

Timeline of Casting Technology

With a history set in motion before the dawn of man, metalcasting was the very cornerstone of humankind's emergence from the Dark Ages and its continued prosperity today.

Michael J. Lessiter, Editor/Publisher
Ezra L. Kotzin, American Foundry Society (retired)

Since the discovery of the earth's minerals, metalcasting has played an important role in society. An integral part of every technological advance, castings have allowed us to build equipment to feed our people, fight for democracy, build infrastructure and manufacture cars, trains and airplanes. In general, castings have been—and will continue to be—the key ingredient in the recipe for a better way of life.

Metalcasters have long been respected and eminent craftsmen in every community. In many cases, their heroics extended far beyond the utilization of molten metal in creating usable products. They have been soldiers, statesmen and inventors—and have reshaped North America with a first-class, working labor force that produces goods for the world. In fact, the conception of the U.S.—not to mention the spread of democracy worldwide—was set into motion by seven foundrymen who signed the Declaration of Independence from Great Britain in 1776.

During the wars of medieval times, foundrymen produced cannons. In peace, they recast the metal back into bells. In the early Middle Ages, church bells were cast in churches by priests, abbots or bishops who were also trained metal founders. As the metal was melted, the brethren stood around the furnace intoning psalms and prayers. The molten metal was then blessed and divine protection was asked for the bell, which usually bore the name of a saint.

The 20th century saw the explosive refinement of processes and materials used in the foundry for more than 400 years. Vannoccio Biringuccio, the 16th century “father of the foundry industry,” recommended using the dregs of beer vats and human urine as binders for molding sand, both of

which were in use well into the 1900s.

“There has been more casting progress since World War II than in the previous 3000 years,” wrote Bruce L. Simpson in *History of the Metalcasting Industry*. “Still, the demand goes on for foundries to surpass themselves in quantity and quality. Metalcasting remains a basically essential industry, as necessary to space vehicles as it was to mankind's very first machines. As science is applied more and more, so the skill, education and pay of foundrymen goes up and ever up, increasing in turn the total wealth of the world.”

There is no better example of the true creation of national wealth than the work of the foundryman. He takes a raw material and through both art and science, creates a product that adds direct value to our society's ever-progressing way of life.

Beyond the fact that castings are all around us (it is often said one is never more than 10 ft from a casting), metalcasting was ecologically friendly long before it was in vogue. Known as the “original recycler,” the foundry industry gives a new useful life to as many as 15 million tons of scrap metal each year that would otherwise be rendered useless.

From its contributions in providing jobs and employee skills to delivering the dependable, high-quality and cost-effective components necessary to advance technology, metalcasting has impacted virtually every improvement seen by each passing generation. Simply put, our world could not have advanced at its rapid rate without the strength, endurance and ingenuity of the foundryman.

Following are some of the key technological events that have changed the face of the casting process and its end products.

Our world could not have advanced at its rapid rate without the strength, endurance and ingenuity of the foundryman.

B.C.

9000 B.C.—Earliest metal objects of wrought native copper are produced in the Near East.

3000-2500 B.C.—Small objects are cast via lost wax (investment casting) process in the Near East.

3200 B.C.—The oldest casting in existence, a copper frog, is cast in Mesopotamia.

3000 B.C.—Early foundrymen cast bronze tools and weapons in permanent stone molds.

1500 B.C.—Wrought iron is discovered in the Near East.

600 B.C.—The first cast iron object, a 600-lb tripod, is cast by the Chinese.

233 B.C.—Iron plowshares are cast.

200 B.C.—Oldest iron castings still in existence are produced during the Han Dynasty.

A.C.

500—Cast crucible steel is produced in India.

1200s—Loam or sweep molding is used by European foundrymen to cast bells for cathedrals.

1252—The colossal statute, the Great Buddha at Kamakura, Japan, is cast in high-lead tin bronze. The project began in the 700s and its head alone weighed 140 tons.

