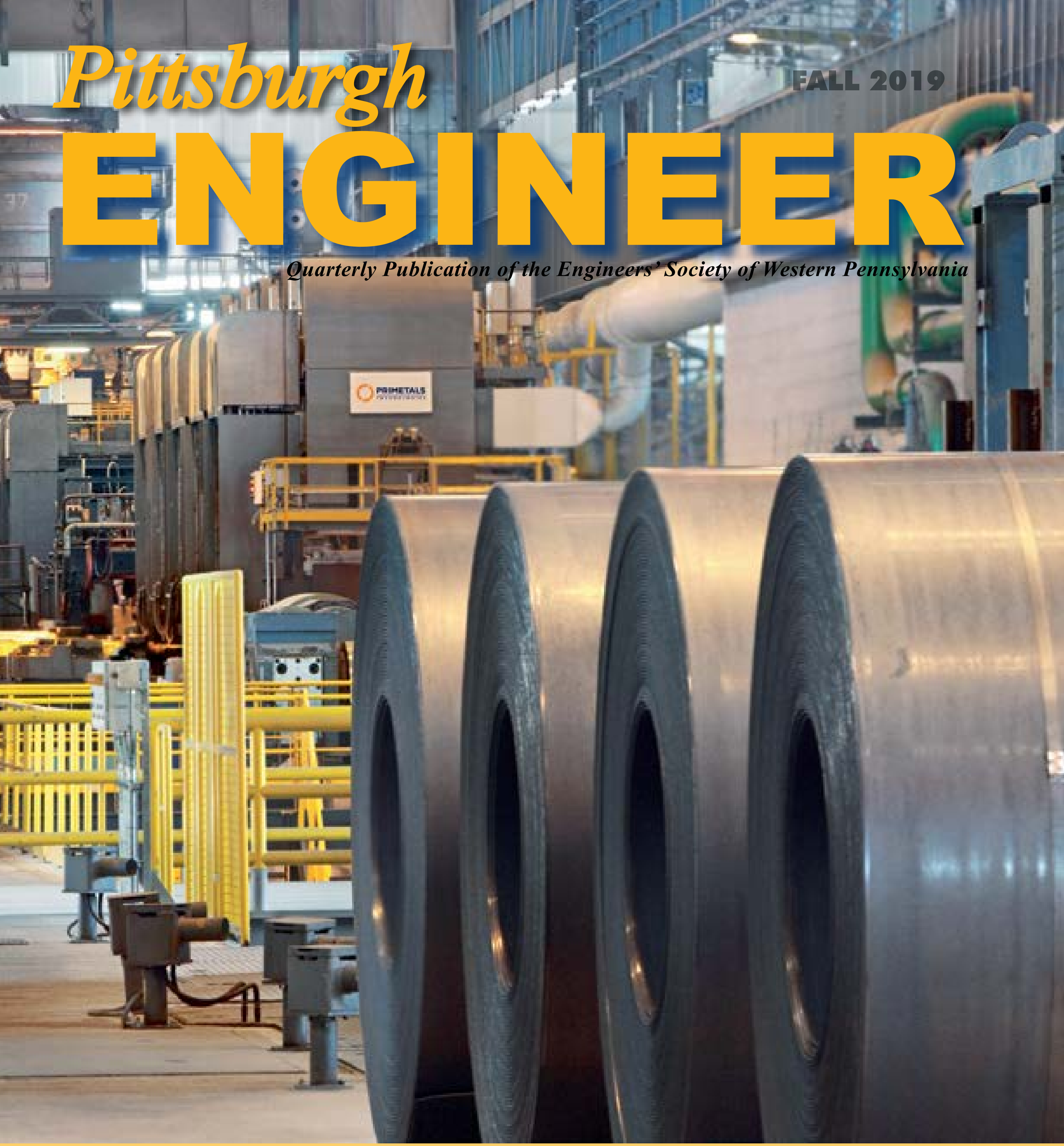
Pittsburgh ENGINEER

FALL 2019

Quarterly Publication of the Engineers' Society of Western Pennsylvania



THE METALS ISSUE

Including articles from:

- **United States Steel Corporation**
- **AK Steel Corporation**
- **Association for Iron & Steel Technology**

Pittsburgh ENGINEER

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In this Issue...

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Guest Editor Column

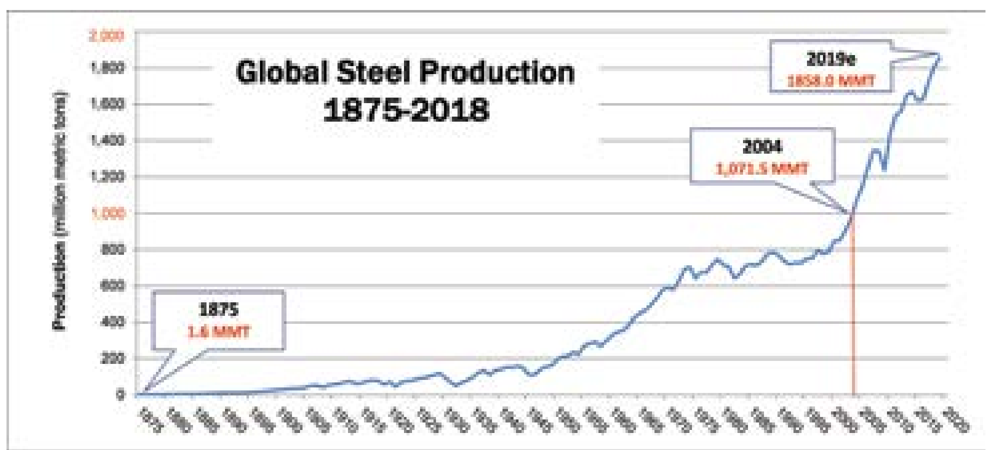
Steel in the 21st Century: Two Billion Tons and Counting

Ron Ashburn
Executive Director, Association for Iron & Steel Technology

Ron Ashburn

My intention with this column is to help you visualize the future. But for the moment, let's consider the past. Specifically, I would like you to think about 2004, a significant year, technologically speaking.

One February day in 2004, two Harvard roommates sat down and created something called Facebook. Then, two months later, Google revealed to the public its email service called Gmail, offering users an incredible 1 gigabyte of storage … for free. And throughout that year, 3G mobile cellular service took off, which led to the ubiquitous smartphone with the cool features that we now take for granted – awesome cameras, streaming video, and global positioning among many others.



But something else happened in 2004, something that I believe delineates the exponential acceleration of technological change for society. In that year, worldwide steel production exceeded one billion metric tons on an annual basis, for the first time ever. It's a staggering volume, enough to construct a 10-inch steel I-Beam (@35 lbs./ft.) long enough to wrap around the earth's equator … 479 times.

