



Internal oxidation of cast iron artifacts from an 18th-century steel cementation furnace

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ABSTRACT

Heavily corroded metal artifacts recovered from the site of an 18th-century steel cementation furnace in Trenton, New Jersey, are cast iron altered by internal oxidation. The progress of the internal oxidation process was followed by comparison with the microstructure of cast iron exposed to high temperature in a wood-burning fireplace. The graphite flake structure of the cast iron allows deep, rapid penetration of oxygen that reacts at the iron–carbon interfaces within the iron to form iron oxides that eventually replace the graphite flakes. Microprobe analyses show that the silicon in the cast iron is converted to knebelite that also serves as the host for phosphorus. Sulfur dispersed in the internal oxidation product and porosity appear to be responsible for rapid rusting of the artifacts. Internal nitriding accompanies the oxidation. The Trenton artifacts are interpreted as grate bars from the fire box of a cementation furnace.

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1. Introduction

Excavations at the site of a steel cementation furnace in Trenton, New Jersey, that operated intermittently between about 1745 and 1782 uncovered the foundations of the furnace house; and traces of the fire box, ash pit, and chest used for the cementation process. Heavily oxidized iron bars were found in demolition rubble adjacent to the furnace house that appeared to be wrought iron stock on hand for conversion to steel, or possibly parts of the furnace (Hunter and Burrow, 2010). The bars have head-like, enlarged ends, and thin in their mid-sections to broken ends, Fig. 1. The bars were approximately 145 mm long, 75 mm deep with heads 70 or 50 mm wide. A section through one of the bars shows a metal core surrounded by a thick coating of oxidation products, Fig. 2. We report here on the identification and function of these artifacts.

The Trenton Steel Works was located on the western edge of the small colonial market town of Trenton, New Jersey (Trenton Historical Society, 1929; Burrow and Hunter, 1996). Bar iron produced in northwestern New Jersey and northeastern Pennsylvania was shipped downstream to the “falls” of the Delaware, off-loaded, hauled a short distance up the riverbank to the steel works, and converted into steel in the cementation furnace. The

finished product, bars of blister steel perhaps up to two meters long and 25 mm thick, was used locally or transported to market either downriver from Trenton Landing or by wagon along the King’s Highway. Most of the output appears to have been sold in Philadelphia and New York, although the documentary record also indicates Trenton-made steel being marketed, not very successfully, as far away as Boston and even London (Bining, 1938; Boyer, 1931:227–231; Hunter and Burrow, 2010).

The origins of the Trenton Steel Works lie in an ironworking complex established on Petty’s Run, a minor tributary of the Delaware that defined Trenton’s western boundary throughout the colonial period. In the early 1730s, Isaac Harrow, a local blacksmith, erected a plating mill on the east bank of the run where he forged a range of plate metal goods with the help of a water-powered trip-hammer. Following Harrow’s death, the plating mill was acquired in 1745 by another Trenton blacksmith, Benjamin Yard, who retained ownership of the site until his death in 1808. After producing arms for the Continental Army in the early years of the Revolutionary War, the plating mill appears to have ceased operation in the fall of 1777 after it was damaged by American forces to prevent it falling into British hands (Hunter and Porter, 1990:89–91).

Benjamin Yard built the cementation furnace directly across Petty’s Run from the plating mill sometime between 1745 and 1750. In the latter year, the existence of both the steel furnace and plating mill was documented in an inventory of late-stage metalworking sites compiled by colonial governors in British North America in response to directives from Parliament and the Board of Trade

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Fig. 1. Iron artifact recovered from the site of the Trenton steel cementation furnace.

following passage of the 1750 Iron Act. Through this legislation, the British government, in an effort to protect the English metalworking industry, sought to maximize imports of semi-processed pig and bar iron from the colonies, and at the same time prevent the emergence of an American metal manufacturing sector. English metalworkers could be assured of both a ready supply of raw material and an American market for their goods. Under the terms of the Iron Act, pre-existing late-stage metalworking operations, such as steel furnaces and plating, rolling and slitting mills, could continue in business, but construction of new facilities was prohibited. The Iron Act was widely disregarded by the colonists, who built many new iron works in the 1760s and 1770s. The rising tension surrounding British attempts at curtailing American metal manufacturing in the period 1730–70 was a major factor in triggering the American Revolution (Bining, 1933; Mulholland, 1981; Bezis-Selfa, 2004).