1313—The first cannon is cast in bronze by a monk in the city of Ghent.

1400s—During the siege of Constantinople, heavy guns are cast from bronze “on the spot,” virtually under the walls of the besieged city... Movable, cast lead type for printing presses revolutionizes the world's methods of communication.



Discovery of molten metal (copper beads in fire)

1480—Vannoccio Biringuccio (1480-1539), the first true foundryman and the “father of the foundry industry,” is born. The founder of the Vatican, his *De La Pirotechnia* is the first written account of proper foundry practice.

1500s—Sand is introduced as a molding material in France.

1600s

1612—Mined from under the sea, sea coal is mentioned for the first time by German foundryman and inventor, Simon Sturtevant.

1619—North America's first iron furnace is built at Falling Creek, VA, a branch of the James River, 60 miles from Jamestown colony. Three years later, Native Americans destroy it during a raid.

1645—Earliest recorded use of term “foundry” appears in the Oxford English Dictionary in its variant “founderie.”

1646—America's first iron foundry (and second industrial plant), Saugus Iron Works,

near Boston, pours the first American casting, the Saugus pot. The Saugus River site was selected by Richard Leader and was built to produce iron products for Massachusetts and England.

1661—First U.S. copper deposits are discovered by Gov. Winthrop in Middletown, CT.

1700s

1709—Two developments by Abraham Darby, Coalbrookdale, England, improve casting methods. He developed the first true foundry flask to modernize molding practices (which had been carried out in pits on the floor by use of pattern boards tied together or in crude box frames). He would later initiate the use of coke as a furnace fuel for iron production.

1722—A.F. de Reamur, recognized as the world's first metallurgical chemist, develops first malleable iron, known today as European Whiteheart malleable.

1750—Benjamin Huntsman reinvents the cast crucible steel process in England, a process that disappeared after first being developed in India...The English parliament prohibits the refining of pig iron or the casting of iron in the American colonies, contributing to the American Revolution.

1756—Coalbrookdale's Richard Reynolds oversees the invention of cast iron tram-road rails, replacing wooden rails.

1775—Revolutionary patriot Paul Revere, who operated a bell-and-fittings foundry in Boston, rides from Boston to Lexington warning colonists of the British invasion.

1776—Foundrymen Charles Carroll, James Smith, George Taylor, James Wilson, George Ross, Philip Livingston and Stephen Hopkins sign the American Declaration of Independence.

1779—First iron bridge ever erected (above England's Severn River) was cast and constructed at Coalbrookdale Works.

1794—Englishman John Wilkinson invents the first metal-clad cupola furnace, using a steam engine to provide the air blast.

1797—First cast plow in U.S. is invented by Charles Newbold, Sauk, NJ.

1800s

1809—Centrifugal casting is developed by A.G. Eckhardt of Soho, England.

1815—Cupola is introduced to the U.S. (Baltimore).

1817—First iron water line in the U.S., 400 ft long, is laid in Philadelphia.

1818—First U.S. cast steel is produced by the crucible process at historic Valley Forge Foundry.

1825—Aluminum, the most abundant metal in the earth's crust, is isolated from aluminum chloride by Denmark's Hans Oerstad.

1830s—Seth Boyden, Newark, NJ, produces U.S.' first blackheart malleable iron.

1837—First reliable molding machine on market is made and used by S. Jarvis Adams Co., Pittsburgh.

1832—Nickel-bronze is produced commercially in England.

1847—Cast steel guns are made by Krupp Works in Germany...Asa Whitney, Philadelphia, obtains a patent on a process for annealing chilled-iron car wheels cast with chilled tread and flange.

1847—John Deere commissions Jones and Quiggs Steel Works, Pittsburgh, to cast and roll a steel plow, which it accomplishes at one-half the product's previous cost.

1849—A manually operated diecasting machine is patented to supply rapidly cast lead type for newspapers.

1850—The drop-bottom cupola is developed.

