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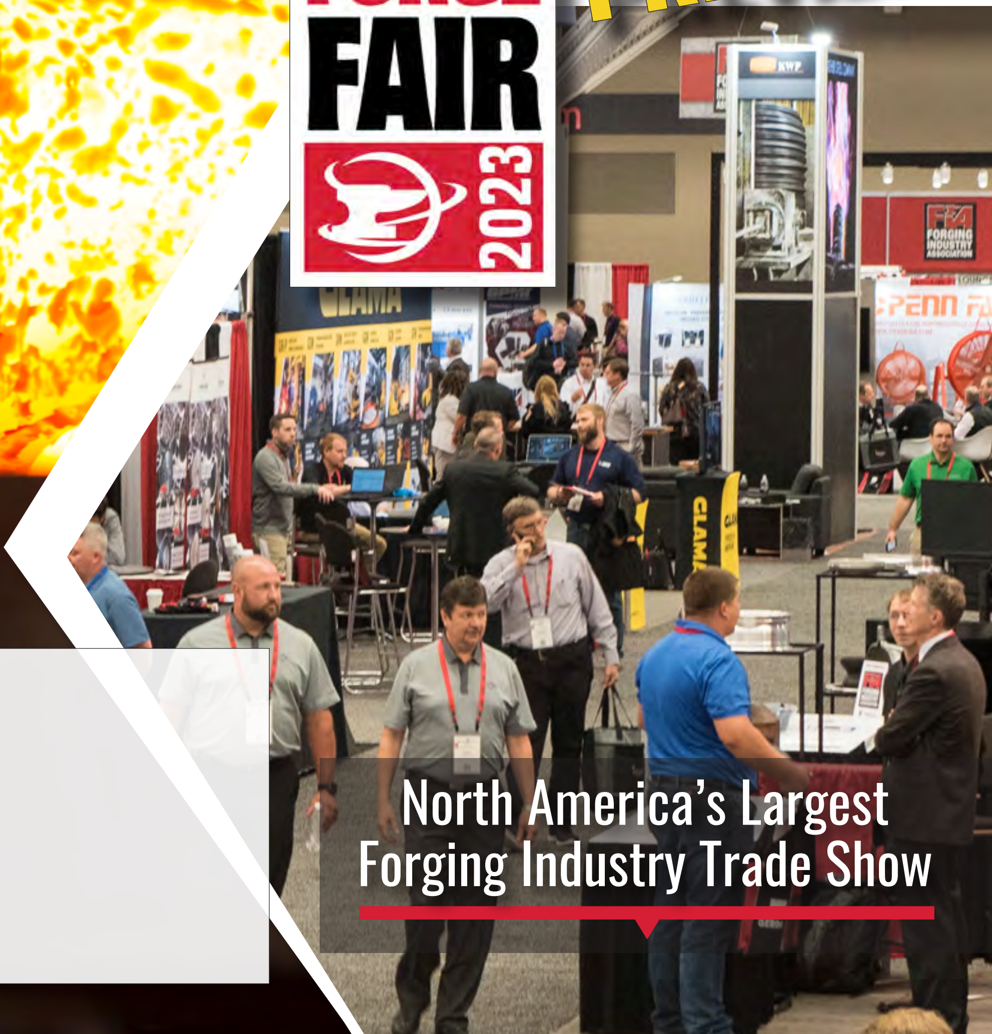


North America's Largest Forging Industry Trade Show

Total Productive Maintenance in the Forging Shop

By Jeff Fredline

Total Productive Maintenance (TPM) is an often-repeated phase, however, has not been implemented as widely as it should be for several reasons.

- It is a long process where not just procedures, but attitudes must be modified.
- It requires an investment of time and money to achieve success.
- Success/Positive Results may not be evident in the short term.
- Requires discipline to stay on track for the long haul.

Above are a few of the obstacles to implementation of TPM, now let's look at benefits. TPM drives us toward Perfect Production.

- Minimizing Breakdowns in your manufacturing equipment.
- Reduces the number of defects in manufactured components.
- Creates a much safer working environment.
- Streamlines production methods to obtain the highest efficiency.
- Using benchmarking, you come to fully understand your processes, identify each bottle neck, and improve through put of quality product.

The key to implementation of Total Productive Maintenance is adoption of the principles of 5S.

1.) **Sort -** Clean up and eliminate anything in the work area that is not necessary.

