Two Hundred Years of Rolling on the Brandywine

Today, there are 11 rolling mills in the United States that can produce approximately nine million tons of plate per year. ArcelorMittal Coatesville, located 40 miles west of Philadelphia, in Chester County, Pa., is one of these plate mills. The Coatesville facility is the oldest continuously operated steel mill in the country, and celebrated its 200th anniversary on 2 July 2010.

The ArcelorMittal Coatesville plant employs 840 people and covers 950 acres that straddle the Brandywine Creek in and around the city of Coatesville in Southeastern Pennsylvania. The plant produces carbon and alloy plates in gauges from 3/16 to 28 inches, in widths from 48 to 195 inches, and with weights up to 60 tons. These plates are used for construction and mining equipment, bridges, process vessels, and military applications such as ballistic protection for surface ships, submarines and land vehicles.

The story of this mill, from its inception in the early 1800s to its transformation into a producer of the largest and heaviest plates available in North America, is a saga of survival, perseverance, innovation and vision. The achievement of a historic milestone such as a 200th anniversary warrants a look back at some of the pioneers and their mills that allowed this journey to succeed.

The Beginning — A New Mill Is Born

In 1810, the site of today's plant was home to a water-powered saw mill. Isaac Pennock (Figure 1), a Quaker ironmaster, chose the location to expand his rolling and slitting business. He had previously established the Federal Slitting Mill in 1793. His first iron works was located 4 miles south of present-day Coatesville on Buck Run, which flows into the Brandywine Creek.

Although Pennsylvania was not the birthplace of ironmaking in America, by 1800 the commonwealth had become the center of the iron industry. The Keystone State was blessed with the essential ingredients for ironmaking — ore deposits lying on or close to the surface, abundant forest lands for charcoal fuel and limestone for furnace flux.

Figure 1

Isaac Pennock, founder of Brandywine Iron Works and Nail Factory.

In 1805, the Federal Slitting Mill was one of 11 such establishments in Pennsylvania that produced 2,750 tons per year. Chester County was home to four of these 11 rolling and slitting mills. They could obtain forged blooms from one of eight forges in the county.[1]

The Coatesville site, located where the Philadelphia and Lancaster Turnpike crossed the Brandywine, offered several commercial advantages. The Turnpike was the first hard road built in America. Completed in 1794, it offered all-weather transit between the two major cities in the state. The Brandywine was also much larger than Buck Run, and its swift waters offered the potential of greater water power to drive a rolling and slitting mill. Larger waterways were also less sensitive to dry spells, which halted operations when the flow was insufficient to turn the waterwheel and power the mill.

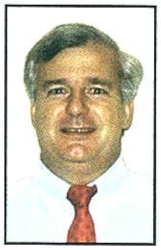
Pennock partnered with Jesse Kersey. Together they purchased a 110-acre farm from Moses Coates, the man for whom the city of Coatesville is named, and converted the saw mill into an iron works. Locally forged iron bars, produced from pig iron made in nearby cold blast furnaces, were heated on a grate over an open charcoal fire and rolled to narrow flat stock. The rolled iron was either sold for use as wagon wheel bands, barrel hoops and general blacksmith use, or it was slit into rods and made into nails.[2]

By the time the Brandywine Iron Works and Nail Factory, as the new enterprise was called, began operations in 1810, there were 47 rolling and slitting mills in the young nation. Spread across 10 states, these establishments converted 10,000 tons of bar iron into narrow stock and nail rods.[3,4]

The American iron industry had 153 blast furnaces that made 53,908 tons of iron in 1810, and 330 forges that produced 24,541 tons of bar iron to feed the rolling and slitting mills.[4] The balance of the blast furnace iron presumably was used in the production of hollow ware, such as pots and kettles, and stove plates.

Pennsylvania led the nation with 18 rolling and slitting mills, followed by Massachusetts with 13 such establishments. The Pennsylvania mills produced 4,502 tons of iron.[5] Six of the mills were located in Chester County, and rolled 1,472 tons of iron valued at $158,600.[5]

Although no drawings or pictures are available of that first mill along the



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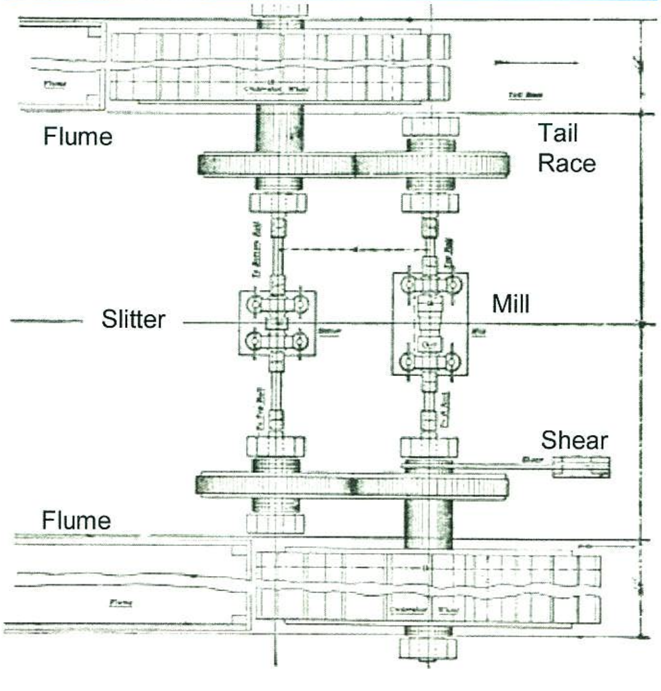
Brandywine, descriptions of the equipment indicate it was similar to documented facilities. Harrison described a mill in Middleboro, Mass., which is often cited as the first rolling mill in America.[6] Built in 1751, it was powered by two water wheels — one for the top rolls of the rolling mill and the slitting mill, and the other for the bottom rolls (Figure 2).[7]

Peter Oliver, a crown judge in the province, built the mill. He was a native of Birmingham, England, which was an iron producing center. The English government, by an Act of Parliament in 1750, prohibited the making, the importing or the operation of machinery to roll and slit iron in the colonies. Oliver received special consideration to import the equipment and operate the mill. This exemption was most likely due to his extensive political connections, including the influence of his brother, who was the Lieutenant Governor of Massachusetts.

The Act of 1750 restricted the activities of the colonies to the production of pig iron, castings and bar iron. It was designed to keep the colonies dependent upon England for finished products.[8]

To determine compliance with the Act, marshals were ordered to document all existing iron manufacturers and report on their operations. One rolling and slitting mill was reported in Chester County in 1750, operated by John Taylor.[9] According to local records, the mill was built in 1746 and was located on Chester Creek alongside the Sarum Forge that had been established in 1742.[10,11] This mill predates the Middleboro mill by five years. It continued to operate during the Revolutionary War. The Sarum Iron Works operated until 1836, when the site, which became known as Glen Mills, was converted to a paper mill.[12]

Figure 2



A diagram of the Middleboro, Mass., rolling and slitting mill.

Early Rolling Mills

Harnessing the energy of moving water from a stream or river provided free power, but it did have its drawbacks. Since water flowed in one direction, a water wheel turned in only one direction. Powering two rolls in opposite directions required either two water wheels, or a series of gears to transmit power from the water wheel to the opposite side of the mill, where wooden gears could drive one of the rolls from the other side.

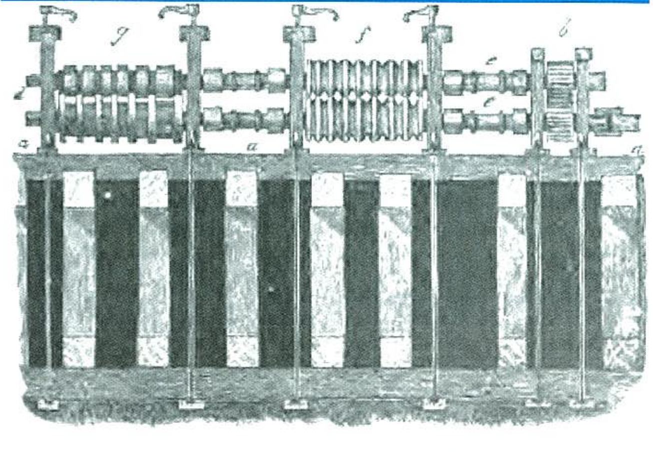
The two-water-wheel option could be employed with either two wheels on one side of the mill, or a headrace (or flume) on both sides of the mill. Problems with turn-up or turn-down of the rolled bars could be corrected by adjusting the gates in the headrace, thereby altering the speed of the water wheel and one of the rolls.[13]

A typical water-powered rolling mill employed four or five simple pieces of equipment. A shear cut the forged bars into smaller pieces, a small furnace was used to heat the forged bars, a narrow mill rolled the bars and a slitting mill cut the rolled bars into narrow rods. Occasionally, a hammer was employed to forge pig iron, to further reduce a bar supplied by the local forge, to weld scraps of iron together to re-roll into plate, or to flatten a rolled plate or bar.

