, Colt, Ames, and others were penetrating world markets for manufactured goods.

At the start of the Civil War, the surviving national small-arms factory, the Springfield Armory, got its files, most of its steel, and all its gun iron from England. If the Union navy had failed to keep command of the sea, the federal war effort would have been crippled. However, the new tariff of 1861, which substantially raised duties on imported steel, proved a more powerful stimulus than military self-sufficiency in getting Americans to break their dependence on Sheffield steelmakers.

STEELMAKING TECHNIQUE

To make steel an artisan first had to get the right amount of carbon in his iron. A steelmaker could start with pig iron and remove all the silicon and most of the carbon, or he could begin with wrought iron and add the desired amount of carbon. Although bloomers usually wanted to make wrought iron free of carbon, their products often contained steely patches. A bloomer could deliberately increase the ratio of fuel to ore in his hearth and keep the loup in contact with the hot charcoal to increase the amount of carbon dissolved in the metal to make so-called natural steel. Since he did not melt the loup, he could not get a homogeneous carbon distribution in it. Although Americans experimented with steelmaking in bloomeries (as well as in fineries to make "German steel"), they had little success making a useful product.

Because of the difficulty of controlling the carbon distribution in natural steel, artisans often preferred to let carbon diffuse into bars of carbon-free wrought iron. Archaeometallurgists have generally believed that wrought iron free of carbon could be carburized (steeled) in a smith's forge fire by being held at high temperature in contact with charcoal or anthracite. At best, it would have been a long process because of the slow rate at which carbon diffuses into iron. Then, the smith might well lose the thin carburized layer through oxidation in his forge fire in his subsequent attempt at hardening.

BLISTER STEEL

Several colonial entrepreneurs, such as Samuel Higley and Aaron Eliot, attempted steelmaking by the cementation process in the first half of the eighteenth century. They intended to make blister steel by diffusing carbon into wrought iron bars
These sections through a cementing furnace used to convert wrought iron to blister steel show the chests (C) in which steelmakers packed iron bars between layers with charcoal or anthracite. They sealed the chests and held them at bright red heat for about a week with a fire on the grate below. The roof over the chests retained heat while the exterior cone provided the draft necessary to keep the fire hot. (From C.J.B. Karsten, Handbuch der Eisenhüttenkunde [Berlin: G. Reimer, 1841], pl. L)
This sample of blister steel was made by artisans at the Collins Company in Connecticut in 1867. Iron oxide in the slag inclusion in the iron reacted with the carbon that diffused into the bars to form carbon monoxide gas. The pressure of the gas raised blisters on the surface of the steel.

Table 7-1 Temper Designations for Blister Steel

<table>
<thead>
<tr>
<th>Temper No.</th>
<th>Mean Carbon</th>
<th>Name</th>
<th>Fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.65%</td>
<td>spring heat</td>
<td>80% sap</td>
</tr>
<tr>
<td>2</td>
<td>0.80</td>
<td>cutlery heat</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>0.95</td>
<td>shear heat</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>1.1</td>
<td>double shear heat</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>1.3</td>
<td>steel through heat</td>
<td>0</td>
</tr>
</tbody>
</table>

in purpose-built furnaces. English steelmakers packed the iron with charcoal dust in stone chests, sealed the chests with sand and clay, and placed them over a fire in a cementation furnace (Fig. 7-1). They kept the chests at a bright red heat for about five days. As the carbon diffused into the wrought iron, some of it reacted with the iron oxide in the slag inclusions, releasing carbon monoxide gas that made blisters on the surface of the bars (Fig. 7-2). After the chests had cooled, the artisans withdrew the bars. To succeed, the steelmaker needed wrought iron with a very low phosphorus content because phosphorus inhibited diffusion of the carbon into the iron. The steelmaker had to be careful not to overheat the chests because the carbon-rich outer layers of the bars could be easily melted, making it difficult to get the bars out. He had to be sure the chests did not leak because air decarburized the bars, leaving them with a soft outer skin. (These were known as aired bars.) For want of adequate knowledge of these problems, many artisans considered cementation an obscure art and one that was difficult to execute.

Because the carbon diffused in from the surface and did not always reach the center of the bar, blister steel was inhomogeneous. Steelmakers called the center parts of the bars that were deficient in carbon the sap. An experienced steelmaker could recognize the percentage of sap and the carbon content in a bar from the appearance of its fracture. Makers of blister steel described the carbon content of their product as its temper (not to be confused with the tempering of steel, the amount that the hardness is drawn down in heat treating). American makers generally used the Sheffield temper designations (Table 7-1).