It took the world nearly 130 years and significant leaps in technical know-how to reach that milestone. The innovations that made it possible date back to the 1870s with the Bessemer process deployed right here in Western Pennsylvania and concurrently in the United Kingdom. You can learn more in this issue about how Pittsburgh leveraged technology to become the Steel City with the retrospective by Ken Kobus.

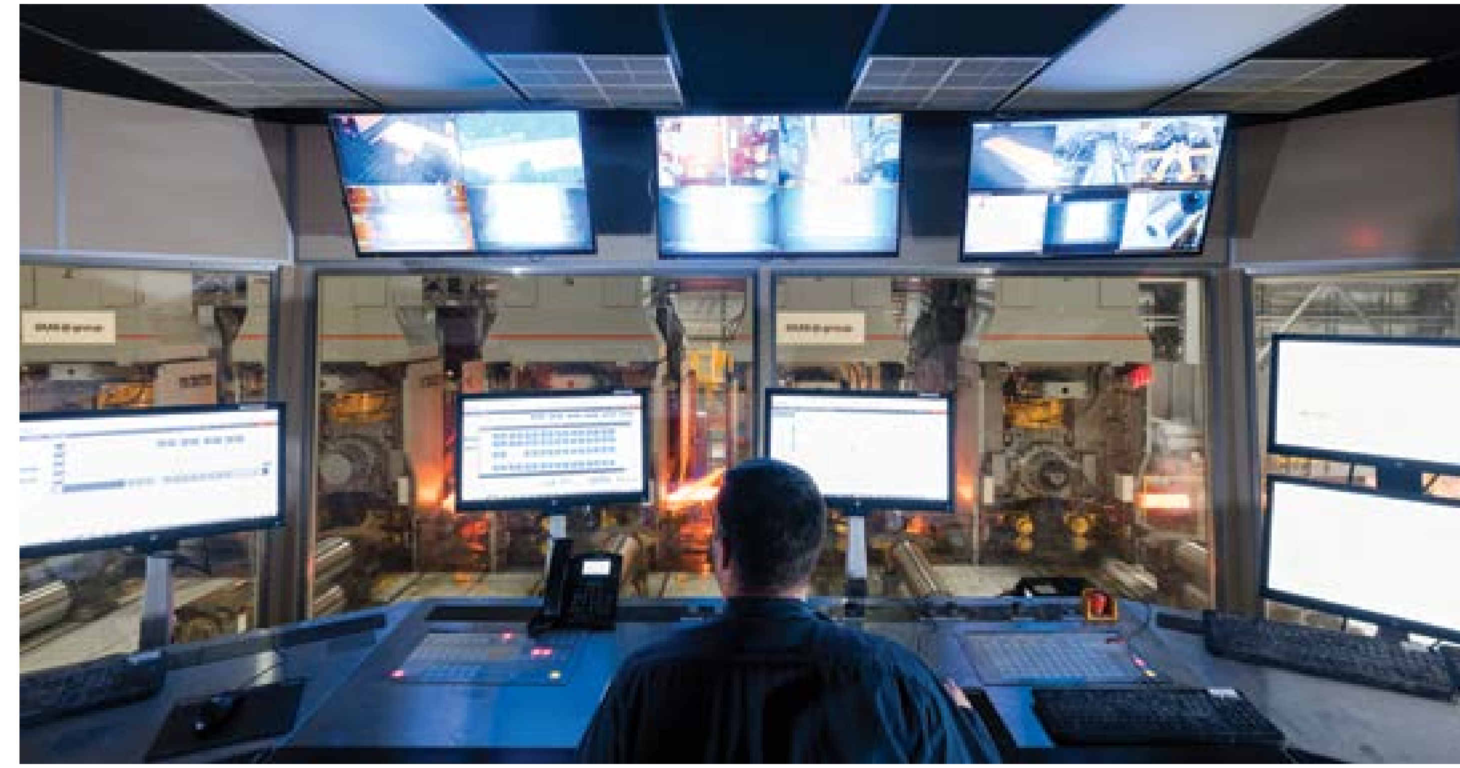
Now, let's return to the present day of 2019. We're only 15 years removed from achieving the billion ton threshold, a mere blink-of-the-eye since modern steel production began. And yet, the world now stands on the verge of two billion metric tons of annual steel production.

The growth can be explained in part with basic math – as countries such as China and India industrialize, there simply are more mills making more steel. For starters, it's good for employment … but that's another story for another day. These countries and many others need basic infrastructure such as roads and bridges, and that requires steel. While we in the United States and throughout Western Europe may take these necessities for granted, you might be amazed at how much the rest of the world does not.

If one ponders the need for housing, sanitation, schools, hospitals, automobiles, trains, ships … steel's role in serving societal evolution transcends roads and bridges. Steel is the foundation for any economy to grow and prosper because it's strong, easy to build with, environmentally sensitive and affordable! Much more so than any other engineered material available today.

But what cannot be overlooked with this massive acceleration in global steel production is the role of digital technologies.

With the advent of smart sensors, machine connectivity, cloud computing , big data and artificial intelligence, we're rapidly increasing the rate and efficiency with which steel is manufactured. We're in the midst of a digital transformation, what Europe has dubbed Industry 4.0, representing the fourth industrial revolution.



The first industrial revolution was marked by mechanization and steam power, the second by electrification and assembly line production, and the third by electronics and basic automation: think programmable logic controllers and Excel spreadsheets. And now we have digital technologies… Andrew Carnegie surely would have clicked the "like" button!

With digital technologies, we are harnessing significant advances in low-cost computing power, feeding it with huge amounts of data, and racing to develop algorithms to divine patterns in that data. This confluence represents the advent of production scale artificial intelligence whereby networked machines are quickly learning to not only execute processes, but make decisions about those processes to eliminate errors and improve efficiency.

"To be sure, the steel industry of today is relentless in its pursuit of ever greater levels of production efficiency"

Consider that at the turn of the century, the speeds of the fastest supercomputers were measured in teraflops, a trillion calculations per second. They cost millions of dollars to build and were locked away in government laboratories. But now, the fastest supercomputers are operating a thousand times faster, in petaflops, and they are in the hands of profit-making enterprises all around the world.

At the same time, the cost of data storage has dropped 100,000-fold, making it economically feasible to save vast amounts of information. So we now have at our fingertips the means to find previously hidden patterns and relationships at the bottom of unfathomably deep lakes of data.

One of the newest greenfield steel plants in the United States, Big River Steel, opened in 2017 in Arkansas with equipment supplied by the SMS group, headquartered on Pittsburgh's North Shore. The Big River Steel mill is already leveraging supercomputing power to create what it calls the world's first self-learning mill. Others will soon be following; the economics are just too great.