The Middleboro mill received hammered bars that measured 3 inches by $^{3}/_{4}$ inch by 8 feet long from Leonard's Forge. The bars were sheared into smaller lengths and heated in a charcoal-fueled furnace. The mill, with rolls 15 inches in diameter and 36 inches long, rolled the $^{3}/_{4}$-inch-thick bars down to $^{1}/_{4}$ inch in four passes, which would suggest $^{1}/_{8}$-inch drafts were taken on each pass. After the last pass, the bar was passed to the slitter and cut into $^{5}/_{16}$-inch-wide nail rods.[14] Nail rods were usually bundled and distributed to local craftsman, who returned forged nails. The Brandywine Iron Works and Nail Factory presumably operated in much the same manner.

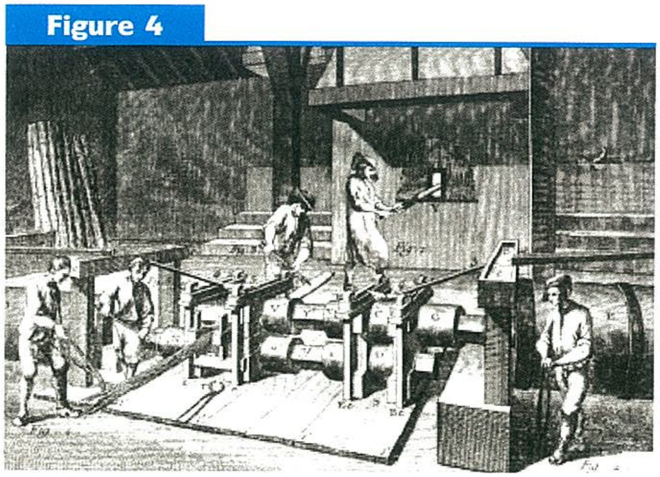
Nineteenth-century rolling mills were fairly simple pieces of equipment. Small cast-iron housings were

Figure 3



Nineteenth-century rolling mill and foundation.

Figure 4



Powertrain of a water-driven mill.

mounted on timbers buried below floor level, and anchored with long bolts (Figure 3).[15] Power was transmitted to the cast-iron rolls from the water wheel by a wooden shaft, which was connected to a coupling box (Figure 4).[16] The rolling and slitting mills were usually powered in series, or in a "train," with a shaft connecting the rolls of each stand.

Figure 5 depicts the early days inside the Brandywine Iron Works and Nail Factory. The drawing was commissioned in 1857 by Abram Gibbons, a local banker who had been a partner in the firm from 1847 to 1855.[2] The engraving, used on the bank's notes, shows the mill as it would have looked before several renovations. Its historical accuracy may be questioned, since the engraving was made more than 45 years after the building of the original mill. It does, however, provide insight into the activities conducted inside an early 19th century rolling mill.

The Second Generation of Ownership

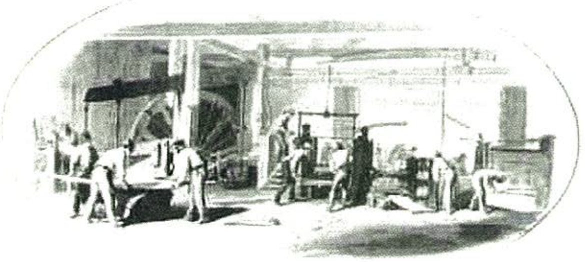
Isaac Pennock and Jesse Kersey ran the Brandywine Iron Works and Nail Factory together for more than six years. Isaac bought his partner's share of the business in January 1817. Rebecca Webb Pennock, Isaac's daughter, grew up near the Federal Slitting Mill and was well versed in the operations of the mill.[17] She married Charles Lukens, a medical doctor from Philadelphia, in 1813 (Figure 6). Dr. Lukens left his practice and joined his father-in-law in the iron business in 1814. He took over the operation of the Federal Slitting Mill and ran that establishment for several years as he learned the iron business. Dr. and Mrs. Lukens relocated to Coatesville at the end of 1816. Early in 1817, they leased the operations of the Brandywine Iron Works and Nail Factory, and together they ran the mill.[18]

The new owners found themselves responsible for capital outlays to replace worn-out equipment in addition to the $420 annual fee for leasing the mill.

The First Boiler Plate Rolled in America

Meanwhile, a new market for iron products was developing. The desire to provide better methods of transportation between cities encouraged enterprising men such as John Fitch, Robert Fulton, Robert Livingston, Oliver Evans and John Stevens to develop steam-powered boats on the Delaware River. Copper plates were initially used to construct the boilers, but these proved to be too expensive. The first iron boilers were made from plate imported from England.[19] Dr. Lukens saw this new development as an opportunity to expand his business into the boiler plate market. He modified his mill, and in 1818 produced the first boiler plate rolled in America. Charcoal blooms weighing less than 100 pounds were heated in a small furnace on a grate over an open fire, transferred by hand to the mill, and rolled to a thickness of $^{1}/_{4}$ inch or $^{3}/_{16}$ inch.[20]

Figure 5



Interior view of the Brandywine Iron Works and Nail Factory, circa 1810.

Figure 6

Dr. Charles Lukens (left) and his wife, Rebecca Lukens.

Although the exact size of the mill is not known, it was said to have "rolls of about 16 inches in diameter and 3–4 feet in length between the housings."[21] This width appears to be confirmed by another notable order received in 1825. John Elgar of York, Pa., ordered plates $^{1}/_{12}$ inch (0.0833 inch) thick and 23, 24 and 25 inches wide — clearly requiring a mill of 30 inches in width or wider. The plates were used to build the Codorus, the first iron-hulled ship constructed in America. The iron plates were designed to protect the hull from the shallow and rocky waters of the Susquehanna River. Despite the fact that the plate market was still in its infancy, even these early customers had their concerns for quality. Elgar specified that the plates should be "particularly clear of buckles or bilges that prevent the sheet from lying flat."[22]

The future of the prospering mill was dealt a severe blow later that year when Dr. Lukens suddenly succumbed to a fever and died in June 1825, at the age of 39. From his deathbed, he was able to secure a promise from his wife to continue their struggle to maintain the iron business. Mrs. Lukens agreed, and in doing so became the first woman industrial leader in America.[23]

Rebecca Lukens made major improvements to her Brandywine Iron Works in 1834. She invested heavily to upgrade the equipment, and virtually rebuilt her entire mill. A new dam across the Brandywine was added to provide a better source of power. A higher dam, with a larger reservoir, meant a greater fall, or head, to drive the mill. In addition to more power, the larger reservoir provided more storage capacity for summer dry spells. The new mill equipment included castings, wheels and furnaces. The building that housed the mill was enlarged, and several tenement houses were built for the mill workers. It appears that the mill may have been widened to 48 inches during this renovation.

As the little rolling and slitting mill on the Brandywine approached its 25th year of operation, a major event occurred that led to significant changes in its future. The Philadelphia and Columbia Railroad was completed in 1834, connecting the largest city in Pennsylvania to the banks of the Susquehanna River, 75 miles to the west. It crossed the gorge near Coatesville, through which the Brandywine flowed, at a point less than one-half mile from Rebecca's mill. The railroad presented opportunities to reduce the cost of bringing raw materials such as forged bars and coal to the mill, replacing the long and arduous journey by pack mules or wagons over rough trails. It also opened a relatively inexpensive avenue to the large and growing Philadelphia boiler plate market.

Local Competition — The Second 25 Years

Following the success of Pennock's two early enterprises — the Federal Slitting Mill and the Brandywine Iron Works and Nail Factory — a local forge built a water-powered rolling mill. Laurel Forge, located on Buck Run where it flows into the Brandywine Creek, about four miles downstream from the Federal Slitting Mill, added a rolling mill in 1825.

The sustained success of Rebecca Lukens; the completion of the Philadelphia and Columbia Railroad; and the blossoming boiler plate market created by the rapid growth of steamships, railroads and steam locomotives led others to follow suit and build additional rolling mills in the area.

Samuel Hatfield owned a grist mill on the Brandywine about three miles upstream from the Brandywine Iron Works. He added a rolling mill in 1836 and built a second mill on the opposite side of the stream in 1843. His mills were known as the West Brandywine Iron Works.[24] Hibernia Forge, located on the Brandywine less than a mile upstream from Hatfield's mill, built a rolling mill in 1837.

Isaac Pennock's widow, Martha Webb Pennock, continued her husband's iron business after his death in 1824. Initially she rebuilt the Federal Slitting Mill, which became known as the Rokeby Rolling Mill. She erected a new rolling mill along the Brandywine in 1837, two miles below Hatfield's mills, and one mile above the

Table 1

Rolling Mill Data 1841
(Iron and Coal Association of the State of Pennsylvania)

Mill	Established	Tons	Product	No. of men	Tons/man
Rokeby	1793	400	Boiler plate	11	36.4
Brandywine	1810	400	Boiler plate	11	36.4
		100	Nails	6	
Laurel	1825	200	Sheet iron	12	16.7
		300	Bar iron	16	18.8
		60	Nails		
West Brandywine	1836	400	Boiler plate	11	36.4
Hibernia	1837	400	Boiler plate	10	40.0
		300	Bar iron	17	17.7
Caln	1837	200	Sheet iron	12	16.7
Triadelphia	1838	400	Boiler plate	12	33.3
Total boiler plate and sheet iron		*2,400*	*Employees*	*79*	*Avg = 30.4*
Total bar and nails		*760*	*Employees*	*39*	*Avg = 19.5*
Total product		**3,160**	**Total employees**	**118**	**Avg = 26.8**

original Coatesville mill, which was now operated by her daughter, Rebecca Lukens. Martha's mill, known as the Caln Iron Works, was built on land that was originally owned by her husband, and that she acquired in the settlement of his estate.