1863—Metallography is developed by Henry C. Sorby, Sheffield, England, enabling foundrymen to polish, etch and microscopically examine metal surfaces for physical analysis.

1867—James Nasmyth, inventor of the steam hammer, develops a gear-tilted safety ladle to prevent pouring accidents.

1870—Sandblasting is developed for large castings by R.E. Tilghman of Philadelphia.

1874—The Colliau cupola, the first commercially made cupola in America, is introduced.

1876—The first authenticated aluminum castings were produced by Colonel William Frishmuth at his Philadelphia foundry. Assembled to produce an engineer's transit, these castings were made from \$1/oz chemically produced aluminum...Manganese-bronze patent is granted to Parsons in England. Tobin Bronze develops manganese-bronze in U.S.

1880-87—W.W. Sly, Cleveland, develops the first casting cleaning mill, greatly reducing hand-chipping and grinding to allow a custom-finished product.

1884—The first architectural application of aluminum, a cast aluminum pyramid produced by Col. William

Frishmuth, is mounted on the tip of the Washington Monument.

1886—Charles M. Hall, a 22-year-old student at Oberlin College, discovers a process of aluminum reduction through electrolysis. The invention replaced chemical reduction and lowered the metal's cost (from \$15/lb in 1884 to \$0.50/lb in 1890), spurring a new industry of aluminum applications.

1887—Eli Millett invents a core oven for drying small cores in individual drawers.

1890—The first motor-driven mold conveyor is installed, integrating molding, pouring and cooling operations.

1897—Iowa dentist B.F. Philbrook adapts the lost-wax investment casting process for producing dental inlays, the process' first non-art application of the modern metalcasting age.

1898—Poulson and Hargraves (U.K.) produce the first sand molds bonded with sodium silicate...Germany's Imperial Navy recommends copper-nickel alloys containing 4-45% Ni for salt-water piping system.

1899—Electric arc furnace, developed by France's Paul Heroult, begins commercial production.

1900s

1900—Brinell hardness test machines are introduced...Aluminum-bronze begins regular production in the U.S.

Early 1900s—First patent for low-pressure permanent mold casting process is issued to England's E.H. Lake.

1901—American Steel Foundries (St. Louis) produces the first centrifugal cast rail wheels.

1903—The Wright Brothers' first successful machine-powered aircraft contains a cast aluminum block and crankcase (together weighing 152 lb), produced either at Miami Brass Foundry or the Buckeye Iron and Brass Works.

1905—H.H. Doehler patents the diecasting machine.

1906—The first electric arc furnace is installed in U.S. at Halcomb Steel Co., Syracuse, NY... First low-frequency induction furnace is installed at Henry Diston & Sons, Tacony, PA.

1907—Alfred Wilm discovers that the properties of cast aluminum alloys can be enhanced through heat treating and artificial aging.

1908—Stockham Homogenous Sand Mixer Co., Piqua and Newark, OH, releases the sand cutter.

1910s

1910—Matchplates are developed, fostering



Early iron foundry



Cast copper frog, 3200 B.C.



Saugus pot, 1642

the viability of jolt-squeeze machines.

1911—Metallurgical microscope is obtainable... First electric arc furnace for metalcasting is installed at Treadwell Engineering, Co., Easton, PA.

1912—The first muller with individually mounted revolving mullers of varying weights is marketed by Peter L. Simpson... Sand slinger is invented by E.O. Beardsley & W.F. Piper, Oregon Works.

1915—Experimentation begins with bentonite, a colloidal clay of unusually high green and dry strength... Ajax Metal Co., Philadelphia, installs first low-frequency induction furnace for nonferrous melting.

1916—Dr. Edwin Northrup, Princeton Univ., invents the coreless induction furnace.

1917—Alcoa completes a great deal of early development work in aluminum as World War I generates great demand for high-integrity castings for aircraft engines.

1918—The first fully automated foundry in Rockford, IL, casts hand grenade hulks for the U.S. Army.