2.) **Straighten -** Organize all the items necessary for production. Have an organized place for everything and make sure that it is in its place. Shadow boards are a good start to keeping things organized.

3.) **Shine -** Now that the work area is organized, clean and inspect it regularly.

4.) **Standardize -** Streamline, create standards, work instructions, and eliminate duplication. Standardize machine components and systems where position. Such as standardizing conveyor systems and components.

5.) **Sustain -** This is the most difficult step. Once you begin, you cannot stop, or it is all for nothing. 5S must become the mindset of the organization and leads to all improvement.

If you are not willing to fully implement the principles of 5S and live by them, you will not succeed in total process improvement.

The true aims of TPM are zero breakdowns, zero defects, and zero work accidents. So how do we achieve these positive results? We have looked at implementation of 5S which is the first step in the process. If you are not willing to fully implement 5S you are able to move forward to the 8 Pillars of TPM.

1. Focused Improvement

Are your priorities clear? Goals should be to constantly improve. Focus on avoiding loss in equipment, talent, materials, and plant energy systems. One common cause of loss is compressed air. Benchmarking is the key. Machinery maintenance, operator training and monitoring of plant energy costs are critical to success.

2. Autonomy

This will cause a change in the process for most plants. The machine operators become more than just button pushers. This approach trains each operator to become responsible for their machine/work cell. They perform operational maintenance checks. They become trained to spot the problems as the machines are operating and by doing so can alert management when they first begin to see a problem. This approach can accomplish multiple benefits. First the problem is identified and corrected immediately thus saving major downtime and expense. Second the operator's self-esteem is increased as they feel more important to the operation. As you train your operators you will need to compensate them, this small cost will greatly enhance your operations. Always remember the goals: Eliminate waste and improve quality throughput to enhance profitability. One key to accomplishing this goal is improved communication between your staff.

3. Quality Maintenance

There are different aspects of Quality Maintenance. Machine inspection is key. Know what you know. Inspect, inspect, inspect. Everyone in the work cell is a machine inspector. If there is a change in function or noise for a specific machine something has changed. It is critical to investigate the changes and correct any issues. One key element of this process is Root Cause Analysis. Utilizing the Root Cause Analysis process will cause each phase of the operation to be looked at and changes put in place which will eliminate the same issues occurring in the future. Sometimes it is an unpleasant process, but the key is total honesty in evaluation of causes, effects, and correction of the issues.

4. Planned Maintenance

The best method to avoid unplanned downtime is preventative maintenance. Preventative maintenance is the process that ensures that every asset is up and running properly to maintain quality throughput without unplanned downtime.

5. Early Equipment Maintenance

Identify when your machinery may be approaching its useful life. When it is time to choose a different machine or upgrade, consider the problems of the past regarding this machine and plan to eliminate the reoccurring problems by purchasing the right machine for the future. Consider issues such as increases in production requirements. Perhaps purchasing machinery that has increased ability to diagnose problems such as robots that can self-monitor changes in production.

6. Training and Education of Operators

In order to trouble shoot a machine operation, the Operator/Maintenance Technician must have an understanding of the machines proper function. Training is the first step in implementation of preventative maintenance. Training is an ongoing process; training never stops in a world class manufacturing facility. Think about how fast machinery and particularly controls are changing. A good example of this is the introduction of Servo Press Drives for presses. In order to remain competitive in today's market, companies must continue to invest in the best technologies and increase profitability moving forward.

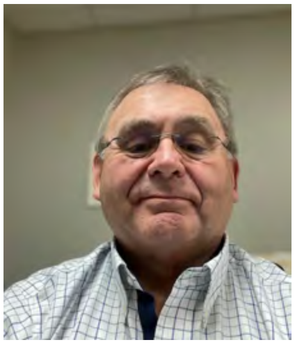
7. Health, Safety and Environment

Health, safety and environment as part of TPM include the goal of no work accidents, minimized pollution, and providing as much as possible, a work environment with the least amount of stress so that the employees do not experience fatigue or burnout. In addition, there are on going chemical conditions that must be maintained in a safe condition. The buildup of oils, die lubrication, grease, and dirt/slag around the machines is always a trip/slip hazard. Pneumatic and hydraulic lines are an ever-present hazard. In forging plants, you also have additional hazards from heated components.