In 1838 two brothers, James and John Forsythe, and their brother-in-law, John Yearsley, built a rolling mill alongside the Philadelphia and Columbia Railroad Bridge that spanned the Brandywine. The mill was named Triadelphia Iron Works, or "Three Brothers," reflecting their Quaker heritage.[26]

Information gathered by the U.S. Census of 1840 indicated that there were 169 rolling mills, bloomeries and forges in Pennsylvania. The Iron and Coal Association of the State of Pennsylvania procured returns with production information for 1841 from 30 rolling mills in March 1842. The data from the report, listed in Table 1, show that the Federal Slitting Mill (now known as Rokeby), the Brandywine Iron Works, the West Brandywine Iron Works, Hibernia Forge and Triadelphia each produced 400 tons of boiler plate per year. The Caln Iron Works and Laurel Forge each made 200 tons of sheet iron per year. The two forges, Hibernia and Laurel, each also made 300 tons of bar iron annually. The Brandywine Iron Works produced 100 tons of nails and Laurel made 60 tons of nails.[27]

Each of the rolling mills employed 10–12 men, indicating that the establishments were quite similar in the manning of their operations, but not in their productivity. The tons of plate produced annually per man varied from a high of 40 to a low of nearly 17, and averaged 30.4 tons per man per year. In addition, Hibernia employed another 17 men in the forge, Laurel had 16 additional hands involved in the forge and nailmaking, and the Brandywine Iron Works also had six men in their nail operation. The productivity of these operations averaged 19.5 tons per year per man, reflecting the lower productivity typically associated with a forge.

Since the division of labor between plate, bars and nails is unclear, these productivity figures may not be exact. However, if the total production of plate, bar and nails (3,160 tons) is divided by the total reported employment (118 men), a productivity of 26.8 tons of annual product per man is obtained. Mason's Nail Factory, also located in Coatesville, employed 42 men and produced 1,000 tons of nails. It is likely that they consumed a considerable portion of the sheet iron produced in the local mills.[27]

In 1846, the partnership that had formed the Triadelphia Iron Works was dissolved. Two of the owners, John and James Forsythe, withdrew and established the Thorndale Iron Works in 1847. Their new mill was located along the tracks of the Philadelphia and Columbia Railroad, two miles east of Coatesville. This was the first area rolling mill that was not built along water's edge. The selected site reflected the growing importance of rail transportation. The rolling mill was powered by a steam engine rather than a water wheel, and represented the introduction of this new rolling technology to the area.

Steam power eliminated the mill's dependency on a source of moving water to drive the rolls. It extended the time available for production, since it was immune to the winter freezes that not only halted rolling but could also damage the water wheels. Steam power was also insensitive to summer droughts that reduced the flow of water enough to halt the wheels and stop the rolling operations. The more consistent power produced by steam engines helped to prevent damage to the mill rolls. Low water flow could cause a bar to become stuck in the rolls before the completion of a rolling pass, resulting in heat cracking of the iron rolls. During periods of low water flow, the mill hands would be ready to climb onto the water wheel to prevent a stalled piece, or "sticker." Their added weight allowed the wheel to continue turning, complete the pass and prevent the iron rolls from cracking.[28] A mill location

Table 2

Rolling Mill Data, 1849
Documents Relating to the Manufacture of Iron

Mill	Year built	No. of roll trains	No. of puddling furnaces	No. of heating furnaces	Tons	Product	No. of men	Tons/ man
Rokeby	1793	1	0	3	875	Boiler and flue plate	22	39.8
Brandywine	1810	1	0	2	944	Boiler and flue plate	17	55.5
Laurel	1825	1	1	2	854	Boiler and flue plate	18	47.4
West Brandywine	1836	2	0	4	1,000	Boiler and flue plate	30	33.3
Hibernia	1837	1	0	2	450	Boiler and flue plate	16	28.1
Caln	1837	2	2	3	800	Boiler and flue plate	42	33.3
					600	Bar		
Triadelphia	1838	2	1	2	550	Boiler and flue plate	20	27.5
Thorndale	1847	1	2	4	725	Boiler and flue plate	32	22.7
				Total tons	**6,073**	**Employees**	**197**	**Avg = 34.5**

away from moving water also eliminated the possibility of damage to the mill dam, the mill race, and the waterwheel caused by spring and fall floods.

The cluster of rolling mills around Coatesville reflected the advantages the location had to offer. Power was supplied by the Brandywine. The Philadelphia and Columbia Railroad afforded reliable transportation to distant markets, while the Philadelphia and Lancaster Turnpike provided a local avenue of transportation. The connection between the local mills and the distant markets was made possible by independent sales agents.

A meeting of ironmasters was convened in Philadelphia in 1850 to discuss the concerns of the industry — mainly the subject of tariffs. Documents issued from that meeting provide another snapshot of the mills in and around Coatesville for the year 1849. The information for the rolling mills in the vicinity of Coatesville is shown in Table 2.

Production at the local mills had increased significantly in the eight years following 1841. The total output of the eight mills was almost 6,100 tons per year, up from 2,400 tons from the seven mills in 1841. Hatfield's West Brandywine Iron Works added a second rolling mill in 1843 and produced 1,000 tons of boiler and flue plate per year with 30 men. The Caln Iron Works added a bar mill, and with 42 men annually made 800 tons of boiler plate and 600 tons of bars. The Triadelphia mill also added a second train of rolls and produced 550 tons of boiler and flue plate per year with 20 men. The Brandywine Iron Works produced 944 tons annually with 17 men and a single rolling mill. The Laurel Iron Works was close behind with 854 tons. The steam mill at Thorndale produced 725 tons with 32 hands. Hibernia Forge lagged with only 450 tons and 16 employees. The Rokeby mill had fallen on hard times and was sold at a sheriff's sale in 1849. It returned to operation with 22 workers and a capacity of 875 tons.

Four of the mills also added puddling furnaces, with Laurel and Triadelphia each installing one, and Caln and Thorndale each having two. Puddling furnaces, the forerunner of the open hearth furnace, allowed blooms to be made from pig iron without completely melting the pigs, and eliminating the forging step. The temperature of the pig iron was raised in the furnace until most of the impurities were driven off, leaving a pasty mass. The puddle ball was removed from the furnace and the liquid slag was driven out of the pasty mass by hammering, squeezing or rolling. The rolled bars, called muck bars, were often broken into pieces and remelted to further refine the iron. Muck bars were rolled into flue plate, but were not considered high enough quality to use for boiler plate. Charcoal blooms produced at the forge were the feedstock for high-quality boiler plate.[30]

A New Generation Assumes Control

Rebecca Lukens retired from active management of the mill and became a silent partner in 1847.[31] The operation of the mill was carried on first by Rebecca's son-in law, Abram Gibbons, who entered the business in 1842. Gibbons was joined in 1847 by another son-in-law, Dr. Charles Huston.

Dr. Huston made the last renovation to the original mill layout in 1853. He installed a new breast wheel with gearing designed to convey more power to the mill's rolls. A heavy flywheel was also installed so that power could be stored and used to minimize the fluctuations inherent to water power. Any variation in the flow of water was almost immediately reflected in the movement of the rolls.[32] The new water wheel gearing combined with the large flywheel allowed the mill to be enlarged to 66 inches wide with rolls 21 inches in diameter. Additional improvements were made to the heating capacity, including a replacement furnace.

Rebecca Webb Pennock Lukens passed away the following year, on 10 December 1854, leaving the ownership of the mill to her heirs. After her death, the name of the iron works was changed to Lukens Rolling Mill in her honor.

Maintenance and quality problems presented challenges to the early rolling mills just as they do today. Broken rolls could be replaced in a few hours. Failure of the powertrain could shut the mill down for longer periods. Methods to achieve consistent plate properties were the result of trial and error. Variations in raw materials — the blooms purchased from local forges — as well as in heating and rolling practices combined to generate inconsistent results. Once a successful process was identified for a combination of blooms and practices, every attempt was made to follow the same recipe for each plate.

The water-powered rolling mills were non-reversing mills — they could roll only in one direction. The iron sheets had to be passed back over the top of the mill for each subsequent pass. This practice resulted in significant temperature losses, particularly in light-gauge plates. The high rate of cooling on iron sheets less than $^1/4$-inch thick caused temperature variations that resulted in the sheet buckling, and was usually accompanied by customer complaints.[33]

Improvements in workmanship generated enough confidence for the owners to issue a warranty with their products starting in March 1857.[33] The warranty guaranteed boiler plates to be free from manufacturing defects. Any plate found to have a defect could be returned for a refund or replacement.