The steelmaker’s final task was to reheat the blistered bars carefully so as to avoid decarburization, and to forge them to the desired size. To make the steel more homogeneous, he might cut the bars, bundle them into a pile, and forge them again, making “shear” steel. Forging did not remove the slag inclusions in the steel, and particularly in small objects, these weakened it and made it susceptible to fracture. The quality of the final product depended on the diligence with which the maker cut, bundled, heated, and hammered the bars to homogenize them.
Although some Americans made blister steel from the mid-eighteenth century onward, their customers bought English steel when they wanted quality metal. After 1850 American crucible steelmakers built large converting furnaces on European designs. These would have been similar to those used in Sweden into the twentieth century, for which we have a good description. The chests were more than 10 feet long, 3 feet wide, and 4 feet high. Workers entered the chest through a manhole measuring about 20 by 30 inches. Once in, they had to pack the 10-foot-long, 2½-inch by ½-inch bars in layers separated by ⅛-inch-thick layers of charcoal dust wetted with salt water. In every fourth layer, they placed the bars on edge. As a steelmaker got a chest nearly full, he could not squat low enough and had to lie down as he packed in the last of the bars and charcoal.

After sealing the chests, the steelmaker fired the furnace; he controlled the temperature by observing the color of the chests and manipulating the fuel additions and draft. Variations in the temperature, as well as any nonuniformity in the phosphorus content of the iron, caused variation in the degree of carburization. Steelmakers dealt with this by withdrawing test bars they had placed with their ends protruding from the chests. They judged the progress of cementation from the appearance of the fracture of a broken bar. After firing, they had to wait at least a day and a half for the furnace to cool. Three men worked eighteen hours to empty a converting furnace. Taking out the steel was "the worst job imaginable" because of the heat, salty charcoal dust, and dim light of the lanterns within the chests. Steelmakers found washing away the grime almost impossible. 18

CRUCIBLE STEEL

To make blister steel homogeneous and free of slag inclusions, artisans had to melt it in crucibles and cast the liquid into ingot molds. Benjamin Huntsman of Sheffield had started crucible steelmaking in 1742. The English steelmasters achieved their success with reliance on the skills of the experienced artisans concentrated near Sheffield, cautious innovation, and reliable supplies of Stourbridge clay and Swedish iron. American steelmakers found it hard to duplicate these special circumstances. They faced three difficulties in transferring the crucible steel process to the United States. First, they needed a source of iron free of sulfur and phosphorus to convert to blister steel, because the purity of the finished steel depended entirely on the purity of the iron from which it was made. Swedish charcoal-smelted finery iron worked best, and English steelmakers controlled the supply through long-term contracts. Second, the Americans needed crucibles that artisans using tongs could lift without breaking while full of liquid steel and that also satisfied the chemical requirements of the process. Sheffield steelmakers used an English Stourbridge clay for their crucibles, which Americans could not easily get. Third, the Americans

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needed experienced melters. Despite the apparent simplicity of the process, crucible steelmaking was an art not easily learned. Although the artisans in a new steelworks might acquire by practice the dexterity needed to pull and teem the crucibles, the judgment skills necessary for controlling the temperature and deoxidizing (killing) the steel were hard to learn for anyone who had not grown up in the trade in Sheffield. Americans began to have success with crucible steelmaking only after 1860.

In 1848 the proprietors of the ironworks at Tahawus in the Adirondack wilderness of New York thought they made iron suitable for conversion to crucible steel. To make a new market for their iron, they hired Joseph Dixon to erect a crucible steelworks in Jersey City, near the Morris Canal terminal. Dixon, an inventor whose early interests had been in dye chemistry, printing, and photography, had established a business making graphite pencils and stove polish in Salem, Massachusetts, in 1827. In 1847 he had moved to Jersey City and begun manufacturing graphite crucibles. By 1849 he had shown that crucibles made of a mixture of graphite and ordinary clay would hold molten steel. He had also found that a furnace in which anthracite was burned with the aid of draft induced by a blower would reach the temperature necessary to melt steel. (West of the Appalachians, American steelmakers used coke or, later, natural gas and did not need the blower.)