As the World Economic Forum forecasts, digital technologies will generate $320 billion in additional value for the metals and mining industry, prevent 1,000 workplace fatalities and 44,000 injuries, and reduce carbon emissions by 610 million metric tons … all over the next 10 years.

To be sure, the steel industry of today is relentless in its pursuit of ever greater levels of production efficiency. In fact, the world's accumulated steel production has for all intents doubled every 15 to 20 years, going back to the 1920s, when the open hearth process dominated. In the 1950s, basic oxygen furnaces (BOFs) displaced that technology and cut melt times per heat from 10 hours to 45 minutes. In the 1960s, the industry began to adopt continuous casting, which transformed solidification and rolling time from days to mere hours. Technology continues to march on.

As the 21st century unfolds, we now see the rise of optimized electric-arc furnaces (EAFs) which are challenging the dominance of the blast furnace fed basic oxygen furnaces (BOFs). The last bastion of technological defense for the BOFs has been volume and quality, but the EAFs are quickly closing these gaps.

Globally in 2018, approximately 71% of all steel was produced with the BOF process. In the United States, approx. 68% of all steel is produced with the EAF process, so America has become a leader in EAF process, which is also growing each year in global market share.

Despite the process route, the winners will need to harness the power of digital transformative technologies. Deployment of these technologies won't be easy and will require the commitment of significant capital. But we're already seeing that today. Buoyed by a healthy economy, tax reform and the cover afforded by President Trump's steel tariffs, the industry has the means and the confidence to make these necessary investments.

We are in the midst of a Golden Era for steel mill investment. In 2019 just about all of the country's major steelmakers have at least one significant upgrade or expansion underway. Nucor, one of America's largest steelmakers, is building a $1.35 billion plate mill in Kentucky and micro-mills for rebar production in Missouri and Florida. Steel Dynamics is investing $1.9 billion in a sheet mill in Texas. More recently in August, North Star BlueScope Steel in Ohio announced a $700 million expansion through which it will add an additional EAF and caster.

Locally, United States Steel Corporation is building a $1 billion advanced cast-roll sheet mill that will not only improve its energy conservation and reduce its carbon footprint, but will allow it to produce its branded array of advanced high-strength steels, a class of steels that leverage the latest advances in metallurgical development.

The evolution of microscopic metallurgy and a greater understanding of the complex interplay among chemistry, temperature and force has enabled the creation of these steels – which defy a longstanding problem of combining strength with elasticity.

We could always make steel strong, and we could always make steel more formable … but it was hard to do both at the same time. The stronger the steel, the more brittle it tends to be, and therefore the more susceptible it is to cracking when formed into components. At the same time, the more formable the steel, the softer it tends to be and therefore the more susceptible to deformation when subjected to force.

But with today's advanced high-strength steels (AHSS), it is possible to have both strength and formability. In the last 15 years, the maximum tensile strength of steel has increased six-fold, with those in the best-of-class strength climbing from then 340 mega-pascals to now 2,000 mega-pascals. And much of this evolution is due to advances in computing power which accelerates modeling techniques and brings product implementation about much more quickly.

With these new steels, we can do more with less, meaning that it is possible to make parts that are stronger, but require less steel, making them lighter. These new steels rival aluminum on weight, but are less costly to produce and have a lower environmental impact. You can learn more about AHSS in this issue from the experts at AK Steel and United State Steel Corporation, both industry leaders with long-standing ties to Western Pennsylvania.

Although development of these steels has been aided by digital technologies, they have not come about solely because of digital technology. People very much remain at the heart of steel innovation. And to ensure we are able to make the most of these new tools, we will need creative thinkers who are well-versed in math, computer science and of course engineering.

We need mathematicians and computer scientists to develop algorithms that leverage our data, and we need engineers to identify and prioritize weak links in the process where better solutions can be developed and readily adopted. In regard to the diversification of talent and skill sets within our industry, AIST is working to lessen the gender imbalance in steel manufacturing.

Armed with new tools capable of performing at levels not before possible, and working with a workforce replete with diverse skill sets, steel will continue to be the go-to solution for modern society for another century – and perhaps another billion tons – to come.

How Pittsburgh Became the Steel City

By Ken Kobus

Pittsburgh's ascendency to become a steelmaking leader occurred in two distinct phases. Prior to the American Civil War, crucible steel and wrought iron were produced here in small batches, which usually measured only several hundred pounds for wrought and less than a hundred for crucible. Wrought iron was manufactured in a puddling (reverberatory) furnace developed by Cort in England and later modified by Hall. Wrought ironmaking typically used pig iron, the product of a blast furnace, as a feedstock. This was in turn used to feed crucible steelmaking. Huntsman developed the crucible process near Sheffield, England. These processes required intelligent operators who also possessed both great strength and stamina. By 1860, Pittsburgh became the crucible steelmaking center of America despite having no local blast furnace. Charcoal pig, often called "Juniata iron," was routinely imported from central Pennsylvania.

In late 1859, Pittsburgh's first successful mineral-fueled (coke) blast furnace (Clinton) went into operation in what is now Station Square. An immensely important discovery was made almost immediately. The fuel made from Pittsburgh Seam coals mined nearby proved inadequate. It was quickly discovered that coke manufactured in ovens on the Pittsburgh Seam in a small region neighboring Connellsville and Uniontown (3 X 50 miles) proved superior to that produced elsewhere on earth. Thus began an important new American industry.

Following Clinton's success, a number of other ironmaking facilities sprouted along Pittsburgh's rivers. In 1872, several new plants were built, one with two furnaces in Etna named Isabella [were both furnaces called Isabella?] and another in Lawrenceville called Lucy. These three furnaces were nearly identical. By 1874, Lucy produced 100 tons of iron in a day, the first in the world to reach this inconceivable target. Some time later, Isabella made 1,000 tons in a week. The British, responsible for developing coke fueled smelting when the Darby's were the first to overcome all of the obstacles to this process at Coalbrookdale some 150 years earlier, simply refused to believe that was possible, let alone accomplished by some upstart Americans. Lucy was the first blast furnace owned by Carnegie, along with brother Tom, Henry Phipps and Andrew Kloman.

Carnegie's group must have done something right; although, attaining a thing is not as challenging as maintaining it. Because no obvious physical modifications were made to the plant while it continued as a production leader, the reasons for success are invisible to routine scrutiny. One change at Lucy was to switch blast air to flow control, an idea originally adopted at a Struthers (Ohio) plant, as opposed to the norm of regulating pressure. The change was implemented by simply counting the revolutions of the blast air piston pump drive instead of checking a gage. Examination showed that a constant flow of raw material required a constant flow of air (not pressure alone), so counting revolutions was, in fact, a revolution. They hired an in-plant chemist to guarantee proper selection, proportioning and use of raw materials, moving away from an aggressive, authoritarian, seat-of-the-pants–based management toward a more scientific, fact-based style.