The Civil War Brings Expansion and Growth

The years during the Civil War were prosperous ones for the local mills. Every mill grew in size as a result of the increased demand for iron sheet and boiler plate. Employment at the Lukens Iron Works doubled from 17 workers in 1850 to 34 during the war years of 1861–1864.[34] Plate production, which seldom exceeded 100 tons per month through the 1850s, broke the 1,000-ton annual barrier for the first time in 1862, and peaked at just over 1,700 total tons in 1864. The mill weathered an economic slowdown following the war, and Lukens' output never again fell below 1,000 tons per year.[35]

Although significant production increases had been realized, the size of the Lukens mill and the method of production remained relatively unchanged from the time of the renovations in 1853 to the end of the 1860s. Despite improvements made in other local mills, including the installation of wider rolling mills — and additional mills — Dr. Huston resisted the recommendations of his selling agents to widen his mill.

The recovering economy of the late 1860s resulted in increased demand and finally convinced Dr. Huston to expand the iron works. The local economy was also bolstered by the construction of the Wilmington and Northern Railroad. This north-south rail line, headquartered in Coatesville, opened the Wilmington to Coatesville portion in 1869 and was extended to Reading in 1872. The new rail link brought coal used for fuel from the mines of central Pennsylvania and ore from the Wilmington docks to the local iron mills. It was also used to deliver plates to the growing shipbuilding industry in Wilmington and other shipyards along the Delaware River.

Lukens Enters the Steam Era

Lukens stayed with its original water-powered mill long after the local competition had progressed to steam. Their selling agents encouraged them from time to time to upgrade to a wider mill and newer technology whenever an order was lost because the desired plate widths could not be rolled. In the 1850s Lukens occasionally had wider plates rolled for them by other Coatesville mills — Valley (formerly Caln) and Viaduct (formerly Triadelphia).[36] With business recovering after the postwar slump, and financed by the wartime profits, Dr. Huston and his business partner, Charles Penrose, began to investigate improvements to their mill. The building that housed the original mill was not suited for expansion, and construction of a new building was required. All possibilities were examined for the new undertaking during 1868–1869, including reversing steam engines and 3-high mills up to 96 inches wide. After the lengthy investigation, a rather conservative solution was chosen. A new steam-driven, 84-inch, 2-high non-reversing plate mill, with chilled iron rolls 25 inches in diameter, was installed in 1870 and put into operation in November. It was housed in a new double-bay mill building adjacent to the original mill.

The new, wider mill allowed Lukens to enter the market for wide boat iron. This was a growing market in Philadelphia and nearby Wilmington, where the shipyards were building an increasing number of iron-skinned vessels. The traditional shipbuilding centers of Boston and New York were giving way to facilities on the Delaware River — Philadelphia, Chester and Wilmington — cities closer to the rolling mills that supplied the iron plates.[37]

The first order for "boat iron" plate was received in February 1870 and produced on the old mill. The selling price for boat iron was lower than that of boiler plate, and a lower grade of iron could be used. After the installation of the steam mill, a puddle furnace was installed in the original mill building; and for the first time in its history, the company had its own source of iron to feed the mills. Although several of the local mills had been operating puddling furnaces for a number of years, puddled iron had not been used at Lukens for the production of boiler plate because it was considered inferior to forged iron. It was, however, well suited for boat iron, and Lukens entered the era of iron production.

Iron was heated in a reverberatory furnace and entered the mill on short roller tables, generally 50–70 feet long. After being rolled to gauge, the plates were removed from the tables, then piled, cooled and sheared. Distortion in the plates caused by uneven cooling was removed by a tilt hammer, which had the disadvantage of leaving unsightly hammer marks, which damaged the surface.

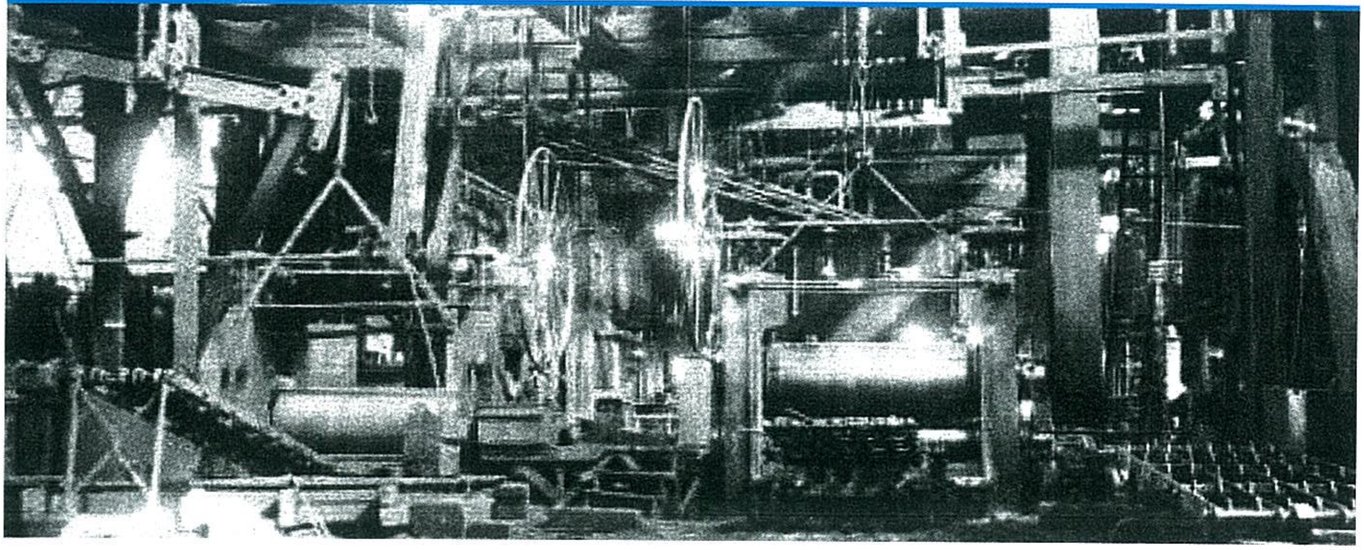
As steel became more popular, the iron works experienced broken rolls in the 84-inch mill due to its higher strength. An 84-inch, 3-high finishing stand was installed in 1880 next to the 2-high mill and was driven by the same steam engine (Figure 7). The 3-high mill was invented in 1857 at the rail mill of the Cambria Iron Works in Johnstown by John Fritz. A gifted engineer of legendary proportion, Fritz was born in 1822 less than 10 miles from the Brandywine Iron Works in Londonderry Township, Chester County.[38]

After the installation of the 3-high, the 2-high mill was used as a breakdown mill to rough the slab while it was still hot and relatively soft. A transfer table moved the piece over to the new 3-high mill, where the plate was finished to the ordered thickness. The greater stiffness of the 3-high mill allowed the plate to reach the final gauge before it lost valuable temperature. The gauge uniformity of the finished plate was also improved, since the roll wear was divided between the roughing mill and the finishing mill.[39] Since the same engine powered both mills, only one mill at a time could roll a plate. While one mill was in operation, the other sat idle, waiting for its turn to roll. However, the greater speed resulting from rolling in both directions on the 3-high finishing mill without reversing the steam engine increased the mill's capacity from 6,000 tons per year to 11,000 tons.[40,41]

Three developments occurred in the last two decades of the 19th century that changed the rolling mill landscape along the Brandywine. The first trend was a growing demand for steel boiler plate that had been reducing the market for iron plate. The second was an emerging preference for wider plates by boilermakers, who could reduce the number of riveted seams required to fabricate a vessel if wider plates were available. The rivets used to secure a seam could create a weak point and become a potential source of failure in a boiler. The preparation of the holes to accept the rivets and the actual process of riveting the seams also increased the amount of labor required to fabricate a boiler.

Some of the older, narrow, water-powered rolling mills could not make the transition to rolling wider steel plates and were eventually abandoned. Isaac Pennock's original enterprise, the Federal Slitting Mill, was destroyed by fire in May 1865.[42] The rolling mills at Hibernia, Hatfield and Laurel, financially weakened by the Panic of 1873, were abandoned in the late 1870s and early 1880s. The Thorndale Iron works managed to hold on until 1893, but then it too fell victim to the changing times. Meanwhile, the success of the stronger mills was

Figure 7



The steam-driven 84-inch 2-high mill (on left) and 84-inch 3-high mill (on right). Note the large flywheel on far right.

reflected in the rise in the number of men employed. In 1881, the Valley Iron Works (formerly Caln Iron Works), with four trains of rolls, employed 200 men. The Viaduct had 150 hands tending their four roll trains. One hundred men worked at the Lukens mill, with two trains of rolls — the muck rolls and the 84-inch mill with two stands. Thorndale employed 80–90 men.[43]

The third major development in the local industry was the emergence of the Worth brothers in the 1880s. They were the sons of a well-known ironmaster, Sheshbazzar B. Worth, who ran two of the local rolling mills with his partner, Hugh E. Steele. John Sharpless Worth and William Penn Worth established the Brandywine Rolling Mill in 1881. The new mill was put into operation in February 1882 with two trains of rolls — one set of 20-inch muck rolls for making bars 4 inches by 6 inches, and one 90-inch-wide plate train with 28-inch-diameter rolls.[41] They also had three double puddling furnaces for making puddled iron for muck bars, which were then used to roll plates. The Brandywine Rolling Mill started up with an annual capacity of 4,000 tons, but quickly grew to 6,000 tons by 1884.[44]