1920s

1921—Modification of the silicon structure in aluminum begins as Pacz discovers that adding metallic sodium to molten aluminum just prior to pouring greatly improves ductility... Copper-silicon alloys are prepared in Germany as a substitute for tin bronzes.

1924—Henry Ford sets "production record" of 1 million autos in 132 working days. Automotive manufacturing will grow to consume one-third of casting demand in the U.S.

1925—X-ray radiography is established as a tool for checking casting quality. By 1940, all military aircraft castings require x-ray inspection prior to acceptance... American Brass, Waterbury, CT, installs first medium-frequency induction furnace in the U.S.

1928—Alcoa develops the first aluminum vehicle wheel, a sand-cast 355 alloy designed for truck trailers.

1930s

1930—First high-frequency coreless electric induction furnace is installed at Lebanon Steel Foundry, Lebanon, PA... Spectrography is pioneered by Univ. of MI professors for metal analysis... Davenport and Bain develop the austempering process for iron castings.

1937—ARL founder Maurice Hasler produces the first grating spectrograph for the Geological Survey of California. Spectrometers begin finding their way into foundries by the late 1940s, replacing the previous practice of metallurgists estimating chemical compositions with

a spectroscope and welder's arc... The austempered microstructure in cast iron is recognized.

1940s

1940—Chvorinov develops the relationship between solidification time and casting geometry.

Early 1940s—Statistical process control is first employed as a quality control tool in U.S. machine shops, principally to control dimensional tolerances... Inoculation of gray iron becomes common, as high quality cast irons replace scarce steel.

1941—U.S. Lt. Col. W.C. Bliss tells the AFS St. Louis Chapter that "the side which maintains the larger production of war goods is going to win the war." The War Production Board reports later that each U.S. soldier requires 4900 lb of steel compared to 90 lb in World War I.

1942—The use of synthetic sands increases as a replacement for many war materials.

1943—Keith Millis, a 28-year-old metallurgist working at INCO searching for a replacement to chrome due to interrupted supply, discovers that magnesium alloy in molten iron produces a spheroidal graphite structure. In 1949, he, Albert Gagnebin and Norman Pilling would receive a U.S. patent on ductile iron production via magnesium treatment.

1944—The first heat-reactive, chemically-cured binder is developed by Germany's Johannes Croning to rapidly produce mortar and artillery shells for Axis troops during World War II. Two years after the war, his shell process is discovered among other inventions in the German patent office and made public. Croning is recognized with an AFS Gold Medal in 1957 for his invention.

1946—Allied investigators uncover German foundry research on high temperature alloys... Having 'heard' of the Croning discovery (prior to the release of the report), Ford's Ed Ensign and E.I. Valyi, Navy Bureau of Ships, attempted to replicate the process and produced shell-molded castings at Midwest Foundry, Coldwater, MI.

Late 1940s—Thermal sand reclamation is applied to core sands and, to

a limited degree, clay-bonded sands.

1948—First non-laboratory ductile iron casting is produced at Jamestown Malleable Iron Co., Jamestown, NY, as a 66-in. test bar is poured... Industry's first ductile iron pipe is cast at Lynchburg Foundry, Lynchburg, VA.

1949—Keel blocks, diesel engine parts, a pressure cylinder, an 8-in. cube and two cylinder liners become ductile iron's first commercial castings at Cooper-Bessemer, Grove City, PA... Development of magnesium-ferrosilicon makes ductile iron treatment far easier... Buffalo Pipe & Foundry Co., Tonawanda, NY, is the first U.S. operation to pour castings using Croning's shell process.

1950s

Early 1950s—Experimentation in high-pressure molding begins, as foundrymen begin to increase the air pressure in air squeeze molding machines to increase mold hardness (density)... Fast-drying core oils are introduced... The pneumatic scrubber is developed to reclaim clay-bonded sands. Several wet reclamation systems are also in operation.

1951—Ford Motor Co. converts 100% of its crankshaft production to ductile iron.