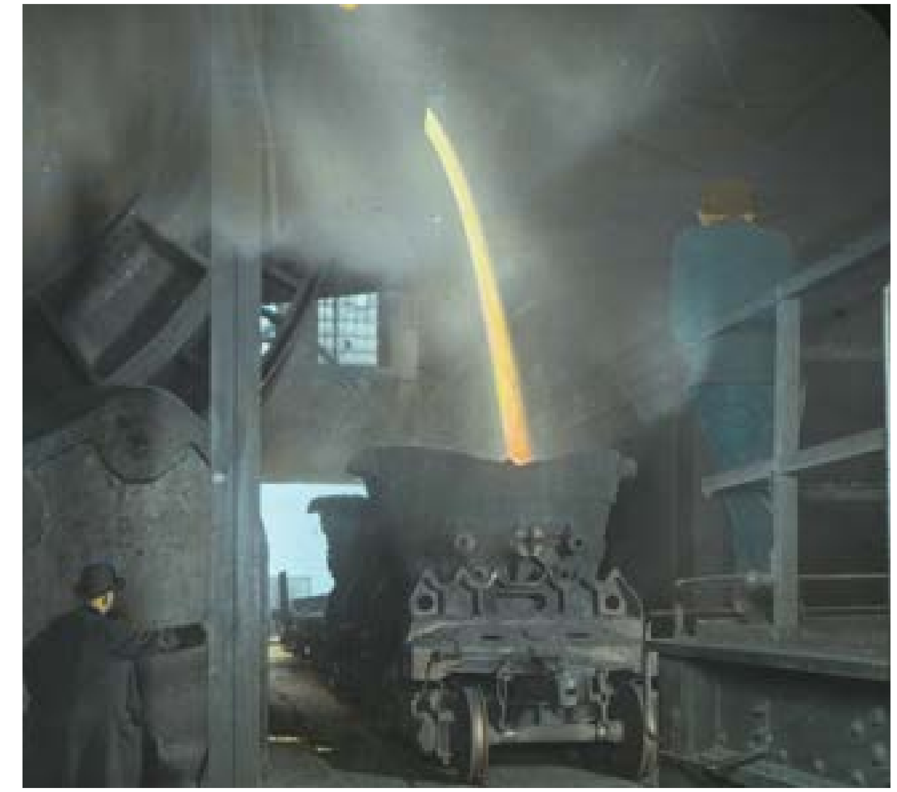
In 1875, when Carnegie opened the Edgar Thomson (ET) Works in Braddock to manufacture the region's first mass-produced Bessemer steel, Pittsburgh again entered the competition to become a major steel center, but coming from behind because it had relinquished its lead. In Bessemer steelmaking, tons could be produced in minutes where old methods produced only pounds in hours. Within only a few years, Edgar Thomson was one of the premier plants in America for making steel, and it finally became the best.

After building a second furnace (1877), Lucy still could not supply sufficient iron to ET for conversion to steel; such was the success of the new steel plant. A plan was implemented to build more blast furnaces for ET in Braddock instead of Lawrenceville, approximately 9 miles distant. As soon as the new furnaces were put on-line in 1880, various trials were begun. The "new" secondhand former charcoal first furnace, "A," was shorter and slimmer than Lucy, with about 40% of its cubical capacity, but on start-up used as much air as the larger furnaces (15,000 cu. ft./min.). Though its fuel (coke) rate was 1/3 less, "A's" several-month run on iron produced a remarkable 80% of the 91 tons-per-day average of Lucy at the time. When the larger "B" Furnace was put on-line several months later, it too was overblown with 30,000 cfm air or about twice its cubical capacity. The results were phenomenal. In its sixth month of operation, "B" produced 4,722 tons: more iron than had ever been produced at one time anywhere.

At ET during the 1880s, more furnaces were built or relined. Tests and forensic inspections were performed on varying parameters of air temperature, volume, pressure and furnace shape, as well as evaluating the effects of a campaign on the lining. This was considered by many to be the birth of ironmaking as a science. Production continued to climb. In 1890, America surpassed England as the world's leading iron producer. Ultimately, an artificial production plateau of approximately 400 tons per day was reached, primarily due to the fact that blast furnaces were hand-charged. This level required manhandling 800 tons of ore; 100 tons of limestone; 400 tons of coke or at least 1,300 tons total, twice, once at the bottom and again on top.

In 1897, for the third time in as many decades, Carnegie embarked on a journey to improve iron production. The new furnaces at the Duquesne Works were planned for 600 tons per day per furnace of a similar size to ET, which is a 50% increase in production. The obvious approach was to mechanize numbers of pre-existing manual practices, such as skip charging, for instance. However, automation had been tried previously at numerous other facilities and simply did not work. At the Duquesne Works, the new approach focused on understanding what was happening on the inside of the furnace rather than the outside. This seemed to be a lesson in accomplishing the impossible. Adopting the newly devised Neeland bucket charging system, provided a workaround of a permeability problem on the inside previously encountered by others, while simultaneously addressing automating the furnace loading issues on the outside. This was not a total solution, however, because the four furnaces required the handling of several millions of tons of raw materials… each and every year. What we know today as the "ore field" was developed together with the equipment to unload, store and recover the materials; storage bins for rapid access to stock for charging; and even all steel, high-capacity, rapid-discharge railroad hopper cars along with a railroad to deliver the ore. (1 or 2 photos) Almost immediately, production reached 600 tons and often 700. Industry leaders frequently referred to this as the "Duquesne Revolution," made more interesting with the realization that the Carnegie Company's chief competitor in this endeavor was in fact itself.

The factors responsible for Carnegie's advances in producing Bessemer steel at ET, Homestead and Duquesne are generally obscure but clearly attested to by these immense advancements in making iron. Bessemer steel plants of the period were noted for their giant mounds of scrap, a curiosity, because for various reasons, pneumatic steelmaking did not, nor could not, assimilate all of the scrap generated via the steelmaking processes. The Jones Mixer was one of those advances. This simple idea, devised and patented in 1889 by Bill Jones, Superintendent of ET, appears to be nothing more than a holding vessel for molten iron, a buffer, but it was not that at all. The concept was to maintain this large vessel as full as practical for the purpose of blending out the variability of the incoming stock, thus making the outgoing metal as consistent as possible. A uniform feed to the steel furnaces could be translated into higher production while generating lower scrap volume. Not directly detailed, but inferred, was that two steps of the steelmaking process were eliminated, i.e., casting iron to pigs and remelting the iron for use in the converters, thus increasing profits by saving the costs of labor, the fuel and the capital for equipment to do so.