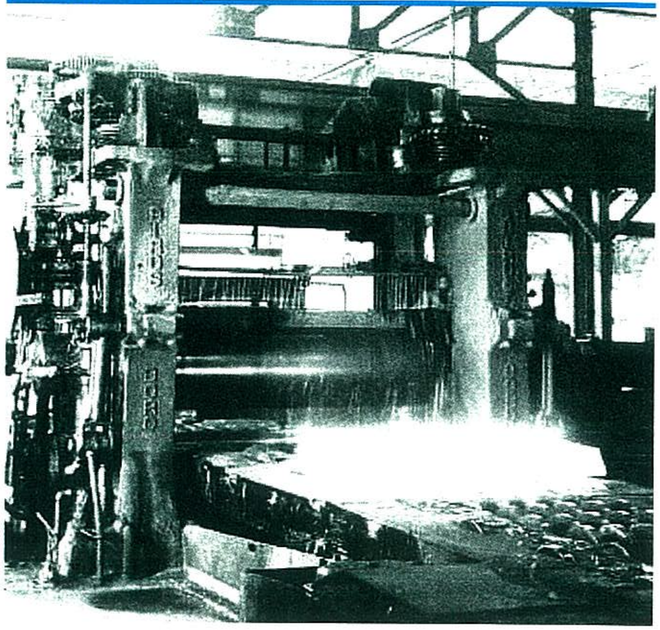
By 1890, the capacity of the five active mills remaining in Coatesville had increased by almost 50% from their 1880 output. The Viaduct Rolling Mill was producing 15,000 tons per year with four rolling mills. The Worth Brothers could produce 12,000 tons with their single 90-inch-wide mill at the Brandywine Rolling Mills. Lukens had a capacity of 11,000 tons with its 2-high and 3-high roll train. The Valley Iron Works was rebuilt in 1888 and was operating two 72-inch-wide mills, a 96-inch-wide and a 110-inch mill, with a total capacity of 11,000 tons per year. The Thorndale mill, struggling to survive in the changing market, remained at a capacity of 4,000 tons per year, unchanged since 1880.[45]

The Lukens Rolling Mill was poised to make bold changes that would propel the works past the other local mills. The firm was incorporated in 1890 as the Lukens Iron and Steel Co., with Dr. Huston as president, and his two sons, Abraham F. Huston and Charles L. Huston, running the company. Infused with new capital and ideas, a plan for growth was initiated that would take the company to the forefront of the plate industry.

The Largest Plate Mill in the United States

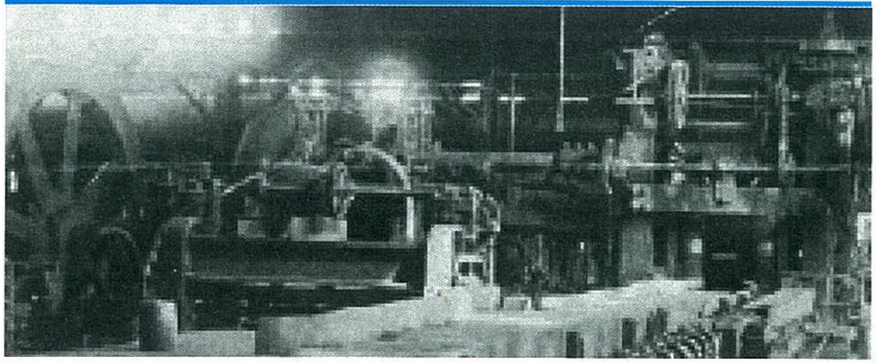
Lukens began construction of a new 3-high mill, designed to meet the demand for longer and wider plates, in 1889. The mill was built as an addition to the 84-inch mill, not as a replacement. The new Birdsboro mill had chilled iron rolls 34 inches in diameter and 120 inches long, and was the largest plate mill in the United States (Figure 8). The new mill was driven by a large Corliss steam engine and was equipped with automatic hydraulic lifting tables. It rolled its first plate on 2 July 1890 — on the 80th anniversary of the company's founding.[46]

Figure 8



The 120-inch 3-high mill built by Birdsboro in 1890.

Figure 9



A 48-inch universal plate mill with movable roller leveler in the off-line position.

The 120-inch mill was served by a hydraulic crane, which allowed a single man to draw ingots from the heating furnaces, set them on the feed tables and deliver them to the mill. Heating was provided by three gas furnaces with hearths 28 by 7 feet and one three-hole gas pit furnace. The finishing equipment included mechanical transfer cooling beds complete with hydraulic lifts for inspection of the bottom surfaces of plates. This new method of cooling on tables, rather than in piles, prevented the distortion often seen in the plates that was caused by uneven cooling, and resulted in much flatter plates. The plates were next transferred by mechanical devices to either large hydraulic or steam shears for trimming to the ordered size.

The new mill had a capacity of 40,000 tons per year, far outpacing any of the other Coatesville mills. With the added capacity, Lukens' share of plate production along the Brandywine jumped from 20% to more than 50%.

The installation of two 30-ton open hearth furnaces was completed in early 1892, and the first heat of steel produced in Coatesville was tapped on 25 February 1892. Lukens now had a source of steel ingots to feed the growing appetite of its hungry mills.

A Period of Rapid Expansion

Construction was started in 1899 on a 48-inch universal mill (Figure 9). The new 3-high steam-powered mill was put into operation in May 1900. In addition to the three horizontal rolls (28-inch-diameter top and bottom rolls, and a 21-inch-diameter middle), it had four 17 1/2-inch-diameter vertical edging rolls which rolled the plate edges to a uniform width along the entire length. These plates were ideal for use in the fabrication of long beams for bridges and buildings.

The universal mill was housed in a U-shaped building that was 400 feet long. One leg of the building contained four horizontal gas heating furnaces. The small ingots rolled on the mill were handled with an electric charging and drawing crane. Ingots were delivered on roller tables to the mill, which was located in the center portion of the three buildings. Here the ingots were rolled on the reversing mill to plates ranging in size from 1/8–1/4 inch thick, 8–42 inches wide, and up to 100 feet long. The plates left the mill on the last pass and were flattened by a 9-roll leveler. The leveler was designed with the bottom rolls in the table line. The top frame was positioned off-line until the last pass, so as not to interfere with the rolling process. Charles L. Huston received a patent in 1902 for his unique leveler design.[47] The 130-foot-wide building also contained a long runout table which transported the plates from the mill to a large cooling bed equipped with a mechanical transfer mechanism. After cooling, the plates were moved onto another set of roller tables and delivered to the electric powered shears for cutting to length. The rolled edges of universal plates allowed them to be used without shearing. The finished plate dropped from the shears onto yet another set of roller tables located at one end of the shipping building. The shipping bay was the third building in the universal mill complex. The plates were weighed before they were moved by a large overhead electric crane equipped with several trolleys. The multiple trolleys were designed to handle the 100-foot-long plates without bending or dropping them.[48] Often the plates were loaded directly onto rail cars for shipment.

Although narrow in size, the new universal mill was extremely productive and had an annual capacity of 75,000 tons. The extreme length of the universal plates precluded the manual handling typically used in plate mills. The mill was designed to allow mechanical devices to load and remove ingots at the heating furnaces, place them onto tables and continuously move them through the rolling, cooling and shearing process until they were ready for shipping. This design set the stage for the layout of the larger plate mills that would be built at Lukens in the future — mills constructed to meet the growing demand for thicker, wider and longer plates for boilers and shipbuilding.

Lukens entered the new century as one of the premier makers of plate steel in the country. For most of the 19th century, it had remained unremarkable as a member of a group of small Coatesville rolling mills producing similar products for the same markets. The most remarkable accomplishment was its ability to avoid financial trouble throughout the periodic recessions and economic downturns that created ownership changes and eventual closure of all but one of the other mills. Lukens emerged from the 19th century as the leader in the plate market.

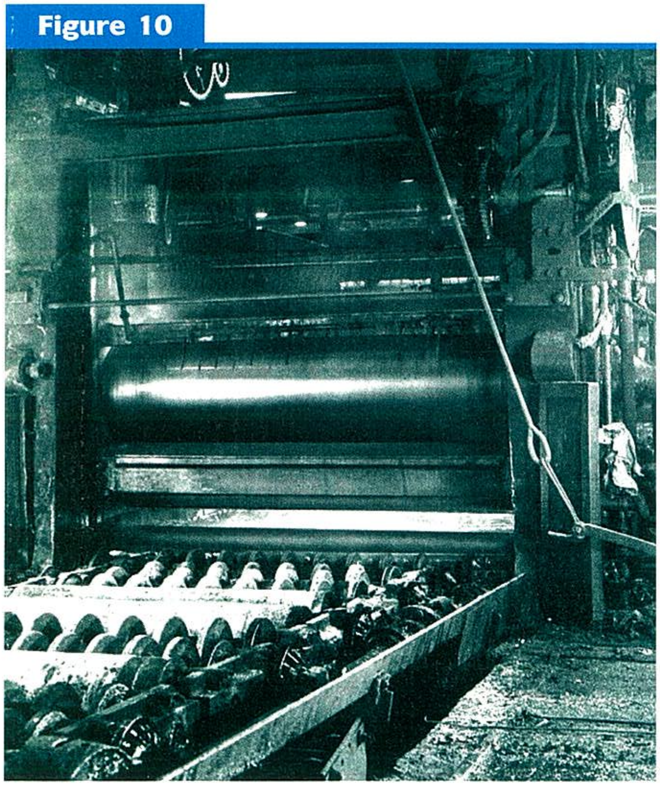
The New Century Brings New Mills

A large slabbing mill was built in 1901 and put into operation on 23 December of that year. It had rolls 34 inches in diameter and 108 inches long and reportedly was the largest slabbing mill in the country.[48] Ingots from the open hearth shops were heated in four soaking pits, each having three holes. The bottom poured ingots were rolled to slabs that ranged in size from massive pieces over 100 inches long, measuring 50 by 18 inches and weighing 30,000 pounds, down to 4-inch by 4-inch billets. Slabbing mills were used to prepare material for rolling on the finishing mills. Usually a manipulator was used to turn the ingots on their side so that all four sides could be rolled. Slabbing the ingots in a separate operation reduced the work necessary on the finishing mill, and increased total output of the plant. Slabbing also reduced the number of different ingot sizes needed to accommodate the range of finished plate sizes. The capacity of the slabbing mill was 300,000 tons per year, although the melting capacity of the plant was far less.