1952—D Process is developed for making shell molds with fine sand and fast dry oil by Harry Dietert... Sodium-silicate/CO₂ system is introduced.

1953—Hotbox system of making and curing cores in one operation is developed, eliminating the need for dielectric drying ovens.

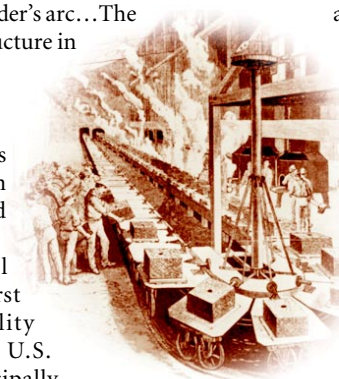
1954—The CO₂ process, a novel mold and coremaking process, is introduced from Germany... Working closely with General Motors, B&P develops a method for coating individual sand particles with resin binder. It also introduces a coreblower capable of producing cores with resin-coated shell sand—a modification to the Croning process.

1955—People's Gas of Chicago is the first to install ductile iron gas mains.

Mid-1950s—Squeeze casting process originates in Russia.

1956—First Betatron is installed in U.S. foundry at ESCO Corp., Portland, OR, for radiography of heavy steel castings.

1957—The vertically-parted flaskless green sand molding machine is invented by



Foundry conveyor, 1890



Signers of Declaration of Independence, 1776



Lost Foam Pattern, 1950s

Vagn Aage Jeppesen, a 40-year-old professor at the Technical University of Denmark. He was granted a patent in 1959, which was purchased by Dansk Industri Syndikat in 1961.

1958—Harold F. Shroyer obtains a patent for the full mold process, a process developed by artists in which simple patterns and gating systems are carved from expanded polystyrene and placed into a green sand mold. The process, known today as lost foam casting (using loose, unbonded sand), is patented a short time later...Phenolic and furan acid-catalyzed nobake binder systems are introduced...Ductile iron desulfurization via shaking ladles is developed in Sweden.

1959—General Electric utilizes the Transient Heat Transfer digital computer program and successfully applies the finite difference method to heavy steel casting production.

1960s

1960—Furan hotbox binders are developed for core production...Deep bed filters are used commercially for aluminum casting at Alcoa and British Aluminum in the U.K...Compactibility and methylene blue clay tests are developed for green sand control.

1961—Alcohol-borne shell coating process is introduced (warm-coated).

1962—New CO₂ sand testing method is introduced for sands bonded with sodium silicate and cured with CO₂...Beardsley & Piper's Al Hunter, Bob Lund and Angello Bisinello develop the first automated green sand molding machine. In their design, the cope and drag are side-blown simultaneously and then hydraulically squeezed. The birth of automated matchplate molding reportedly improved foundry productivity by levels as much as 60% in a short amount of time...Phenolic hotbox binders introduced.

1963—Shell flake resin is introduced, eliminating the need for solvents.

1964—Dell & Christ's paper on mold inoculation spurs the development of many of today's forms of mold and late stream inoculation... The first vertically parted green sand machine (max. 240 molds/hr) is delivered to United Danish Iron Foundries in Frederiksvaerk, Denmark. Early adopters report man-hour per ton improvements on the order of 50%.

1965—Oil urethane nobake binder systems are used for cores/molds...General Electric's Jim Henzel and Jack Kevearian predict freezing patterns in large steel

castings via computer...Cast metal matrix composites are first poured at International Nickel Co., Sterling Forest, NY.

1968—The coldbox process is introduced by Larry Toriello and Janis Robins and introduced to the foundry industry by Ashland Chemical Co. for high-production coremaking. Germany's Daimler-Benz foundry in Mannheim is the first to run the process for automotive parts. John Deere Silvas Foundry, Moline, IL, is the first to use the process for mass-production in North America.