Around the same time that Jones devised the mixer, Carnegie was entering the basic open hearth steelmaking market at the Homestead Works. Note that this use of basic does not mean fundamental, but chemically basic. His was the first successful basic plant in America. What this meant is that he could remove potentially destructive chemicals such as phosphorus from the steel. As a result, large volumes of scrap, arising either from excess at the Bessemer shops or due to contamination, could now be used, creating a synergy between the open hearth and the Bessemer, where previously there was none. Additionally, open hearth steels were higher-quality, higher-priced, higher-value steels, and could now be made with no raw material cost from the low-utility scrap produced within the company. Each of these advances is a story within itself.

Both the Bessemer and open hearth processes were devised in England.

At his three steelmaking plants in Pittsburgh (which was all there were), Carnegie basically adopted English ideas of production that were then built, expanded upon, massaged and modified. To put this in perspective, using data for 1898, the British reported that the Carnegie Company's output was 56% of the total output of the United Kingdom, the world's largest steelmaker. That same year, it exceeded the sum total production of open hearth steel of Germany, Belgium and France. The U.S. Government reported that Carnegie made 20–30% of the steel made in the U.S.: 50% of plate, 30% of rail, 50% of armor and 70% of U.S. exports. Other steelmaking firms in our region during Carnegie's time were small and numerous. Typically located along the Allegheny River, including the esteemed Jones & Laughlin firm, they were largely irrelevant to the assent of Pittsburgh to its final pinnacle. Given the significant national and global market share of the Carnegie Steel Company, the die was cast for Pittsburgh to forevermore be known as the Steel City.

Innovative, Cost Effective Solutions with Advanced High-Strength Steel

by Brian Bishop, AK Steel Corporation

Advanced high-strength steels (AHSS) are prominently used in the design of automobile body structures today. The use of these innovative lightweight, strong and flexible steels has driven cost-effective new solutions for auto designs today and for the future.

In recent years, automakers have accelerated their efforts to lightweight vehicles to meet the original corporate average fuel economy (CAFE) mandate of 54.5 mpg by 2025. With that drive to minimize auto tailpipe emissions and meet CAFE standards, automobile companies (OEMs) have been aggressively trying to take mass out of vehicle bodies and structures—while maintaining or improving passenger safety—in order to reduce fuel consumption and increase overall vehicle efficiencies. As a result, steelmakers, such as AK Steel, are investing in efforts to develop new types of steel to meet these challenges.

NEW MATERIALS

The development and proliferation of AHSS products, including third-generation AHSS, continues to grow. According to the most recent Ducker Worldwide study commissioned for the Steel Market Development Institute, accelerated use and adoption of AHSS, which includes ultrahigh-strength steels (UHSS) and third-generation products, into vehicle designs will continue through 2025 and beyond (Fig. 1).

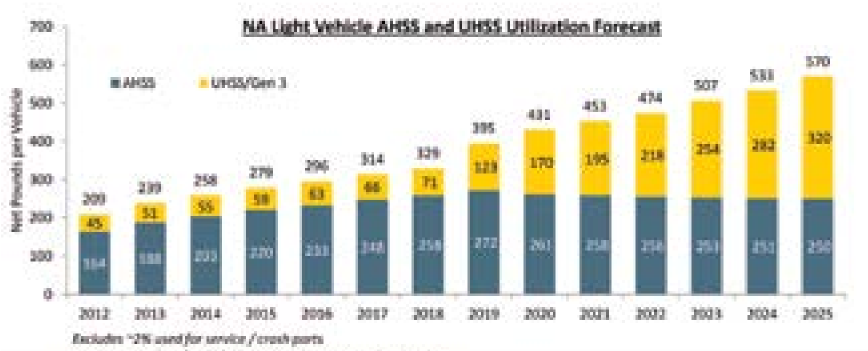


Fig. 1--NA Light Vehicle AHSS and UHSS Utilization Forecast

It is commonly reported that a 10% reduction in vehicle mass translates into a 6–8% reduction in fuel consumption. While alternative low-density materials such as aluminum have been offered, their adoption in vehicles has not developed to the level once projected, due in part to continued innovation of AHSS by the steel industry. As a result, automotive OEMs have new cost-effective, flexible and safe steel options that enable them to also make significant mass reductions.

NEW PROCESSES

The simultaneous development of new processes and equipment to produce, form and fabricate new steels has been essential for expanding the use of AHSS. In some cases, these new processes have been met with significant capital investment by the steel industry.

This investment is important because it further demonstrates the steel industry's commitment to maintaining steel as the material of choice for vehicle design. Collaborative research, funded and led by groups such as the Auto/Steel Partnership and WorldAutoSteel, has also focused on new technology and training associated with the adoption and implementation of AHSS into the existing automotive manufacturing supply chain. This type of technical support, along with new steel products and application solutions, is part of the overall strategy to drive further use of steel in automobiles.

A RANGE OF NEW OPTIONS

Fig. 2 shows the current variety of sheet steels available to automotive engineers and highlights the wide range of ultimate tensile strength (150–2,000 MPa) and ductility (2–60% total elongation) levels that can be achieved through deliberate changes in the composition and processing of steel.

Ductility, which is how much a material can stretch before it

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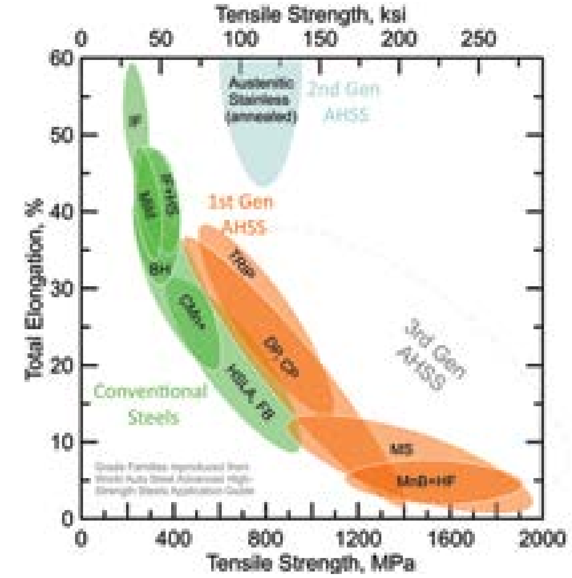

Fig. 2--Properties of AHSS Grades

breaks, is often used as a measure of sheet formability — the ability to form a flat, two-dimensional sheet into a complex, three-dimensional shape. In general, formability decreases as the material strength increases. Steels are often classified by their strength, although there is some overlap of the different steel grades at the extremes of each range.