The Largest Plate Mill in the United States (Again)

The 120-inch, 3-high mill was the largest plate mill in the United States when it was built in 1890. However, in 1896 the Worth Brothers' Brandywine Rolling Mills, located adjacent to the Lukens facility, installed a 3-high mill that was 132 inches wide. Their new mill, with 36-inch-diameter rolls, was then recognized as the country's largest, and had an annual capacity of 40,000 tons of plates. The Huston brothers reacted to this development by widening the 120-inch mill in late 1900. The 34-inch-diameter rolls were replaced by larger rolls, 36 inches in diameter with a length of 134 inches — two inches wider than the Worth Brothers' mill. The middle roll had a diameter of 21 inches. The wider mill increased the plant's capacity from 60,000 tons per year to 100,000 tons, and once again it was proclaimed the largest plate mill in the country.

Figure 10



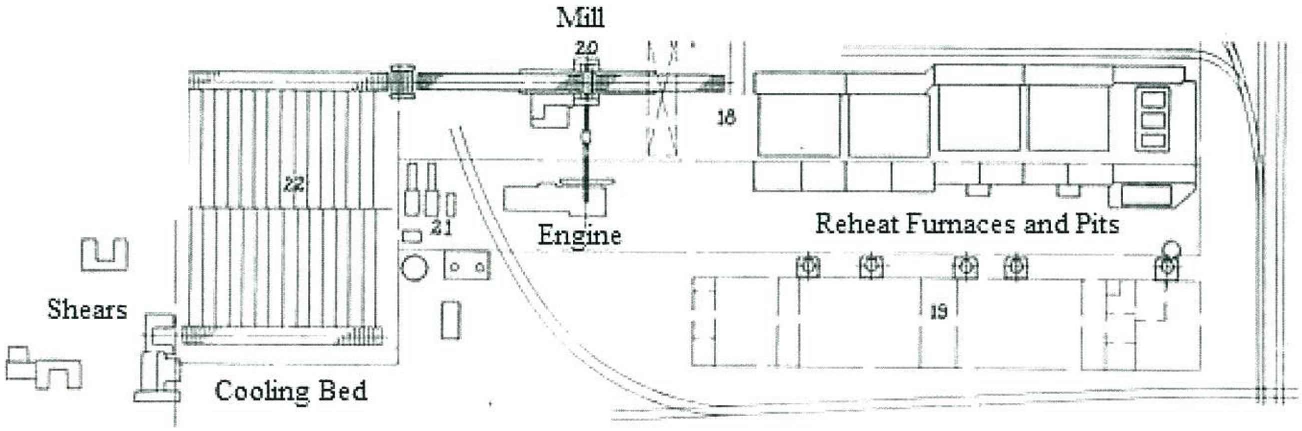
Garrison 140-inch 3-high mill.

In addition to widening the existing 3-high mill, plans were developed to add another new plate mill to roll even wider and thicker plates. Construction was started in 1901, and a new 3-high, 140-inch-wide mill began operations on 2 June 1903. The new mill, built by the A. Garrison Foundry in Pittsburgh, Pa., had two rolls 38 inches in diameter and a middle roll that was 22 inches in diameter (Figure 10). The middle roll was shifted from the lower to the upper position by two hydraulic cylinders located in a pit beneath the mill. The top and bottom rolls were driven by a 2,250 hp Corliss non-condensing steam engine with a flywheel. The engine was connected to the mill rolls by 18-inch-diameter spindles.[49]

Building on the design concepts employed in the universal mill, the new plate mill was designed with several goals in mind: to completely eliminate manual labor in the rolling process; to keep the plate moving continuously on tables or roller conveyors; and to produce the largest, flattest plates available in the country. To achieve these goals, the mill was designed with ample roller tables, a roller leveler, a large cooling bed and large trimming shears. The layout of the mill is shown in Figure 11.

Ingots were broken down on the slabbing mill and heated in three continuous heating furnaces that measured 9 feet wide by 50 feet long. Ingots that rolled direct to plates were heated in two large four-hole pit furnaces.

Figure 11



Layout of the 140-inch 3-high mill, circa 1946.

An electric overhead crane removed the heated material from the furnaces and placed it on an ingot transfer car, which conveyed it to the 54-foot-long approach tables. Dual drives were used with tapered rolls in the tilting tables on both sides of the mill to turn the piece for cross-rolling to width. After rolling, the plate was flattened on a 9-roll leveler that had 14-inch-diameter rolls. The plates were cooled on a chain-type bed 110 feet long and 90 feet wide. Hydraulically operated arms tilted the plate to allow inspection of the bottom surface.[49] A set of table rolls received the plate at the end of the cooling bed, where they were laid out for shearing. The cooling bed and layout area provided 11,000 square feet of plate cooling area. The rolls moved the plates to a 12-foot end-cut shear for trimming to length. Two additional 12-foot guillotine shears located in the shearing bay were used for side trimming, along with smaller shears and circle cutters to provide blanks for the flanging department. The annual capacity of the new 140-inch mill was 200,000 net tons per year, giving Lukens a total plant capacity of 380,000 net tons — almost double the output of the neighboring Worth Brothers' mill.[50]

With the large width capacity of the new mill and the mechanical equipment to handle heavy plates, the importance of the 134-foot, 3-high mill was somewhat diminished, and its role was subsequently changed. In 1904, the mill was rebuilt once again. The rolls were reduced in size to 112 inches long, while maintaining the 36-inch-diameter rolls. The large-diameter rolls allowed thin-gauge, wide plates to be rolled with minimal thickness variation across the width, resulting in very flat products.[51]

The 140-inch-wide mill did not hold the title of the country's largest plate mill for very long. While Lukens was building its new 140-inch mill, the owners of the neighboring Worth Brothers plant were busy planning their next move in the battle for the widest rolling mill. Just two months after the Huston brothers began rolling on their new mill, Worth Brothers commissioned a new 152-inch-wide plate mill.[46] Their new 3-high mill had 42-inch-diameter rolls for increased stiffness. The new mill was hailed as the country's widest, and once again the title had been passed from one neighbor to the other.

The World's Largest Plate Mill

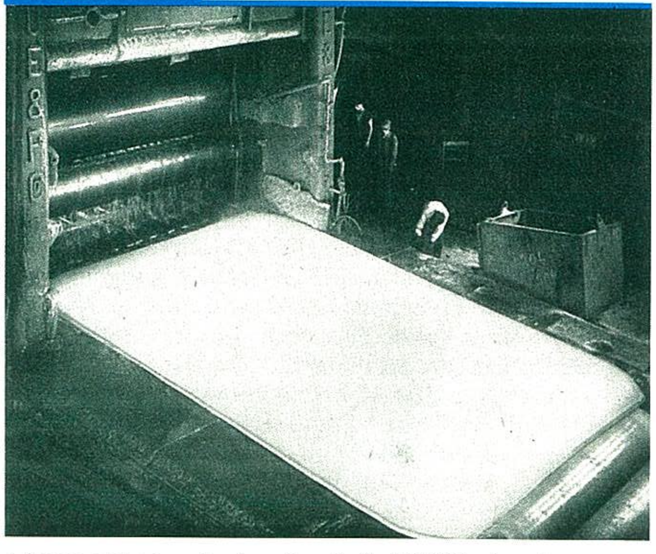
In 1918, Lukens Iron and Steel Co. established another first in the plate industry when the company installed the first 4-high plate mill in the world (Figure 12). The new mill was 17 feet wide, or a full 204 inches, exceeding the European mills by a wide margin. These included the 178-inch mill of the Witkowitz works in Austria and the 168-inch, 2-high mills in Britain. It also surpassed the two largest domestic rolling mills, which were the 152-inch mills of the Worth Brothers' works in Coatesville and the Otis Steel Co. in Cleveland, Ohio. The new mill rolled its first plate on 22 May 1918.