1969—The Chevrolet Vega is introduced by General Motors, featuring the first all-aluminum block with no cast iron cylinder liners. A total of 2.5 million blocks were produced during the vehicle's life cycle.

Late-1960s—Scanning electron microscope (SEM) is invented in England...Thermal analysis begins to be used in iron foundries for the rapid determination of carbon equivalent and phosphorous contents, making it possible to study the transformation of an alloy during cooling...Manganese Bronze & Brass Co. and J. Stone & Co. join to promote nickel-aluminum bronze propellers.

1970s

1970—The sodium-silicate/ester catalyzed nobake binder system is introduced for cores/molds...Safety-critical

ductile iron steering knuckles are introduced on Chevrolet's Cadillac...A new phenolic urethane nobake process is introduced by Ashland Chemical, replacing oil sand dump box operations and significantly reducing energy requirements for core/ mold production throughout the 1970s...Diran Apelian's doctoral work at Massachusetts

Institute of Technology (MIT) leads to the development of foam filters for metalcasting by Olin Metals. Commercial ceramic foam filters will be in use in foundries by 1974.

1971—The vacuum-forming or V-Process molding method of using unbonded sand with the use of a vacuum is developed in Japan...MIT doctoral candidate David Spencer performs experiments leading to semi-solid molding

(SSM), a process in which a partially frozen metal (fluidity similar to machine oil) can be poured into a die cavity. Following advancement in metal slurry consistencies with Professor Mert Flemings, Newton Diecasting Co., New Haven, CT, produces the first semi-solid castings.

1972—A 1-lb crankshaft for a refrigerator compressor produced at Wagner Castings (designed and engineered by Tecumseh) becomes the first production-volume austempered ductile iron (ADI) component. Wagner also produces first as-cast ductile iron connecting rods for passenger cars...CANMET uses real-time radiography to study the flow of

steel in molds... Hitchiner Manufacturing, Milford, NH, patents counter-gravity (vacuum) casting process.

1973—The first U.S. foundry argon oxygen decarburization (AOD) unit is installed at ESCO Corp.

1974—Fiat introduces the in-mold process for ductile iron treatment...The phenolic urethane nobake binder system is introduced for mold production.

Mid-1970s—Alcoa and Union Carbide commence rotary degassing for wrought aluminum. Reading Foundry Products would apply this technology to aluminum foundries in the mid-1980s...Digital codes are developed to simulate solidification and fluid flow analysis...Ultrasonic verification of ductile iron nodularity is developed...Foundries examine new beneficial reuse routes for spent foundry sand, leading to applications such as cement and paving products, bricks and flowable fill.

1976—Foote Mineral Co. and BCIRA (U.K.) develop compacted graphite iron...Acid-slag cupola practices plus external desulfurization with CaC₂ begin to replace basic slag cupolas.

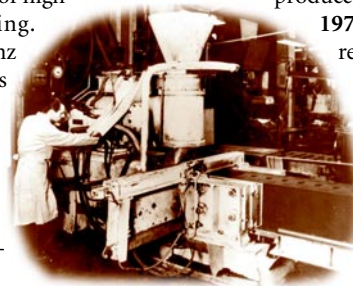
1977—General Motors installs ADI rear differential sets in passenger cars...The alumina phosphate nobake binder system, an inorganic nonsilicate binder, is introduced for mold production.

1978—Furan/SO₂ binder system is developed for cores/molds...Polyol urethane nobake binder system is introduced for aluminum applications.

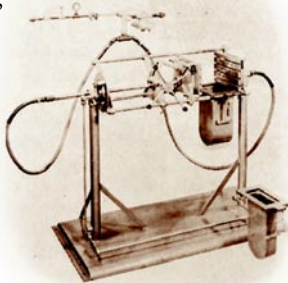
1980s

Early 1980s—Tundish ladle is embraced by industry as favored practice of nodularizing ductile iron...Three-dimensional relational parameters are developed for CAD solid models.