Conventional low-strength steels and high-strength steels (green in Fig. 2) typically have an ultimate tensile strength (UTS) less than 700 MPa and include steels used for exterior panels on automobiles — parts of the vehicle that require high formability; or as structural parts — parts that require higher strength. Advanced high-strength steels (orange and blue in Fig. 2) most commonly have a UTS greater than 700 MPa and are used for structural parts on automobiles.

Early development of AHSS began as far back as the 1970s, but widespread application did not begin until the early 2000s when they were recognized as a new generation of steels.

CREATING AHSS

AHSS are designed to address the inverse relationship between strength and formability. They are natural composites comprised of varying amounts of components including iron in different phases or atomic arrangements, carbides, supersaturated solid solutions and nanometer-sized precipitates.

Some of these components are metastable. As a result of these deliberately engineered structures, AHSS are able to maintain relatively high formability at high strengths, and thinner and lighter AHSS can replace a lower-strength steel in the same application (Fig. 3). Further weight savings can be achieved by combining components into more complex monolithic designs and changing the part geometry to improve the performance characteristics of the part. That simply was not possible prior to the introduction of AHSS.

At AK Steel, the development of AHSS has involved a comprehensive and steady progression, expanding the company's portfolio of zinc-coated dual-phase steels and aluminum silicon-coated press-hardenable steel. This has resulted in the introduction of a variety of AHSS products

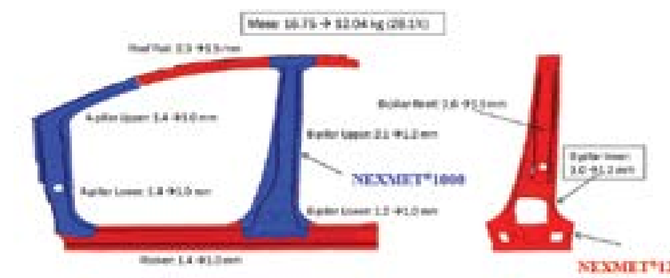

Fig. 3--Mass Reductions in a Sedan Body Side Module

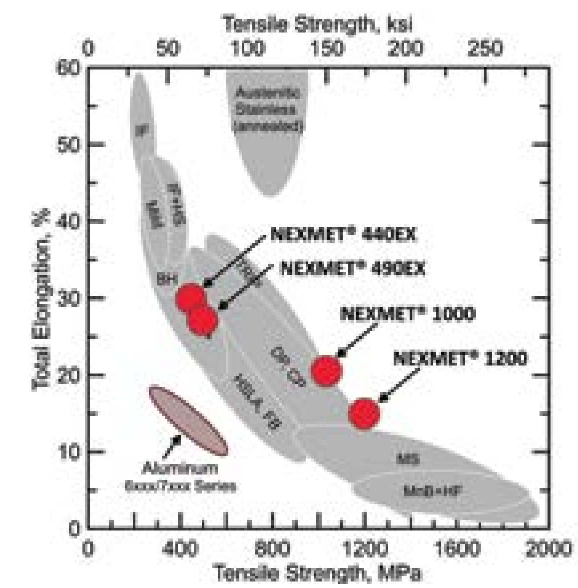

Fig. 4--Properties of AK Steel's Third-Generation AHSS Products

for automotive lightweighting, including third-generation AHSS, which AK Steel launched in 2017. Its NEXMET® 1000 and 1200 products provide ultrahigh strength while maintaining excellent formability (Fig. 4). NEXMET AHSS products are rapidly gaining traction in the market place and will be included in the design of new vehicles to be released starting next year (see Fig. 5 for typical applications).

PERFORMANCE AND VALUE

A key factor in the growth of AHSS is the value proposition it brings to automakers. Not only can automakers arrive at their end goal of lighter, more fuel-efficient and safe vehicles through the use of AHSS, they can do it more

Fig. 5—NEXMET® Applications in New Vehicle Designs

cost-effectively. Steel (whether it be mild steel or AHSS) is simply a more cost-effective option than other alternative materials.

Beyond economics, steel is also more sustainable than alternative materials due to its ability to be endlessly recycled with no degradation in quality. Further, steel offers the lowest carbon footprint of all lightweight material, when measured across its entire life cycle. When you consider safety, cost, sustainability and performance, which includes enhanced manufacturability that allows the efficient production of complex automotive parts, steel continues to provide the best overall value to automotive designers.

Advanced High-strength Steel (AHSS) Development at United States Steel Corporation: *A Unique Perspective*

Brandon M. Hance, Ph.D.
United States Steel Corporation

My career with United States Steel Corporation began in 1996 in Western Pennsylvania, where I spent the following decade as a Research Engineer at the U. S. Steel Research & Technology Center in Monroeville (now in Munhall, Pennsylvania). Now, at mid career, I reflect naturally on the struggles and accomplishments, the mistakes, my friends and colleagues, and the extraordinary changes that have shaped my journey along the way.

From 1996 to 2006, my fellow Research & Technology Center colleagues and I worked our way along the automotive high-strength steel development curve. We began with high-strength, fully stabilized (IF) steels and bake-hardenable (BH) steels, and by the end of that decade, GI 780DP was in commercial production at PRO-TEC Coating Company (PRO-TEC) in Leipsic, Ohio. GI 780DP is a cold-rolled, hot-dip galvanized, first-generation (GEN1) advanced high-strength steel (AHSS) with 780 MPa minimum tensile strength — i.e., 780 class. PRO-TEC began operations in 1993 and remains a key AHSS-enabling joint venture between United States Steel Corporation and Kobe Steel, Ltd. of Japan. Figure 1 (left side) shows the progression of high-strength steel development through 2006: high-strength IF steels → mild and BH steels → carbon-manganese (CMn) and low-alloy (LA) high-strength steels → first-generation AHSS (GEN1) up to GI 780DP.