The company's original plans were to build a 180-inch, 3-high mill to reclaim the title of the widest plate mill in the world. However, none of the roll manufacturers could produce the required size and weight of the 50-inch-diameter chilled rolls necessary for the mill. An alternate 2-high design was considered, but the roll deflection would have resulted in excessive plate crown and precluded the production of thin plates with a uniform thickness profile. Engineers on the Lukens staff began collaborating in 1915 with the United Engineering & Foundry Co. (UE&F) of Pittsburgh on an idea to support the smaller work rolls of a 2-high mill with cast steel rolls in order to stiffen the mill. UE&F designed the mill with 34-inch-diameter work rolls, each weighing 30 tons, and 50-inch backup rolls that weighed 60 tons each.[52] The weight of the bottom backup roll was so great that it was feared that friction alone from the bottom work roll would not turn the backup when the mill was idling. A third spindle connected with a friction clutch was installed between the pinion stand and the bottom backup roll to turn the bottom backup roll.

The dimensions of the mill housing, almost 40 feet in height, also exceeded the size and weight that could be cast or machined in one piece. The steel housing was designed as a four-part fabrication — two side posts connected by a top bridge piece that contained the screw box and a bottom bridge piece containing the seat for the bottom roll. The rolls were driven by a 20,000 hp twin tandem compound steam engine built by the Mesta Machine Co. of Pittsburgh. Steam was provided by waste heat boilers in the open hearth meltshop and the reheating furnaces.[53]

Several other special features were also designed for this unique mill. The work rolls were changed with the help of a buggy that was inserted into the housing below the bottom work roll, after the work rolls were lifted by the top roll balancing cylinder. The buggy removed the rolls, which could then be lifted by the overhead crane. Ample table rolls were installed to receive ingots and slabs from the soaking pits or transferred from the 140-inch mill and transport them to the mill rolls. A hydraulic ingot tilter rotated heavy ingots from the vertical position to lie horizontally on the tables in a controlled fashion without damaging the table rolls. Runout tables

Figure 12



A large plate is rolled on the United 206-inch mill.

on the mill delivery side moved the plates to a mammoth set of electrically powered straightening rolls built by Hilles and Jones of Wilmington, Del.[53]

Plates left the straightener and cooled on a massive chain-driven cooling bed measuring 180 feet long and 90 feet wide, which provided more than 16,000 square feet of cooling space.[49] The bed was divided into three separate sections to handle plates up to 35 feet long, 70 feet long or 90 feet long. A tilting device with hydraulic cylinders was included in the cooling bed for bottom inspection of plates up to 192 inches wide. After crossing the cooling bed, the plates moved onto the shear runout tables, located in the shearing building. Here the plates were transported on roller tables to the end cut shear. The hydraulically operated shear had a 210-inch-wide opening, large enough to accommodate the widest plate rolled.[53] Side shears, also 210 inches in length, trimmed the plate to the ordered width. Specially designed tables were installed between the end cut and side shears to handle the extreme dimensions of the long and wide plates coming from the mill. Prior to the design of these tables, caster rollers were used to manually move plates around in front of the shears. Another set of transfer chains moved the cut plate into the shipping building for weighing and loading.

The large expanses of approach tables, runout tables, cooling beds, shear tables and transfer tables eliminated the manual labor previously required to move plates in the mill area and around the shears. Mechanical movements allowed wider, longer and heavier plates to be produced. The heaviest plate that the 140-inch, 3-high mill could handle was 25,000 pounds.[54] That limit was more than tripled, as the 204-inch mill was designed to handle ingots weighing up to 90,000 pounds.[55] The mill was widened to 206 inches in 1919.

A New 84-Inch Tandem Mill

The old 84-inch, steam-powered, nonreversing mill was replaced in 1927 with a modern electric-powered 84-inch tandem mill. This was the first new mill installed with an electric motor. However, experience with motor driven rolls was gained in 1925 when the 112-inch mill was electrified.[56] The old Corliss steam engine installed with the mill in 1890 was replaced by a Westinghouse 3,750 hp electric motor, operating at 2,200 volts and 500 rpm. The electric motor developed an operating torque of 39,300 foot-pounds and a maximum torque of 98,250 foot pounds.[49]

The new facility was installed in the building that originally housed the 34 by 108-inch slabbing mill built in 1901. The layout included an 84-inch, 2-high roughing stand with 34-inch-diameter rolls, and an 84-inch, 4-high finishing stand. The work rolls in the finishing mill were 23 inches in diameter and the backup rolls were 40 inches in diameter. The layout of the mill, conceived jointly by United Engineering and Lukens, was designed to remove slabs from the heating furnaces and continuously move them through the rolling process until they were ready for shipment. To accomplish this goal, the mill was filled with transfer tables, conveyors, cooling beds, shears and auxiliary equipment, which minimized the storage space required to hold in-process material. The mill was designed to produce light-gauge plates down to $^{1}/_{8}$-inch thick and up to 72 inches wide, in lengths up to 420 inches, with weights as light as 1,000 pounds or up to two tons.[57]

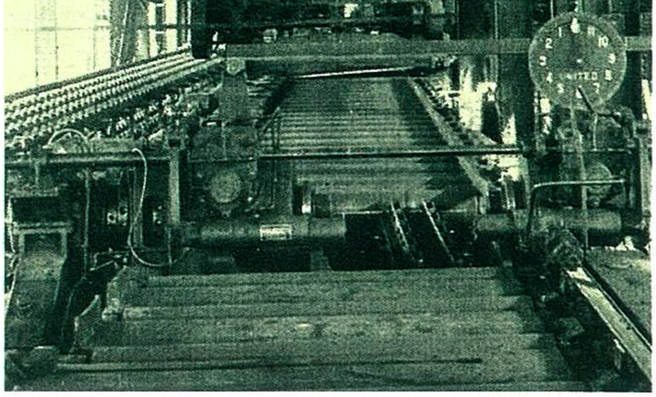
Slabs were heated in two furnaces measuring 15 by 9 feet that had a capacity of only 4 $^{1}/_{2}$ tons per hour, permitting the rolling of about 10 slabs per hour. The furnace doors were electrically controlled from the crane operator's cab, eliminating the job of the doorman.

The mills were also designed with several new features never installed on prior mills. Both the roughing and finishing stands were equipped with differential screwdown control to allow the operator to level the mill. They also had a quick roll changing rig to change rolls faster and safer. The 4-high mill had 40-inch-diameter backup rolls equipped with roller bearings instead of bronze bearings — a first for plate mills. It was said that the roller bearings "promise to have far reaching advantages in that they are expected to reduce greatly the power required for rolling and to eliminate the heat caused by neck friction where bronze bearings are used."[58] A General Electric motor drove each mill through a pinion stand, utilizing the largest flexible couplings ever built.

Plates left the mill after rolling, were taken across a transfer bed and were flattened on a 17-roll roller leveler built by the R.S. Newbold and Son Co. of Norristown, Pa. The plate traveled down a long cooling conveyor to an inspection turnover, and was then transferred to roller tables that conveyed the plate back toward the mill. The sides of the plates were trimmed to width using newly designed rotary side trimmers developed by United (Figure 13). The side scrap was cut into "short charging box lengths"[58] for the open hearth furnaces. A Newbold end shear cut the pattern to length using a specially designed gauge which eliminated manual layout of the plate. Scrap from both shears was taken by conveyor to charging boxes outside of the building. The plate, cut to ordered size, was moved across a third transfer bed into the shipping bay.

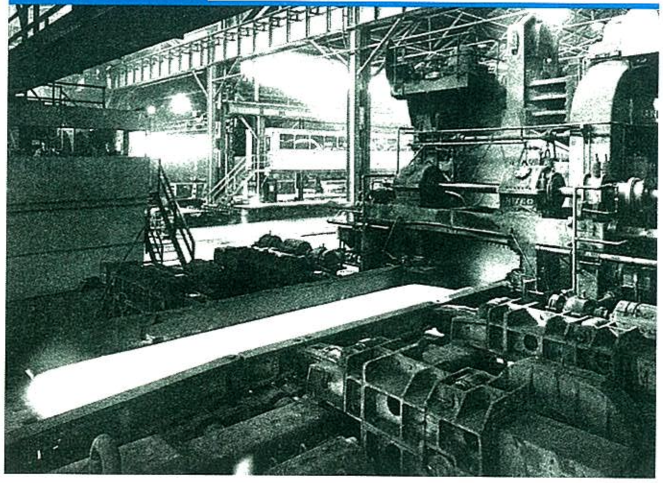
An annealing furnace was installed in-line, after the first transfer bed, to heat treat plates directly from the mill. The continuous furnace was provided for the

Figure 13



Rotary side trimming shears in the 84-inch tandem mill.

Figure 14



United 120-inch 4-high mill.

production of blue annealed or deep drawing stock, and measured 8 feet wide by 40 feet long. The furnace used newly designed alloy rolls that could operate at 1,900°F, and did not require water cooling. Each roll had four disks that prevented the plate from contacting the roll shaft and promoted uniform heating of the bottom surface. The roll bearings were placed outside of the furnace to prevent overheating. Upon exiting the furnace, the plates moved through the leveler, down the cooling tables and were processed in the manner described above.