8. Office/Management Participation

TPM includes the entire operation. The entire operation strives for continuous improvement to include scheduling and logistics. Every part of a business can be improved and eliminate waste. Remember Total Productive Maintenance begins with a change in culture. Traditionally there have been barriers between management and workers. TPM works to eliminate the barriers and encourages involvement by each employee. Many of the Japanese companies have worked to this goal by providing uniforms for all employees, everyone dresses the same and all are contributors.

I believe that proper maintenance is critical for all manufacturing operations. Maintenance no matter what you call it will always require investment. It has been my experience that there is a cost to not performing maintenance and a cost to properly maintain your equipment. However, there is a difference, if we fail to maintain our equipment, we will experience excessive down time which results in a reduction in throughput. Maintained equipment will also experience down time due to maintenance procedures, however generally it will be planned, thus allowing for continued throughput through preparation, such has producing a bank of parts ahead to maintain throughput even during down time. The choice is yours.



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The Lighter Side of Forged Metals

By Dean M. Peters

The markets and forging opportunities for the lighter metals of aluminum, titanium and magnesium are reviewed in this article. The high strength-to-weight ratios of these metals, their specific strengths, are what make these materials attractive to those interested in lightweighting. Increasing global demand and the geopolitical outlook for raw material supplies has led to supply chain disruptions and long-term resource planning to assure continued supplies.

Boeing 787 Dreamliner

When most people hear about forging they think of the stereotypical blacksmith pulling a glowing workpiece out of a hearth and over to an anvil to be hammered into shape. Some have seen Forged in Fire, a TV show dedicated to forging knife and sword blades. Fictional stories brought to the big screen and TV, such as The Lord of the Rings and Game of Thrones, feature much of swordsmanship and forged blades. And even golfers speak of forged sets of golf clubs as 'blades.'

But this article is not about any of that. Though iron and steel are staples of the commercial forging industry, modern applications across a variety of industrial and transportation sectors require base metals with different properties, especially those that combine strength and light weight.

So let us consider the property of specific strength. A metal's (or any material's) strength divided by its density is its specific strength. This property is also known as a material's strength-to-weight ratio, a high value of which is desirable in applications that require high strength at minimal weight. The units of specific strength are Newton-meters/kilogram. Tensile specific strength is most often considered, though a material to be placed under compressive stresses is evaluated for its compressive specific strength. Materials with high specific strengths are sought for applications in which the weight reduction or savings are more important to the application than the material cost.

Another way of considering specific strength is to determine the length at which a material of uniform cross section will, when vertically suspended in earth's gravitational field, fail of its own weight. And finally, there is the material property of rotation called maximum specific energy (with the same units as specific strength) beyond which a part will fail due to an excess of centrifugal force.

Materials of extremely high specific strengths are fibers of carbon, glass, and some polymers, but the metal forging industry is more concerned with high specific strengths among the lighter forging alloys of aluminum, titanium, and magnesium. These lighter metals and their market dynamics are the focus of this article.

A Little About Lightweighting

Lightweighting is a term that has become ubiquitous in the lexicon of the transportation industries and the metal forming processes that support them. Oddly, the term may never have been spoken by the Wright brothers at Kitty Hawk, but they were employing its concepts by definition of the nature of controlled flight. In the century since first flight, designers of aircraft have maximized the prospect offered by metals that have both strength and lightness -- high specific strength.

In modern practice, lightweighting has evolved into a broader, more formalized design protocol that involves not only materials selected for their specific strength, but variations in their alloying elements, re-imagined part geometries, modern machining capabilities, use of composite materials, and other parameters.

A great example of a coordinated and detailed lightweighting project dedicated to metal forging was Germany's Lightweight Forging Initiative (LFI) started in 2013. With the involvement of the German Forging Association and the VDEh steel institute, fifteen forging companies and nine steel manufacturers disassembled a diesel four-wheel drive car to study all the parts and determine where potential weight savings could be realized, either through material selection, geometry changes, or complete re-designs. Researchers for that first phase found the potential to squeeze out 92.5 lbs. (42 kg). The LFI went on into two subsequent phases that applied a similar analysis to a light commercial vehicle in Phase 2; and a heavy truck and electric vehicle in Phase 3.

The most important aspect of these studies was that they were forging-specific paths to lightweighting. Until then most vehicular weight reduction solutions came from changes in sheet metal applications. The LFI, in contrast, broke down powertrain and other forge-consuming systems into their constituent parts. Each of these was to see where more weight could be shaved and what methods could be used to do so.