Although he had no background in metallurgy, Dixon understood the basic principles of crucible steelmaking and was willing to try altering the process. However, Dixon probably knew little about the finer points of Sheffield technique. The Sheffield crucible (often called a pot) performed an essential chemical as well as mechanical function: a reaction between the clay in the pot and the oxide on the surface of the blistered bars formed a silica-rich slag when the steel melted. Oxygen dissolved in the liquid steel, and as solidification forced it out, bubbles formed that made the steel appear to boil in the mold. Any gas bubbles trapped in the ingots made the steel porous. To get sound ingots, steelmakers had to kill the metal before teeming it, so it would be still in the mold. Just before the puller lifted the pots for teeming, the melter killed the steel by bringing the furnace to the highest possible temperature, thereby reducing some silicon from the slag. The melter had to allow the steel to react with just enough of the silicon contained in the slag to convert the dissolved oxygen into silica (SiO₂). If he let the reaction go any further, dissolved silicon embrittled the steel.

Dixon had a novel idea for the crucible process. In Patent No. 7,260 (9 April 1850), he proposed to dispense with blister steel as the starting material. Instead, he would pack iron oxide between plates of cast iron, seal them in chests, and hold them at red heat for ten days. This would decarburize the cast iron to approximately the carbon content of steel. It is unclear how he would have controlled the degree of decarburization. When it
was time to make steel at the Adirondack works, Dixon followed Sheffield practice and built a cementing furnace instead of using his patented technique. He also built an anthracite-fired furnace that would accommodate sixteen graphite crucibles in which to melt the blister steel. His artisans probably had trouble killing the steel. Additionally, the graphite crucible would have made it difficult for them to control the carbon content of the steel, because carbon entered the metal from the crucible. Dixon could not regularly make uniform steel and found it necessary to remelt almost half of what the works made. Unable to adequately control the quality of its products, the Adirondack Iron and Steel Company in Jersey City closed in 1853.20

A decade later artisans at the Collins axeworks in Connecticut—as well as those at Hussey, Wells, and Company and several other Pittsburgh firms—had made substantial progress in control of the composition of the steel they made in graphite crucibles.21 The Collins Company managers had learned something of the crucible process through visits to England that had begun in 1842. The English steelmakers had responded with the courtesy usually shown good customers. By 1860, however, most Sheffield proprietors would not admit visitors to their works. English steelmakers were then making two technical changes in the Sheffield crucible steel process. In 1854 the Swedish government had removed export restrictions on Swedish pig iron. This meant that steelmakers could eliminate cementation of wrought iron bars to make stock for crucible melting (necessary to reduce the melting temperature of the iron to a range that could be reached in their crucible furnaces). Instead, Sheffield melters could charge their pots with the mixture of pig and wrought iron that would give them the desired temper. The pig melted easily at the operating temperature of the furnace and dissolved the wrought iron. The proprietors of the River Don Works, built in Sheffield in 1863, adopted this new technique; they had no converting furnaces.

They also adopted the dazzle, invented by R. F. Mushet in 1861, to eliminate piping in the steel ingots. Fully killed steel solidified with a deep cavity in the center of the ingot (a pipe) caused by shrinkage of the cooling metal. Piping could make up to one-quarter of the ingot useless. An artisan inserted the dazzle, a clay cone, in the top of the ingot mold near the end of the pour to provide a reservoir of liquid steel. The dazzle reduced losses from pipe to 1–2 percent of the ingot. Americans were slow to use these advances and evidently did not acquire up-to-date knowledge when they hired workers away from Sheffield steelmakers. Instead, the managers of the Collins Company chose to follow the older, established Sheffield methods for their steelmaking venture in 1864. They built a cementation furnace to provide starting material for their new crucible steelworks and bought imported Swedish iron. Through this transfer of proven technique, they were soon able to make usable steel.22

The Sheffield steelmakers had proved they could produce
This ingot, cast in 1867 at Butcher's steelworks in Philadelphia, shows bubbles formed by gas released from "live" steel. The melter at a works making cast steel had to fully kill the liquid steel in the crucible before the teemer poured it into ingot molds. As Americans like the artisans at Butcher's works learned crucible steelmaking in the 1860s, they often had trouble killing their steel and, consequently, poured bad ingots. (Specimen from the Metallurgical Museum of Yale College, New Haven; photograph by William Sacco)

high-quality tool steel on a regular basis. Their success depended on the uniform purity of the Swedish iron they used and on their hard-earned knowledge of the subtleties of melting and teeming steel. Material evidence shows that even when Americans hired steelworkers from Sheffield, they still found it difficult to transfer the technique of crucible steelmaking to the United States. A bar from the Collins converting furnace that the company presented to Yale professor George J. Brush in 1867 is "aired," decarburized by air leakage into the converting chest. Ingots in Brush's metals collection cast between 1866 and 1867 have deep pipes (Fig. 7-3), showing that their American makers had not yet learned to use the dozzle on the mold. An ingot (Fig. 7-4) and sample castings from William Butcher's Philadelphia steelworks in 1868 are full of blow holes, showing that the Philadelphia artisans had not yet succeeded in properly killing their crucible steel before pouring ingots. 23