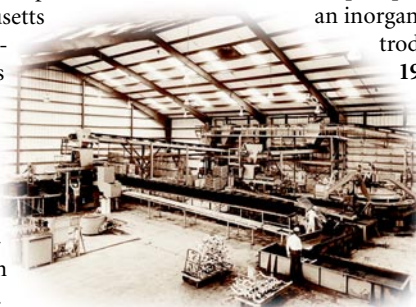
1981—High-production lost foam casting



Prototype Vertically Parted Green Sand Mold Machine, 1959



Shell Core Machine, 1950s



Matchplate Molding Machine, 1960s

begins at General Motors' Massena, NY, plant for aluminum cylinder heads.

1982—Warmbox binder system is introduced.

1983—Air impulse molding process is developed...Free radical cure/SO₂ binder system is introduced.

1984—Charles Hull applies for a patent on stereolithography process. Other rapid prototyping techniques emerge shortly after...Phenolic ester nobake binder is introduced...Thermal analysis makes breakthrough in molten aluminum processing for determination of grain refinement and silicon modification.

1985—Phenolic ester coldbox binder is developed...New automaker Saturn makes a strategic decision to select lost foam process for its aluminum cylinder blocks and heads and ductile iron crankshafts and differential cases.

Mid-1980s—Computer solidification software is commercialized...Amine recycling is introduced to enhance the environmental benefits of the amine-cured coldbox process...Ube Machinery introduces first squeeze casting equipment...Aikoh's (Japan) flux injection technology is initiated into U.S. aluminum foundry market.

Late 1980s—3-D visualization techniques are developed...CaO/CaF₂ desulfurization of cupola-melted ductile base iron begins to replace CaC₂ method...Lanxide, Newark, DE, develops pressureless metal infiltration process for particulate-reinforced metal bodies...Mg wire injection method for ductile iron treatment is first tested...Casting solidification modeling software gains in acceptance, allowing foundries to optimize quality, production and cost prior to actually pouring a casting.

1988—Rapid prototyping and CAD/CAM technologies combine in a breakthrough to shorten tooling development time...Ford adapts Cosworth process precision sand casting process for high pro-

duction...Metallulics Systems combines flux injection/rotary degassing technologies for aluminum processing.

1989—IMI (Yorkshire, UK) begins experimenting with bismuth as a lead substitute in copper alloys.

1990s

1990—Equipment for semi-solid casting is introduced by Alumax Engineered Materials and Buhler, Inc... Fosco patents a direct-pour system that permits casting production without conventional gating/rising. Major automotive application would come in 1995 with CMI International's upper intake manifold...Precision sand casting and casting quality for engine blocks are improved in mass production by major automotive companies with the Cosworth and Zeus processes for aluminum and the Loramendi Key Core process for precision sand cast iron applications.

1991—"Dry ice" CO₂ process is developed for cleaning coreboxes and foundry tooling...A noncontact gauge for accurate dimensional analysis of lost foam patterns and sand cores is developed through the AFS Lost Foam Consortium. Eight years later, the consortium develops an instrument to measure the gas permeability of lost foam pattern coatings (which controls flow of metal and has a dominant effect on casting quality.)

1993—First foundry application of a plasma ladle refiner (melting and refining in one vessel) occurs at Maynard Steel Casting Co., Milwaukee.

1994—Use of low-expansion synthetic mul-lite sand for lost foam is patented by Brunswick Corp., Lake Forest, IL, to enable precision casting of large components...Delphi Chassis Systems and Casting Technology Co. begin program on squeeze-cast aluminum front knuckle, the first high-volume production (1.5 million



SSM billet, 1971



GMBond-produced engine block, 1996

cars) two-cavity squeeze-cast aluminum conversion of its kind.

Mid-1990s—Microstructure simulation is developed, contributing to better understanding of metallurgy effects and the prediction and control of mechanical properties in castings... Semi-solid casting makes commercial inroads and market penetration.