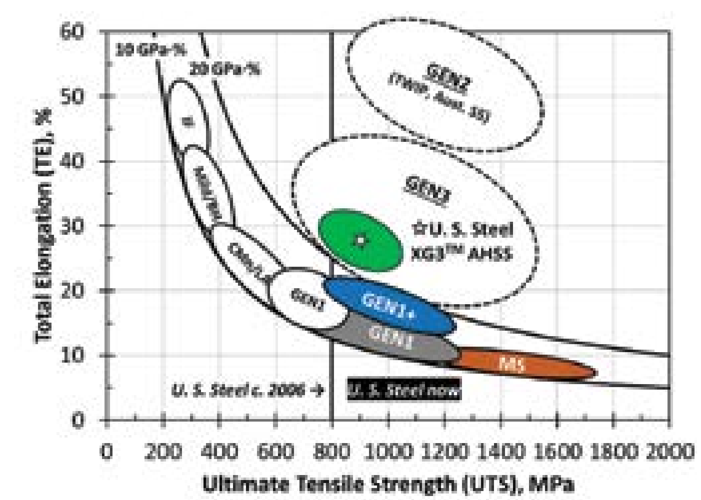

Figure 1 – Schematic global formability diagram [1] or "banana diagram" illustrating the evolution of high-strength steel development at United States Steel Corporation

During this same decade, I earned a Ph.D. in Materials Science at the University of Pittsburgh (part-time). I am and always will be grateful for the support and encouragement that I received from my U. S. Steel Research family. In 2006, I left United States Steel Corporation and entered the "exploratory phase" of my career, where I ventured into high-speed bearing technology, stainless steel alloy development, and aluminum alloy formability.

AN ASTONISHING TRANSFORMATION

In 2014, I rejoined United States Steel Corporation as an Applications Engineer at the Automotive Center in Troy, Michigan. I quickly realized that U. S. Steel had been very, very busy over the previous eight years while I was away. Everyone was talking about 980GEN3, 1180SHF, MS1700, and something called "the CAL". As it turns out, 980GEN3 referred to the first 980 class third-generation (GEN3) advanced high-strength steel developed by U. S. Steel; 1180SHF is a "super high formable" 1180 class AHSS; and MS1700 is a cold-rolled, continuously-annealed 1700 class martensitic steel. Furthermore, the continuous annealing line (CAL) at PRO-TEC was commissioned in 2013 and is equipped with water-quenching capability and a powerful temper rolling mill that ensures industry-leading flatness. In 2018, U. S. Steel won the Altair Enlighten Award (Enabling Technology—Design Optimization) for "Martensitic Advanced High-Strength Steels for Low Mass Structural Components" featured on the 2019 Chevrolet Silverado [2].

Simply put, the U. S. Steel line of advanced high-strength steels had more than doubled in strength since 2006, as shown in the right side of Figure 1 (above) — achieved through the PRO-TEC CAL. Concurrently, the GEN1 AHSS family was extended to 980 and 1180 class in both Zn-coated and uncoated versions. As Mother Nature would have it, formability (e.g. total elongation) naturally deteriorates as strength increases; however, the PRO-TEC CAL enabled a series of 780, 980 and 1180 class "GEN1+" AHSS with improved elongation as well as 780 and 980 class GEN3 AHSS with an exceptional combination of strength and ductility. United States Steel Corporation recently reviewed the progressive development of AHSS generations and the "emergence" of GEN3 AHSS in automotive applications [3]. These generational distinctions are recapped in the following.

ADVANCED HIGH-STRENGTH STEEL "GENERATIONS"

First Generation. GEN1 AHSS evolved from low-alloy (LA) high-strength steels during the 1970s [4] in Japan and include, most notably, dual-phase (DP) steels. AHSS performance is conventionally measured by the product of ultimate tensile strength and total elongation, or UTS x TE. For GEN1 AHSS, UTS x TE is typically around 10,000 MPa·% (10 GPa·%) or greater — similar to mild steels. Recall: 1 GPa = 1000 MPa; and 6.895 MPa = 1000 psi. Note the 10 GPa·% locus in Figure 1. Produced at the PRO-TEC CAL, some advanced high-strength steels show incrementally improved properties compared to GEN1 AHSS — these GEN1+ properties may be defined by UTS x TE > 15 GPa·% [5]. GEN1+ AHSS include TRIP steels (transformation-induced plasticity); micro-alloyed multi-phase (MP) steels, and TBF steels (TRIP-assisted bainite/ferrite) such as 1180SHF, mentioned earlier.

Second Generation. GEN2 AHSS include highly alloyed Fe Mn TWIP steels (twinning-induced plasticity) and, retrospectively, Fe Cr Ni austenitic stainless steels. These materials have shown dramatic improvements to the strength/ductility balance over GEN1 AHSS, where the product UTS x TE is reportedly well above 50 GPa·% [1]. Prohibitively high costs, weldability limitations and other manufacturing issues have restricted the application of GEN2 alloys in the automotive industry.

Third Generation. GEN3 AHSS are a broad class of materials that represents a compromise between GEN1 and GEN2 steels, where the strength/ductility balance is better than that of GEN1 AHSS, but without the associated costs and manufacturing issues of GEN2 alloys. Minimum GEN3-level performance may be defined as UTS x TE = 20 GPa·% [3, 5]. For its XG3™ family of GEN3 AHSS, United States Steel Corporation employs a sophisticated heat treatment practice with a lean chemistry approach, where the overall alloy content is similar to that of GEN1/GEN1+ AHSS. The U. S. Steel XG3™ AHSS concept is shown in Figure 2.

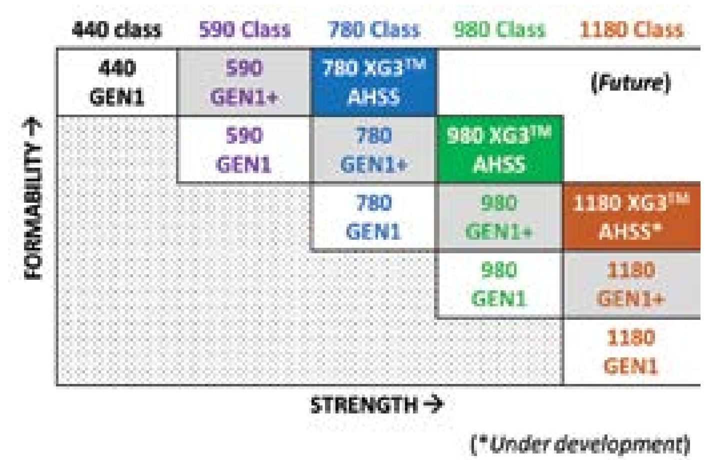

Figure 2. U. S. Steel XG3™ advanced high-strength steel concept

As a rule of thumb, for a given strength level (class), the formability of XG3™ AHSS is equivalent to a GEN1 AHSS two strength classes lower and equivalent to a GEN1+ AHSS one strength class lower. As an example, the formability of 980 XG3™ AHSS is equivalent to a 590 class GEN1 AHSS or a 780 class GEN1+ AHSS. By enabling improved component geometry and reduced metal thickness, it is anticipated that GEN3 steels such as U. S. Steel XG3™ AHSS will facilitate auto body weight reduction and lead to enhanced automotive crash performance. In a joint study with Hyundai Motor Group, it was shown that cold-stamped U. S. Steel 980 XG3™ AHSS performs comparably to hot-stamped, 1300 class press-hardened steel (PHS) when used in automotive body-in-white (BIW) structural pillars [6].