Thus, we return to the lighter forging metals – aluminum, titanium, and magnesium. In North America aluminum and titanium markets are understood and fairly mature. This is less true of forged magnesium.

Aluminum – A Global Market in Flux

About 25 percent of global aluminum consumption is by the transportation industry. Aluminum has been a mainstay of the aerospace industry since its inception, but according to The Aluminum Association (Arlington, VA) aluminum is the "fastest-growing material in the automotive market today, expected to grow around 12 percent on a per vehicle basis by 2026. And, by extending battery range, low weight aluminum will play a key role in the electric vehicle revolution." These facts, along with aluminum used by other manufacturing industries, makes aluminum and its alloys of great interest to the forging and other metalworking industries.

Starting with the COVID-19 pandemic when the world shut down for many months and consumption patterns changed, there were

A Hybrid, Cost-Effective Magnesium Forging Technique

At the University of Waterloo (UW), Ontario, Canada, is the university's Fatigue and Stress Analysis Laboratory (FATSLab). Several years ago, the lab was tasked with examining the idea of using magnesium for automotive structural applications.

Dr. Hamid Jahed is a professor at the university and Director of the FATSLab. He became the principal investigator for the automotive magnesium project, leading a team of researchers from UW (Professors: Wells, Lambert, Arami; Graduate Students/Postdocs: Behravesh, Roostaei, Kodippili, Azqadan, Uramowski). "We considered the relatively good fatigue properties of Mg, and its good formability at higher temperatures and asked ourselves, 'Why not look at an auto component that is fatigue-critical, such as suspension parts?' Since hot forging is one of the processes usually used for suspension parts, we decided to investigate forged magnesium in the application," said Dr. Jahed.

One of the earliest challenges was to determine the optimum pre-form shape. Magnesium is an expensive metal, so the most inexpensive way to purchase it is in as-cast ingots from the smelter.

"We considered our starting point with the as-cast ingot and subjected our project to computer simulations using the Pro-CAST software platform to model the casting process and the Deform 3D platform to model the forging process," explains Dr. Jahed.

Starting with simple geometries, Jahed's research team arrived at a hybrid approach toward a finished forging. "We used an AI algorithm to combine the casting and forging simulations and determine optimum shapes to, first, re-cast the ingot into a pre-form that, second, would be trimmed and prepared to completely fill the forging die and yield a quality part."

The developed cast-forging process was then put to the test by forging an I-beam shape. The as-cast magnesium ingots were re-cast into an optimum I-beam pre-form shape (Figure 1) that was then placed into the forging die and pressed into shape (Figure 2). FATSLab was assisted for some of these steps by CanmetMATERIALS, the Hamilton-based government research center dedicated to fabricating and processing metals and materials; and Multimatic, a Canadian manufacturer of mechanical structural parts, composite materials and suspension systems. With their assistance the UW team was able to fabricate some finished parts, which will eventually be tested in the lab for their fatigue strength and life cycles.

Dr. Hamid is pleased that his research team was able to get to where they are with the magnesium forging program. "Our hybrid results are of huge potential significance to optimizing magnesium forging. I think this is the way to go to control material costs, processing costs, and still get the properties we desire in the end," he concludes.

Financial support for this project has been provided by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Forging Industry Educational & Research Foundation (FIERF).

Figure 1: Re-cast magnesium pre-forms (Courtesy University of Waterloo)

Figure 2: As-forged magnesium parts (Courtesy University of Waterloo)

global and domestic discontinuities in the supply of aluminum. When people were homebound due to the pandemic and working from home, they weren't going to bars for their beers and other beverages. The pubs that tended to serve beverages in glass bottles, were supplanted by home consumption that favored aluminum cans. This created some spot shortages for aluminum used in beverage and food cans. And pricing is also an issue. Since the throes of the COVID-19 shutdown and through to January 2023 – a 32-month span -- the price of raw aluminum increased 76 percent.

Of course, shortages in the 3000 series alloyed aluminum grades used in food and beverage cans are a far cry from the more 'exotic' (6000- and 7000-series) alloyed aluminum grades used in aerospace and other applications in which strength and low weight mattered. However, aluminum for any application starts as primary, unalloyed aluminum production. China is the global giant here, having produced 37 million metric tons in 2020 – more than ten times the production of both India and Russia individually – second and third on the global list of producers. The United States is ninth at 1.1 million metric tons of production.

