by Raymond Monroe, SPI Director, Dec. 2, 2020, *2nd Issue*

Steel Performance

The development of high-performance steel was dependent on and driven by military requirements for attack and defense from the beginning. One of the oldest steel objects ever found is a dagger from King Tut's tomb from 1300 BC, made from a meteorite.

The composition was iron with 11% nickel and 0.6% cobalt, like other meteorites found in the area. Iron objects were more precious than gold or any other metal. The dagger, more than 2800 years old, shows that steel was fundamental material for defense applications from the beginning of civilization. (https://en.wikipedia.org/wiki/Tutankhamun%27s_meteoric_iron_dagger)

In this issue:

Steel Performance Initiative, continued…

Modern steelmaking depended on the ability to melt steel. The early process to melt steel was the crucible process developed by Huntsman around 1740. His steel was too hard for local cutlery makers in Sheffield. He exported his product to France. The quality was so high that English producers tried to get his exports prohibited. (https://en.wikipedia.org/wiki/Benjamin_Huntsman)

The development of steel until the industrial age, and then until today, has been characterized by the quest for higher performance. Better steels that make better swords and spears leads to the need for steels to make better shield and

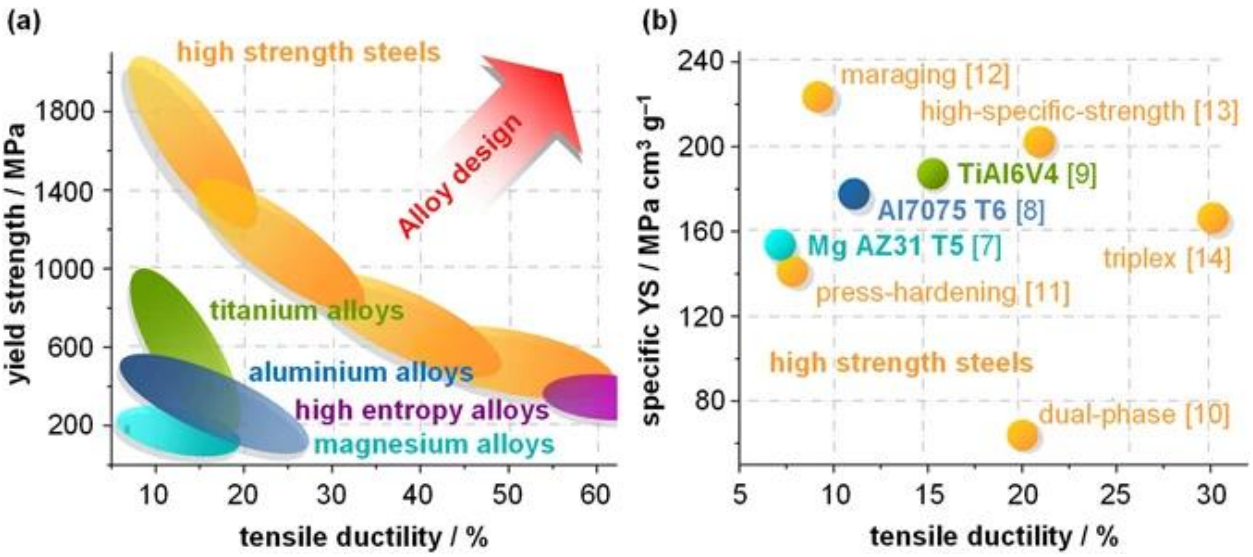
armor. Defense applications have long been the driver for steel development focused on higher performance.

New technologies for the past 50 years shifted the development investment away from steel performance. New materials like advanced composites, engineering ceramics, and light metals like titanium have benefited from the continued defense investment and have played a critical role in improved equipment. In the meantime, due to economic factors, trade strategies, and infrastructure constraints, peer allies and competitors have continued the development of steel performance. Globalization compromised domestic capability for the most advanced equipment. Fewer high-performance steel producers have survived the last 30 years, and this has hollowed out the supply chain. It has also compromised the ability to invest in maintaining the most advanced, highest performance steel production.

The Steel Performance Initiative is one part of a strategy to invest in the most advanced technology in the process and performance of steel to improve the capability of the U.S. defense community with the most advanced steel technology. This program takes the intellectual horsepower of steel experts, and with significant investment, develops domestic steel products that provide affordable equipment giving the warfighter superior protection and lethality.

What makes a steel high performance?

In general, steel performance is a balance of strength and ductility. Higher-strength steels are lower in ductility and toughness. Steel is generally superior to other products by volume but is heavy compared to alternatives like aluminum or titanium. As shown below, steel on a volume basis is stronger and more ductile but based on the weight, can be comparable to lighter materials. (https://www.nature.com/articles/s41598-017-02861-3)



The ideal steel would be alloyed to be lighter, with the highest strength, ductility, and toughness; resistant to corrosion and threats like blast or ballistics. The current developmental path in defense applications is to optimize the highest affordable strength with useable toughness and ductility like low alloy high performance steel, the highest strength with superior toughness that is resistant to cracking like high yield low alloy steel, and lighter weight steels like aluminum manganese steel which is similar to the triplex shown in the graph above.

What materials are of interest to the SPI program?

Steel. High-performance steel for the full range of defense needs is our focus. Steel is a slippery term but our core program is directed at alloys, processes, and parts that benefit defense needs and have commercial relevance. Our program is directed primarily at steel types with innovations in processing, including alloys containing large amounts of iron, nickel, and cobalt; alloyed with chromium, nickel, vanadium, etc. Work would be supported in alloy development, heat treatment, forging, rolling, and casting to affordably meet some defense needs.