WHAT'S IN A NAME?

Our Applications Engineering and Research teams played a small role in naming U. S. Steel's family of third-generation advanced high-strength steels. We aimed for something simple, crisp, memorable and meaningful, and we felt that XG3™ captured this spirit. X is the New York Stock Exchange ticker symbol for United States Steel Corporation, and it evokes words like "excellent", "extraordinary" and "extra". The "G3" part of XG3™ of course refers to third-generation performance, while it also represents three Gs of our daily work: grade, geometry, gage. That is, using a high-performance XG3™ advanced high-strength steel grade will enable more complex and efficient component geometry at lighter gages.

ENABLING INVESTMENTS

New Endless Casting and Rolling Facility. United States Steel Corporation recently announced [7] that it will invest > $1 billion to construct a sustainable endless casting and rolling (ECR) facility at the Edgar Thomson Plant in Braddock, Pennsylvania. (see Figure 3 graphic below) along with a cogeneration facility at the Clairton Plant in Clairton, Pennsylvania — both of which are part of U. S. Steel's Mon Valley Works in Western Pennsylvania. The cutting-edge ECR technology combines thin-slab casting and hot-rolled steel production into a single, continuous process. Once completed, U. S. Steel Mon Valley Works will be the first such facility in the United States, and one of only a few in the world. The Mon Valley Works ECR facility not only will provide hot-rolled substrate for XG3™ AHSS, but also will enhance capability and improve efficiency for other steel products in the appliance, construction and industrial markets. The first coil production at the new facility is anticipated in 2022.

Figure 3. Endless Casting and Rolling (ECR) at Mon Valley Works

New Hot-Dip Zn-Based Coating Line at PRO-TEC. Known as CGL3, a new continuous galvanizing line is nearing completion at PRO-TEC Coating Company. CGL3 will complement PRO-TEC's existing hot-dip Zn-based coating lines: CGL1 and CGL2. This approximately $400 million investment by PRO-TEC will allow the production of galvanized (GI/GA) XG3™ advanced high-strength steels more efficiently and with a larger range of capabilities. This investment was made in response to the increasing demand for third-generation AHSS, and CGL3 will have a yearly capacity of nearly 500,000 tons [7].

THE NEXT DECADE

The United States Department of Energy (DOE) has challenged the industry with specific targets for future advanced high-strength steel development [8-9]. These targets are positioned along the longer axis of the GEN3 ellipse shown in Figure 1 and are described as: (1) Exceptional strength and high ductility, and (2) High strength and exceptional ductility, or, more specifically:

DOE Target	YS, MPa	UTS, MPa	TE, %	UTS x TE, GPa·%
(1)	> 1200	> 1500	> 25	> 37.5
(2)	> 800	> 1200	> 30	> 36

where YS = yield strength, UTS = ultimate tensile strength, and TE = total elongation. With demonstrated commitment to enabling investments, sustained focus on innovation, continuous improvement, and a breakthrough now and then, I believe that United States Steel Corporation is poised to meet these ambitious targets.

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ESWP Young Member Forum

Nick Lehmann

After graduating college in 2016 with a Bachelor of Science degree in Environmental Resource Management from Penn State main campus, I landed an entry-level position at a consulting engineering firm shortly after college and worked my way up to a second-tier position. The company specialized in managing the diverse environmental needs of construction projects, and I learned a great deal within my first year. I performed a range of field duties including sampling of soil, water, and air, providing oversight of contractors during field investigation and remediation, and inspecting the progress of geotechnical or environmental system installations. I continued this work throughout my time there, but eventually began mentoring incoming hires, training my coworkers on new environmental programs, and engaging in project management work as my experience grew. Throughout my two and half years of employment with the firm, I spent a large portion of time in the New Jersey, New York City, and upstate New York area at numerous project sites, and ultimately started missing my home in Pittsburgh, PA. So, I began my job search in the Greater Pittsburgh Area.

I had early success in the application process with a company and drove to Pittsburgh from my New Jersey apartment for an in-person interview in October 2018. The interview went well, however, I didn't hear anything for weeks afterward and was forced continue my search. I ventured on, applying through online job boards and company websites, and procured several phone interviews and Skype calls with a handful of local companies. I squeezed in interviews during business hours, as timely and discretely as possible, even taking a phone interview on lunch break in a noisy Manhattan coffee shop (not recommended). The results of this search were two-fold, either the company decided not to move further in the interview process, or the position was not of interest after speaking with the interviewer. Applying for a job in a different state and interviewing remotely proved more difficult than I anticipated, and the fruitlessness of a few months' labor propelled me to take a different approach.

By advice of a personal connection, I researched ESWP events for young professionals in 2019 and discovered the Engineering Career Fair. It was a no-brainer to sign up – the opportunity to stand in front of employers allowed me to circumvent this issue of communicating and interviewing remotely. I put in notice at my company by the end of January 2019 and drove to Pittsburgh a few days before the event. I spent this time developing a shortlist of attending companies to engage with based on my career goals. I researched the companies' number of employees, business sectors, and open opportunities to better tailor my conversations with them at the Fair. I arrived downtown early on the day of the event and mingled with other attendees in the waiting room beforehand. Once the Fair started, I sought out my top companies first, introduced myself, and discussed our goals. I collected business cards of the company representatives and left them with my resume. The next day, I followed up with a thank-you message to all the folks I met at the fair and received five call-backs and two interviews! Not bad for a days work!

A few weeks following the Engineering Career Fair, I was invited to two in-person job interviews. Shortly thereafter, I accepted a job offer from Advantus Engineers. I currently work as an Environmental Scientist, who consults on flow monitoring projects with the Pittsburgh Water & Sewer Authority and as a Commissioning Technician, who verifies functionality of building subsystems around the Pittsburgh area.

The ESWP Engineering Career Fair is a great networking event for engineers of any discipline or level, especially young professionals and students. My strongest piece of advice is to research company information prior to the event: click through attending companies' websites, read their mission statements, review their senior staff list, and check out the open job opportunities. I recommend polishing your LinkedIn profile – it's the Facebook of the working world – and see what the companies you're interested in posted recently. Companies want to speak with prospective hires just as much as you want to speak with them, so indicate that you did your homework by articulating your personal interest in their company.

Remember to ask them general questions too, beyond the company and its projects, because every employee traveled along a unique career path and could impart potentially valuable information about their journey.

By Nick Lehmann

Advantus Engineers

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ESWP Young Member Corner

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