In addition to their problems with technique, American crucible steelmakers had difficulty getting the high-purity iron they needed for starting material. 24 Sheffield firms had signed long-term contracts to buy all of the best grades of Swedish bar iron made. American importers got brands considered "second mark" or "common" in Sheffield. 25 Swedish ironmasters made the metal favored in Sheffield from Dannemora ore, a magnetite unusually free of phosphorus, which they smelted with charcoal fuel in blast furnaces and converted to bar iron in fineries. When adventurers in the Adirondack region of New York found apparently similar ore, they named a town there (now best known
for its prison) Dannemora. Adirondack ironmasters used the American bloomery process to make metal that could be comparable to good Swedish iron. Others, however, failed to keep up the scrupulous care needed to maintain quality. Artisans at the Collins axeworks found that a lot of iron purchased at one New York forge made excellent steel, and then discovered that the next lot from the same forge was worthless. A Collins employee, in an unannounced visit to the forge, found the proprietor adulterating his charcoal with bituminous coal, thereby contaminating his iron with sulfur. Analyses of samples collected recently at Adirondack forge sites show the variability of their products and confirm that some forge managers mixed mineral coal into their charcoal, contrary to good practice. Both high- and low-phosphorus magnetite ores are found in the Adirondack region, and it appears that forge operators either had not mastered the art of selecting ore or were willing to use poor ore to keep their costs down.

Few crucible steelworks had chemists at this time, and melters evaluated the quality of iron from the appearance of its fracture. This practice did not allow them to assure the level of purity needed in crucible steelmaking, and they often learned about the quality of the iron they had used only after they converted it to steel. By then, they might have lost track of the source of the iron. The absence of adequate tests, and of any organization to assure quality at the Adirondack forges, created opportunities for short-term profits that some forge proprietors found hard to resist. Many American crucible steelmakers eventually built their own puddling shops to secure reliable supplies of pure iron.

Once they had mastered the basic techniques of crucible steelmaking, several American firms pressed development ahead of their Sheffield competitors. Most of the Pittsburgh makers adopted gas-fired regenerative furnaces in place of the traditional coke-fired melting holes favored in Sheffield (Fig. 7-5). They thereby reduced fuel costs and achieved closer control of the composition of their steel. Nevertheless, many American customers still preferred the cachet of English cast steel, allowing Sheffield firms to retain a significant market share. The prejudice against American steel was so well established that when the Disston saw works in Philadelphia started making its own steel, the proprietors found it prudent to keep this information from their customers. Some Sheffield firms, such as Sanderson Brothers, set up American branches to capitalize on their name and reputation. However, as the proportion of Americans who worked with edge tools diminished and as Americans made better steel, customers lost interest in English cast steel. Toolmakers bought steel made to chemical and mechanical specifications from the maker offering the best price and delivery. Gradually, the mystique of the famous English steel houses faded away.
Artisans at this Pittsburgh crucible steelworks, photographed in the 1930s, are preparing the melting holes in a gas-fired furnace to make a heat of cast steel. The melter packed the crucibles (stacked next to the shop wall) with pieces of wrought iron and white cast iron proportioned to yield the temper he wanted in the steel and placed them in the melting furnace. (Courtesy of the Smithsonian Institution)

CRUCIBLE STEELMAKERS’ WORK

Makers of crucible steel depended on three highly skilled specialists: the melter, the puller-out, and the teemer. The melter saw to the charging of the pots and their placement in the furnace, which typically held twenty-four pots. With the anthracite-fired furnaces initially used in America, melting took three to five hours. The melter examined each pot in turn to see that coal was properly packed around it. The liquid steel evolved carbon monoxide in large bubbles known as cat’s eyes. The melter’s most difficult task was judging when the steel was ready for casting. He had to have it at the right temperature and properly killed, free of dissolved gases. Incompletely killed steel spit sparks and boiled in the mold, resulting in a porous ingot. The melter uncovered each of the twenty-four pots in turn, keeping the steel molten until he judged it was just killed. While this was going on,
the teemer adjusted the molds to just the angle he liked to pour into. He and the puller-out wrapped multiple layers of water-soaked sacking around their legs and thighs. When the steel appeared “dead,” the melter signaled the puller-out to start his work (Fig. 7-6).

