INTRODUCTION

In its early years, the United States had a substantial iron industry but little manufacturing capability. In the following decades, American manufacturers such as Collins (edge tools), Colt (small arms) and Ames (machine tools) were not only able to satisfy domestic demand, but also to displace established English makers from their dominance in world markets. Yet the steel in the Collins axe, the Colt revolver and the Ames machine tools was imported from Sheffield, England, and shaped with Sheffield-made files; the American success in manufacturing had not been matched by corresponding success in steel metallurgy.

American attempts at steelmaking through the first two-thirds of the 19th century generally failed to produce the uniform, reliable product needed by the new manufacturing industries. Sheffield steelmakers retained the American market by offering quality products and by inducements to their customers (e.g., gifts, such as the cast-steel bell presented to the Collins Company, and technical assistance with metallurgical problems by sales representatives). At the start of the Civil War, the surviving national small-arms factory, the Springfield Armory, was totally dependent on England for steel and files as well as for gun iron. Had the Union navy failed to retain command of the sea, the federal war effort would have been crippled. However, the tariff of 1861 that substantially raised duties on imported steel seems to have been a more powerful stimulus than military self-sufficiency for Americans to lessen their dependence on Sheffield steelmakers.

High-grade tool steel was made in Sheffield by a two-step process: Bar iron imported from Sweden was converted to blister steel by heating it with coal in sealed chests for up to a week at a bright red heat. After slow cooling, the chests were opened, the blistered bars removed, broken into small pieces, packed in clay crucibles, melted, and the liquid steel teemed into cast-iron ingot molds. The ingots were forged under tilt hammers or, sometimes, rolled into finished shapes. Quality was controlled through skill and experience without benefit of instruments or analyses.

Americans faced three difficulties in transferring this crucible steel process to the United States. First, a source of iron free of sulfur and phosphorus had to be located since the purity of the finished steel depended entirely on the purity of the iron put into the converting furnace. Second, crucibles that were strong enough to be lifted with tongs while full of liquid steel and which satisfied the chemical requirements of the process were needed. Third, while the artificers in a new steelworks might acquire the dexterity needed to pull and teem the pots by practice, the judgement skills needed to control the temperature and kill the steel were acquired by growing up in the trade in Sheffield. The books on steelmaking available in the United States were unhelpful; for example, in The Manufacture of Steel, Frederick Overman tells his readers that phosphorus and arsenic are as essential to good steel as carbon.

MATERIAL EVIDENCE

Historians have been interested in the early stages of American crucible steelmaking as a case study of the difficulties that have to be overcome in transferring a sophisticated manufacturing technology from one country to another. However, they have found that the surviving business and commercial records reveal little about the technical aspects of the American experience with crucible steel. Archaeological evidence could supply some of the missing information but,
Somesilicon from the slag was reduced; so far, no today pots have been found crucibles; a number of these were found of imported clay. Oixon used graphite on onward and was initially managed by Joseph Dixon, was located adjacent to the steelworks. The graphite pot was strong, but its use led to a chemical difficulty—carbon absorption from the pot made control of the temper of the steel uncertain. (In crucible steelmaking, "temper" meant carbon content.)

Initially, the Adirondac steel failed to compete successfully with the Sheffield product because of want of uniformity of temper. Some of the larger works achieved a partial solution of this problem by teeming many pots into a large mixing ladle before pouring the ingots, but Sheffield makers always remained unimpressed by the uniformity of temper of American crucible steel. One sample of cast steel from Collins contains only 0.2% carbon, suggesting that they had mastered the problem of carbon pickup. A steelmaker in Sheffield would say that making steel with such a low carbon content was impossible in a graphite pot.

**Steelmaking Skills**

American entrepreneurs acquired the steelmaking skills required in their works by recruiting experienced Sheffield artificers. The Collins Company was an exception, gaining its initial knowledge of the process through visits to England, beginning in 1842. Initially, the British steelmakers responded with the courtesy usually shown a good customer: by 1860, however, most Sheffield proprietors refused to admit visitors to their works. The metal samples throw some light on two questions about the effectiveness of transfer of technology: how up to date the knowledge so acquired was and how effectively this knowledge could be applied in a new environment.

Two technical changes were being made in the Sheffield crucible steel process shortly before Americans attempted transfer of the technology. In 1854, the Swedish government removed export restrictions on Swedish pig iron. This meant that 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 the crucible furnace) could be eliminated. Instead, the pots were charged with the mixture of pig and wrought iron needed to get the desired temper; the pig melted easily at the operating temperature of the furnace and dissolved the wrought iron. The River Don Works built in Sheffield in 1863 adopted this new technology; it had no converting furnaces.

The second change was the adoption of the nozzle, invented by R.F. Mushet in 1861, to eliminate piping in the steel ingots. Fully killed steel solidified with a deep pipe, resulting in loss of up to a quarter of the ingot. The nozzle was a clay cone inserted in the top of the ingot mold near the end of the pour to provide a reservoir of liquid; with it, losses from pipe were reduced to 1 to 2% of the ingot.

The samples sent to Yale from American steelworks to illustrate their methods include bars of Swedish iron, like the