Why Steel Founders' Society?

Steel Founders' Society (SFSA) has been partnered with DLA for more than twenty years providing technology and support for casting needs. In that involvement, SFSA helped support and develop all the new alloys of interest for defense. As a result of that involvement, it was obvious that the embedded funding structure was unable to invest in harvesting the developing steel technologies in a reduced and challenged specialty steel industry that is the supply chain domestically for defense requirements. In discussion with DoD experts, there was support to create this initiative to support the industry and the DoD.

SFSA is committed to balancing the program to meet DoD needs and support the full range of producers. We want to ensure that the program supports the best investments in forging, rolling, and casting to provide the full range of steel products and processes critical to DoD needs. We need the support of the OEM suppliers that responsible for supplying the equipment to the services.

One big cultural barrier is the willingness to collaborate in our steel-producing industry. We, as an industry, need to collaborate to provide DoD and our commercial customers with the best affordable high-performance solutions. The legacy of seeing other processes and other producers in the same market niches limits our ability to be innovative and robust suppliers. Steel casting producers have a culture of sharing pre-competitive technology within SFSA. In some ways, this is an artifact of the structure of the industry. Few of our casting producers have direct competitors but overlap for smaller market segments with different competitors. We are also smaller enterprises with no commodity products. Virtually all our production is customer engineered parts for a single manufacturer who designed them.

It will be difficult to succeed in the forging and rolling segments if everything is considered proprietary. For example, in steel made to ASTM requirements, the producer must analyze the chemistry and qualify the heat with a tensile test. This was done from the beginning, before the composition could be readily determined. SFSA has collected the most common alloys, thousands of heats of data from multiple sources to provide designers a statistically valid set of properties for the actual alloys instead of only the specification minimum. Data for the common alloys, 8630, 4340, 4130, could be collected from the rolling mills, forge shops, and specialty steel producers for the commercial alloy grades. Proprietary process information like heat treatment details would not be needed. But initial conversations with interested forge shops and rolling mills trigger their corporate immune system, and this data is seen as proprietary. It will be difficult, if not impossible, for the SPI program to fully benefit the forging and rolling mill industry if cooperation is not seen as a benefit rather than a cost.

How will the projects be organized?

SFSA has been organizing technology development for steel foundries for over 70 years. Our model for this is unique. We use a more medical and less industrial-academic structure. We do not see the

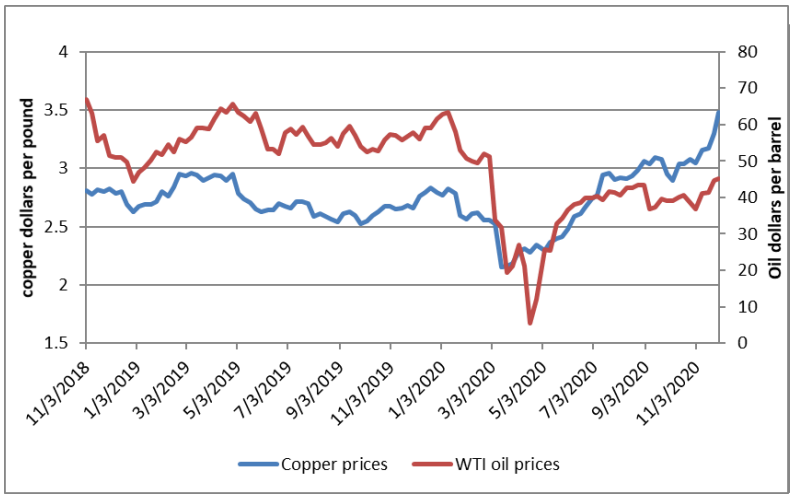
academics as teachers and industry as students. We see the industry as practitioners and academics as researchers. We expect our researchers to be interested in industrial success as the industry provides essential guidance focusing the efforts on projects and trials that will improve either process or performance. Academics tend to search for truth. Industry wants to have improvements. Every improvement is based on truth, but every truth will not yield improvement.

To be outstanding a project should have:

1. a reasonable approach based on current knowledge and intuitions,
2. an identified problem or opportunity that will improve the process or performance,
3. a researcher with a track record and interest in industrial success,
4. a producer that will collaborate with the researcher and the producer,
5. a defense need or application with commercial benefits,
6. a pervasive implementation opportunity if successful, and
7. the ability for this development to benefit the whole supply chain domestically.

SFSA has had success with this type of approach, but it requires a different culture than typical R&D efforts. We think the challenge is less money and more creative people supported to develop meaningful technology for applications. Creating trust, cultural expectations, and personal relationships will be critical is SPI is to succeed and survive.

How's business for the high-performance steel industry?



There are no sources of direct market activity that I can find for gaging the market conditions for high-performance steel industry. As a speaker for AIST EAF training, I annually look at trends in steel production and sales. They are correlated with the price of West Texas Intermediate oil and copper. Steel castings are correlated with the sales and production of steel. These numbers are available on weekly and should provide contemporaneous indications of market conditions for high-performance steels. Steel production due to the COVID shutdown collapsed by April and started increasing from June until November. Prices had been falling since early 2019 and hit the low point in September but have seen sharp increases since then. Copper and oil prices hit bottom in late spring and have rebounded since then.

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