It goes without saying that a man who can lift a pot containing sixty pounds of molten steel with a pair of tongs from a furnace below ground level at a dazzling white heat is no weakling. I say “lift,” but the pot is not lifted; to call the men “lifters” instead of “pullers out” would be insulting. The actual pulling out is like Macbeth’s job; “when ’tis done, then ’twere well it were done quickly” . . . The pot is soft and in a degree yielding . . . The feeling of “give” gives him the confidence to straighten his back and with an unbroken pull and swing to set the pot on the floorplates. His ends of the tongs are held together by his hands only; he might use a ring to hold them together but by doing so his sense of feeling would disappear and the contact between him and the pot would be less intimate.31

7-6. After the melter had satisfied himself that the metal was at the right temperature and fully killed, the puller-out grasped the crucible with his tongs and, in one continuous movement, lifted it from the furnace and placed it on the adjacent floor. He wrapped his legs and arms with wet rags for protection from the extreme heat of the molten steel. (Courtesy of the Smithsonian Institution)
Protected with wet rags, the teemer picked up the crucible and, balancing the long-handled tongs on his knee, poured the liquid steel into iron molds ranged in front of him, being careful not to let any steel splash against the mold walls as he poured. (Courtesy of the Smithsonian Institution)

At this point, the teemer gripped the pot with his tongs while a lad mopped up the layer of slag on top of the steel with a thin iron rod, making the metal visible. If the melter then detected even a few sparks rising from the surface, he knew the steel was not fully killed. The teemer would grumble if he considered the steel to be too cold, since that limited his choice of the moment and manner of teeming: “To hurry molten steel into the ingot mold for fear it will not get there at all is considered a disgrace. Watch him teem; and if the physical grace of the bulky man and the play of colors around the pot do not enchant you, try and realize what it is he is trying to do.” With his tongs clasped around the pot at the place where the balance seemed right, the teemer rested the shanks on his knee while he crouched with his left arm extended as far as he could comfortably reach (Fig. 7-7). At the moment he judged right for casting, he tilted the pot, and a stream of liquid steel passed down the mold, never touch-
ing the side. “No lady, handling a delicate china tea cup, ever sipped tea with a greater niceness than the knowing [teemer] delivers the glistening stream of molten steel into the soot-lined mould.” It was essential that the stream of steel not “catch” the side of the mold. A “caught” ingot was a sign of negligence or incompetence. “By the time that the teemer has got rid of his rags the moulds will have been laid across a horizontal rack and the ingots will be at least partly visible. The old teemer, still mopping his face with a ‘sweat rag,’ will eye them over and have this one or that one chalked, in the spirit of an enthusiastic gardener eyeing his blooms.” 32 The “sweat rag” was toweling that the puller-out and teemer wore around their necks. While near liquid steel, they often held the ends in their teeth so that they would not inhale fumes from the pots.

Other artisans then took the ingots in hand, knocking off the tops and hammering them down into bars. The great care and careful inspection of the metal, known as “crucible practice,” had as much to do with the quality of the product as the crucible melting process itself. Steelmen differed about the merits of rolling instead of forging the ingots. Forging was the traditional way but cost more. Some makers rolled their ingots and then lightly hammered the surface. T. H. Nelson, manager of Disston’s works in Philadelphia, advised, “Unless you know your material is hammered, keep the additional cost in your own pocket, for we can assure you that a bar just planished up . . . is no better than a bar rolled outright.” 33

Soon after they started making crucible steel, American managers diverged from English practice by adopting gas-fired furnaces. This made the melter’s job easier because he could now regulate the temperature by simply manipulating valves, and he did not have to worry about accidentally knocking a piece of coal into a pot, thereby spoiling its intended carbon content. However, the American practice of using graphite crucibles complicated the melter’s job because the steel took up carbon from the crucible, making precise control of the “temper” difficult. American managers approached this difficulty by adopting “ladle teeming.” They had their teemers pour all the crucibles from one furnace charge into a large ladle before filling the ingot molds. All the steel in that lot would then have the same composition. Sheffield makers observed that with ladle teeming, some metal always splashed on the mold walls, making “caught” ingots. They decried the American willingness to sacrifice quality in the interest of faster and cheaper production. 34