Adding to the supply challenge for aluminum forgers and other consumers are the emerging decarbonization efforts in China, which is not only the world's largest supplier of aluminum but also its largest consumer. As it attempts to limit its carbon emission footprint, China limited its production capacity in 2021 to 45 million tons. Also, a July 2021 explosion at Dengfeng Power Group Co. in Henan province further squeezed production and supplies. This turned China into a net aluminum importer in 2021, further unbalancing global supply chain dynamics. In 2022, China remained a net aluminum importer, though at a reduced year-on-year level.

Despite the global discontinuities in raw aluminum supplies, demand for aluminum across most of its consuming sectors is on the rise. For the forging industry demand for forgeable aluminum alloys is driven by lightweighting initiatives for traditional automobiles, the trend toward hybrid and electric vehicles, increasing aircraft build rates by airplane manufacturers such as Airbus and Boeing, construction projects the world over, and activity in other important industries.

A recent study commissioned by the London-based International Aluminum Institute projects that global demand for aluminum is expected to increase 39 percent between 2020 and 2030, ending at 119.5 million tons. On a regional basis, China alone will account for 37 percent of the increase; Asia ex-China 26 percent; North America 15 percent; Europe 14 percent; and others 8 percent. Similarly, by industrial sector the increase in demand will be dominated by the transportation industry at 35 percent; electricity generation 16 percent; construction 14 percent; packaging 10 percent; machinery and equipment 9 percent; other 16 percent.

As will soon be made evident, the global aluminum market is not as subject to current geopolitical influence as the titanium market. Globally speaking, demand for aluminum remains strong, on the rise, and prices for energy-intensive primary aluminum are increasing. This is a scenario for long term shortages to come, or euphemistically speaking among some industry insiders, 'reallocation strategies.' Given that supply-chain issues and high demand aren't expected to be resolved soon, the global aluminum market is expected to remain tight.

Weber Metals' massive 60,000-ton press is used to produce larger forgings of aluminum and titanium (Courtesy of Weber Metals)

Various aluminum forgings (Courtesy of Weber Metals)

Titanium – Prisoner of War?

In February and March 2014, Russia invaded and annexed the Crimean Peninsula from Ukraine. Ukraine and many other countries consider this action to be a violation of international law and support Ukraine's sovereignty over the Crimean Peninsula. The annexation led to other member countries of the then-G8 suspending Russia from the group and introducing sanctions.

To a company like aerospace giant Boeing, the troubling geopolitical events in Ukraine back then prompted the threat of sanctions against the Russian economy. In particular, the Russian company VSMPO-Avisma (VSMPO), one of the world's largest suppliers of aerospace grade titanium, was considered a target for sanctions. Consequently, Boeing started a program of developing alternative supply chain paths and stockpiling titanium resources around the world. This turned out to be an insightful and smart strategic move.

Fast-forward now to February 2022, when Russia began its current invasion and annexation of additional Ukrainian territory. What was supposed to be an easy Russian victory, perhaps only lasting days, has turned into a protracted war that shows no signs of ending militarily or diplomatically any time soon.

At the beginning of the current conflict, the European Union (EU) and other countries in the West, especially members of NATO, were grappling with the question of how far to go with economic sanctions against Russia. The EU and NATO countries had to evaluate the effect of punitive sanctions on their own economies. These have primarily affected Russia's energy production and exports, but originally included in the sanctions was VSMPO, a subsidiary of Rostec, Russia's state-owned mineral and defense company.

VSMPO is a critical source in the global supply chain for titanium and the world's largest aircraft producers, especially Airbus in Europe, the world's largest commercial aircraft manufacturer. Airbus sounded the alarm and lobbied to exclude the company from the sanctions imposed by the EU. By the end of July, it was decided that VSMPO would not be sanctioned by the EU, the EU fearing that it would be like sanctioning itself.

Back in the U.S., Boeing acted a little sooner, confirming last March that it would end its existing contract for titanium with VSMPO. Up until that time VSMPO had been supplying Boeing with about one-third of its titanium. Boeing's titanium inventory and supply chain diversification gave it a head start in deciding against the Russian supplier.

Most titanium is consumed as titanium dioxide, a white pigment used primarily in paint, plastics, and paper. Global demand for titanium sponge is driven by the aerospace and industrial equipment markets. The metal is expensive because, aside even from supply and demand imbalances, the metal has a high melting point, high atmospheric reactivity at elevated temperatures, and it is difficult to form and/or machine. Nevertheless, metallic titanium has a high specific strength, and is sought for use in aerospace engine components such as discs, blades, and shafts. It also is used in airframe components ranging from small fasteners to landing gear assemblies and large wing beams. On some aircraft, titanium components account for up to 10 percent of total weight.