With the installation of the new 84-inch tandem plate mill, Lukens was now operating five mills: the 84-inch tandem plate mill, the 206-inch 4-high steam mill, the 140-inch 3-high steam mill, the 48-inch 3-high universal steam mill and the 112-inch 3-high motor-driven mill. Each one of the rolling mills was equipped with a roller leveler to flatten the plates before they had a chance to cool.[56,58]

A New Mill for the War Effort

The 84-inch mill provided excellent capability for the production of light-gauge plates up to 72 inches wide, but the outbreak of World War II suddenly created an enormous demand for wider plates. A new 120-inch 4-high plate mill was built during World War II to roll light-gauge wide plates for navy ships (Figure 14). The mill was financed by the United States Navy and placed into operation in October 1943. It was built around the existing 112-inch mill in a layout that utilized the old 3-high as a roughing mill. The new mill had 36-inch-diameter work rolls that were supported by 54-inch-diameter backup rolls. The rolls were powered by a single 7,000 hp electric DC motor. At the time of the mill's construction, there were five 4-high plate mills in the country, and Lukens had three of them — the original 206-inch mill, the 84-inch finishing mill and the new 120-inch mill.[59]

A unique feature of the new mill was automatic control of the mill screws, edger position and sideguards. Under this control, the rolling schedule was set up on a switchboard by plugging cords into holes marked with the desired mill opening. It was possible to set up a rolling schedule with as many as 21 passes on the board. Two complete sets of plugs allowed one schedule to be set up while the other was being rolled. Changing from one schedule to the other required only the screwman to operate a small desk-mounted pistol grip control switch.[49]

The layout of the mill followed the same general plan as the 84-inch mill, with the goal to remove ingots or slabs from the heating furnaces or pits, place the piece on table rolls and not handle the piece until it was rolled, cut to size, leveled, marked, inspected and ready to ship. The main difference was a large increase in the scale of the facilities, designed to handle a much greater flow of plates. The mill featured a continuous production line that was more than 2,000 feet long, from the mill approach tables to the final shear tables.[60] The capacity of the new rolling mill was 300,000 tons per year, and complemented the 360,000 tons of the 140/206 mill complex, which transitioned to a focus on heavier-gauge plates. Eventually the large cooling beds and massive shears in the bigger mills were removed to make room for gas cutting facilities. The development of flame cutting enabled the trimming of plates thicker than 2 inches — gauges that could not be sheared with even the largest equipment.

The steam-driven universal mill and the motor-driven 84-inch tandem mill, each with a capacity of 84,000 tons per year, gave the plant a total capacity of 828,000 tons per year. The modern 120-inch mill replicated much of the capabilities of the older 84-inch tandem mill, and led to the decommissioning of the 84-inch mill in January 1945. The shutdown of the universal mill soon followed, after nearly 50 years of operation. It produced light-gauge, wide, long plates for beams, a market that could be supplied directly by beam mills. Rolled beams were final products and did not need welding like beams made from universal plates. The remaining mills were upgraded as needed. The 140-inch mill was converted from steam to electric after World War II. The 2,250 hp steam engine was replaced with a single 4,000 hp DC motor in 1949. The 206-inch mill was electrified in April 1950 with the installation of two 4,000 hp DC motors.[61]

A Slabbing Mill for Alloy Ingots

The original slabbing mill built in 1901 was shut down and replaced by the 84-inch tandem plate mill in 1927. After the closing of the slabbing mill, ingots were usually rolled direct to plate, avoiding the intermediate steps of slabbing, conditioning, trimming and reheating. A range of ingots weighing from 1,000 pounds to more than 67 tons were used to supply the large spectrum of plates rolled in the 112/120 mill or the 140/206 complex.[57]

During the Korean War, the nation geared up to produce armor plate at levels that had not been seen since World War II. The alloy ingots proved difficult to roll direct, and the 206-inch, 4-high mill was used to slab ingots because of its ability to handle larger piece weights than the 140-inch, 3-high mill. As Lukens transitioned from a supplier of high-quality carbon steel to a producer of alloy plate, slabbing on the 206-inch mill increased from 10% of available production time to

40%.[54] Valuable capacity for producing finished plate tonnage was lost.

A new 4-high combination roughing and slabbing mill (Figure 15) was installed in 1959 to relieve the load on the 206-inch mill and increase finished plate tonnage. Ingots could be slabbed on the new Mesta 140-inch mill and conditioned, or could be broken down and transferred directly to the 206-inch mill. Ingots could also be rolled directly to heavy-gauge plates. The mill could handle ingots weighing up to 60,000 pounds, compared to the 25,000-pound limit of the 140-inch, 3-high mill. The mill rolled its first ingot in April 1959.

The new mill had the largest housings in North America, rated at 6,000 tons of separating force. The 39-inch-diameter work rolls were each driven by a 5,000 hp DC motor and supported by 59 $^1/_4$-inch diameter backup rolls. Load cells provided protection from force overloads. A powerful detached edging stand was equipped with vertical rolls 37 $^1/_4$-inch in diameter that were driven by a single 3,000 hp DC motor. The vertical mill was designed to produce uniform width on ingots, reduce edge cracking on alloy material, and break up surface scale during edging. Additional heating capacity was provided by 12 new soaking pits, each rated at 200 tons each, and serviced by a 75-ton stiff leg crane.

The old 140-inch, 3-high mill operated for several years after the new mill came on-line. Eventually it was shut down after more than 60 years of operation. In 1967, the 140-inch, 4-high mill was expanded to serve as a finishing mill, and a hot leveler, a heavy-gauge walking beam cooling bed, a dividing shear and two light-gauge cooling beds were installed. Three additional soaking pits were also added.

Today, the 140-inch mill is the workhorse of the Coatesville facility. The 206-inch mill still operates, 93 years after rolling its first plate. It is pressed into service whenever a customer requires extremely wide or heavy plates that cannot be made on any other mill in North America.

In 1979, the 110-inch mill of the former Alan Wood Steel Co. in Conshohocken, Pa., was purchased. The facility was revamped and restarted in 1980. This mill included a 4-high reversing roughing mill and a 4-high nonreversing stand. During the economic downturn that occurred in the steel industry in the mid-1980s, the 112/120 mill complex was shut down. The mills sat idle for more than eight years. The 120-inch mill housings were removed in 1994 and refurbished for the Steckel Mill project at the Conshohocken plant. The 110-inch nonreversing mill was removed and replaced with the 120-inch mill housings, which were fitted with coiling furnaces, and the reborn mill rolled its first coil on 22 August 1995. Its former partner, the 112-inch, 3-high mill, has managed to survive — 121 years after rolling its first plate on the company's 80th anniversary (Figure 16). It still stands as a symbol of the rolling heritage that grew and matured along the flowing waters of the Brandywine.

Summary

Two centuries have passed since the Brandywine Iron Works and Nail Factory first opened its head race and let the power of the Brandywine turn the water wheel that rolled the first iron in Coatesville. Water power was replaced by steam, and then by electricity as rolling mills grew in size and complexity.

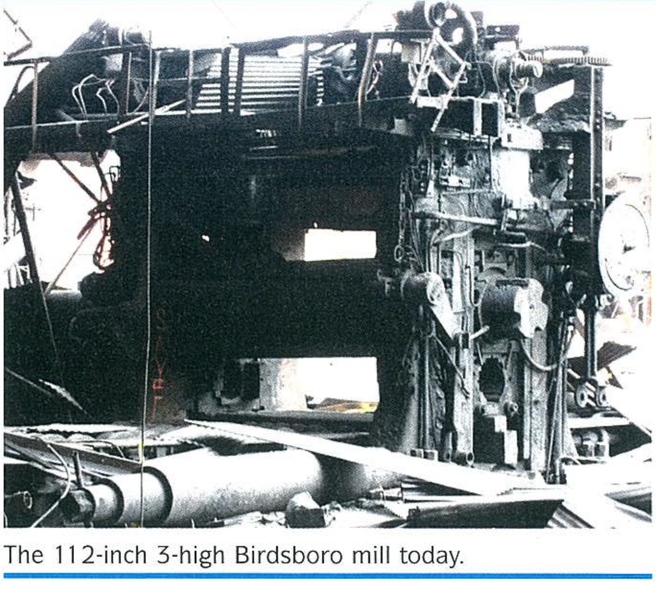
The journey from 1810 to 2010 has spanned 200 years — through periods of war and peace, panic and prosperity, expansion and innovation. It is a remarkable achievement for one plant to have survived and prospered, while others withered and became footnotes in the recording of its history.

It is a story of remarkable men and women, of prudent and conservative decisions made when the business climate warranted, and of visionary and risky investments that propelled the company to a leadership position in the plate industry. Many innovations in rolling

Figure 15

Mesta 140-inch 4-high and vertical edging mill.

Figure 16



The 112-inch 3-high Birdsboro mill today.

were introduced in the mills of Coatesville, including the first boiler plate rolled in America; the largest plate mills in the country, and then the world; the first 4-high plate mill in the world; the first differential screwdown; the first roller bearings for backup rolls; the first rotary side shears; and several groundbreaking designs in quick work roll changing, roller levelers, shears, transfer and cooling beds, and inspection turnovers.

The story continues today — the ending not yet written. New chapters will be added and new plots will emerge. But the theme will remain true to the legacy of the founders: the rolling of quality plate on the banks of the Brandywine in the rolling hills of southeastern Pennsylvania by men and women dedicated to the industry.

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