1996—Cast metal matrix composites (brake rotors) are used for the first time in a production model automobile, the Lotus Elise...Environmentally-friendly (fluorine-free) fluxes are developed at the Worcester Polytechnic Institute and commercialized... General Motors Corp. introduces GMBond, a water-soluble biopolymer-based core sand binder that is nontoxic and recyclable.

1997—AFS Consortium research at CANMET, Ottawa, Canada, results in the development and commercialization of lead-free copper alloys using bismuth and selenium...Following tests at the Germany's Aachen Univ., American Cast Iron Pipe Co., Birmingham, AL, builds a continuously operated electric arc furnace for cast iron production.

Late 1990s—Stress and distortion simulation introduces the benefits of controlling casting distortion, reducing residual stresses, eliminating hot tears and cracking, minimizing mold distortion and increasing mold life.

2000s

2001—NASA and the Dept. of Energy/OIT release physics-based software tool to accurately predict the filling of expanded polystyrene patterns and sand cores as numerous variables are changed...Mercury Marine installs North America's first pressurized lost foam casting line at its new foundry in Fond du Lac, WI. **EC**

Comments on the timeline should be directed to mlessiter@afsinc.org

Sources of Metalcasting Historical Information

C.F. Walton, T.J. Opar, *Iron Castings Handbook*, Iron Castings Society, Inc., (1981). • J. Gerin Sylvia, *Cast Metals Technology*, AFS, (1990). • E.L. Kotzin, *Metalcasting & Molding Processes*, AFS (1981). • J.P. LaRue, *Basic Metalcasting*, AFS (1989). • C.A. Sanders and D.C. Gould, *History Cast in Metal*, AFS, (1976). • Proceedings of 1992 Coreless Induction Melting Conference, AFS, (1992). • B.L. Simpson, *History of the Metalcasting Industry*, AFS (1948). • J.A. Gitzen, *Progress in the Development and Utilization of Additives in the Foundry Industry*, AFS (1957). • 1995 *Lost Foam Technology and Applications Conference Proceedings*, AFS (1995). • *Aluminum: Design and Application (Vol. II)*, ASM, (1967). • *High-Pressure Casting Molding*, 2nd Edition, AFS (1987). • *Foundry Trade Journal* (Sept. 11, 1986). • *Metals Handbook, Ninth Edition, Vol. 15 Casting*, ASM International (1988). • 1991 *AFS International Sand Reclamation Conference*, AFS (1991). • *AFS/CMI Conference on Green Sand Technology—Productivity for the '80s*, AFS (1983). • *ADI: The New Benchmark Material* video, Applied Process, Inc. • "1997 Hoyt Memorial Lecture: Lost Wax to Lost Foam: Reflections on the Past, Present and Future," E.L. Kotzin, July 1997 MODERN CASTING, p. 42-45. • 1999 *Charles Edgar Hoyt Memorial Lecture: "From a Monument to the Vega: The Journey of the Aluminum Casting Industry,"* J.R. Bodine, May 1999 MODERN CASTING, p. 60-63. • *A Tribute to Keith Millis and the Unveiling of Ductile Iron 50 Years Ago*, October 1998 MODERN CASTING • MODERN CASTING's *A Look Back at the 20th Century Series (2000-2001)*. • Special thanks to Bill Henning, Miller & Co. (retired); Diran Apelian, Worcester Polytechnic Institute; Paul Carey and Jim Archibald, Ashland Specialty Chemical Co.; Stubbs Davis, Durametel Corp.; Raymond Donahue, Mercury Marine Div.; Matt Granlund, Foundry Systems Control; Roy Lobenhofer, Lobenhofer Consulting, Inc.; Norris Luther, Luther & Assoc.; Mahi Sahoo, CANMET; Geary Smith, Manufacturers' Brass & Aluminum; Bob Voigt, Penn State Univ.; David Neff, Metallulics Systems, LLC; and Norm Bliss, Ian Kay, Wayne Rasmussen, Steve Robison and Joe Santner, AFS/CMI.