Yard's steel furnace was one of only five documented in the American colonies in 1750 (two more were in Philadelphia, one in Killingworth, Connecticut, and one in Boston). Initially, the furnace likely worked in concert with the plating mill, producing steel that could be used for edge tools and other specialized items. In 1762, however, Yard sold the furnace to a pair of prominent Philadelphia merchants, Owen Biddle and Timothy Matlack, and from this date up until the Revolution, the steel works was controlled by a succession of Philadelphia owners. Biddle's interest in the steel furnace may have been driven by his training as a clockmaker and by his involvement



Fig. 2. Section through the artifact in Fig. 1. Rapid rusting of the exposed iron is visible.

with the American Philosophical Society, both of which would have given him a profound appreciation of the value of steel as a high-quality, strong and durable metal. In contrast, the motives of John Pemberton, the principal owner from 1770 until 1782, were almost certainly mercenary. Pemberton, one of the wealthiest merchants in the colonies, was primarily interested in manufacturing steel on a commercial basis for domestic consumption (Hunter and Porter, 1990:91–97; Hunter and Burrow, 2010:75–77).

The quality of Trenton-made steel was questionable, however, and the steel works seems always to have been a somewhat shaky operation. Throughout the late 1760s and 1770s, advertisements appeared in Philadelphia and New York newspapers, occasionally offering steel for sale, but more often announcing that the furnace property itself was available for purchase (Nelson, 1902). The papers of John Pemberton, held at the Historical Society of Pennsylvania, reveal his difficulties in maintaining production and finding satisfied buyers for the steel. In the early years of the Revolutionary War, Pemberton, suspected of Loyalist tendencies, left Philadelphia for Virginia, but this did not prevent the Trenton Steel Works from supplying steel to Continental Army artificers in 1776. The furnace may have suffered a similar fate as the plating mill, and been damaged later on during the war. By 1781, from correspondence between Pemberton and Trenton merchant Stacy Potts, one of the final owners of the steel works, it was evident that the furnace was standing idle and had not been in operation for quite some time (Hunter and Burrow, 2010, 76).

In 1781–82, Potts and Pemberton engaged in protracted negotiation over the steel works, which ultimately resulted in Potts, a business partner named Samuel Downing and a Philadelphia steel maker, John Nancarrow, acquiring the site. The furnace was rebuilt, Nancarrow soon left following a dispute, and the steel works resumed operation under Potts and Downing in early 1782. The business soon failed, unable to compete with cheaper, better quality British steel imported again following the Treaty of Paris in September, 1783. Potts and Downing were also unable to pay their main supplier of bar iron, and by 1784 were enmeshed in court proceedings which brought the steel works to a halt. No evidence has been found for steel production at the site after 1784 (Hunter and Burrow, 2010:76–77).

2. Archaeological context

In 2008–09, as part of the planning and design work for the proposed Capital State Park – an urban riverfront amenity surrounding the New Jersey State House – the opportunity arose for archaeological exploration of the Petty's Run Archaeological Site. Open-area excavation exposed remains of the furnace house and furnace base, and the footings of the Harrow/Yard plating mill, all thoroughly entangled with and overlain by the foundations of a 19th-century cotton mill and paper mill, Fig. 3. The site is bisected by Petty's Run, today a deeply buried, channelized and culverted water course co-opted into the city storm sewer system. The site is to be stabilized and interpreted within the New Jersey Capitol Complex (Wallace Roberts & Todd, LLC, 2008).

The surviving features of the Trenton Steel Works comprise the foundations of the furnace house, the footprint of which roughly matches the 30 by 34-foot dimensions given for this building in an August 29, 1765 sale notice in the *Pennsylvania Gazette*, and the roughly ten-foot-square, stone and brick base of the steel furnace. The furnace house foundations are rough-dressed gneiss blocks, apparently quarried from the bluff edge adjacent to the building and bonded with a distinctive orange-brown clayey mortar. The furnace itself survives at the level of the bottom of the firebox and ash pit. The arrangement of the masonry indicates a single cementation chest oriented east-west that would have lain within

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