Titanium is produced by the Kroll process, whose steps include extraction, purification, sponge production, and alloy creation. Shaping and forming are subsequent steps to finished parts. It is typical that no company performs all these functions. Much titanium is shipped as titanium sponge, which then goes to titanium melters such as ATI, Howmet, TIMET and others, who convert the sponge to large multi-ton ingots which, in the steel industry, might be thought of as "blooms."

Jim Kravec is Vice President of Sales and Customer Relations for Weber Metals (an Otto Fuchs Company), Paramount, California. He says, "There have been some disruptions in the global supply chain for titanium sponge. Our view coming into 2023 is that we are concerned about potential shortages in the domestic market, though the term reallocation is a more accurate description. There is, however, some greater concern by aircraft engine suppliers who are having a tougher time getting the super pure titanium they need to make engine components."

"One way to get around supply chain disruptions is through 'enabled contracts,' which we have with Boeing," says Kravec. "Since Boeing has stockpiled titanium supplies around the world, we get raw material directly from them that we use to make components for their planes."

And even so, unpredictable wrinkles in the supply chain can disrupt even the most sophisticated of material resource planning models. A case in point is a furnace explosion that happened at a TIMET plant in Morgantown, Pa., on Thanksgiving Day 2022. A furnace explosion damaged the roof their titanium plant in southeastern Pennsylvania. Gladly, no one was injured, but we can assume there was some disruption of supply to the market from that facility.

The bottom line is that demand for titanium sponge is growing, consistent with increasing air travel and growing airplane fleets. Additionally, supply chain wrinkles loom as increased sponge demand is anticipated from emerging South American and Middle East/African markets. Those who supply titanium parts to the aerospace and other durable goods manufacturers need to plan way ahead to secure adequate titanium sponge supplies.

Titanium cockpit window frames (Courtesy of Weber Metals)

Titanium rotating engine disk (Courtesy of Weber Metals)

Magnesium – The World's Lightest Structural Metal

Given the existing shortages and potential supply chain disruptions for titanium and aluminum, interest has increased in the use of magnesium as an alloying material and as a forging metal. Magnesium is considered to be the world's lightest structural material and is about one-third less dense than aluminum. It is used extensively as an alloying element to improve the specific strength of aluminum alloys.

Magnesium is a rather versatile material. The principal ores from which it is recovered are dolomite, magnesite and carnallite. Additionally, it can be extracted from sea water, natural brines, and salt deposits. It can be formed by just about any metal forming process that exists, including traditional casting, diecasting, rolling, extrusion, stamping and forging. Finally, it can be joined by basic arc and resistance welding techniques.

In addition, it has excellent machinability that makes it economical even if weight saving is not critical. Its machinability is about the same as that of aluminum, but the drawback is that magnesium in chip form is considered a hazardous waste, and thus more costly to transport and recycle. In this situation, briquetting is the best solution, but the use of a coolant when machining magnesium (the safest approach) makes it more difficult to recycle. Finally, compared to the aluminum industry, the number of magnesium recyclers is extremely limited.

One of magnesium's more passionate proponents is Steven Barela, Metallurgical Engineer of Magnesium Products for Ohio-based Terves, Inc./Magnesium - USA. "Magnesium is one of the ten most abundant elements on the planet," he says. "Its number one use is in the desulfurization of steel, second is as an alloying element for aluminum, third is in the production of titanium, and fourth as a diecast product for automotive applications."

"Magnesium forging stock costs 3-4 times that of Al (6061, 2024, 7075), but a lot of this price disparity has to do with the scale of economy of magnesium as compared to aluminum," he continues. "The size of the magnesium industry is a small fraction of aluminum's, and the metal is not even listed on the London Metal Exchange."

A 2022 Market Research Report produced by the U.S. Department of Energy (DOE) claims that "magnesium alloys, being the lightest construction materials and showing good heat dissipation and vibration damping, are found to have more and more applications in the automotive industry." Automotive magnesium is used to produce components that operate at ambient temperatures.

The International Magnesium Association (IMA), St. Paul, MN, offers an attractive and useful 3D Mg Automotive Application Demonstrator on its website. According to IMA the largest producers of magnesium are China, USA, Israel, Brazil, Russia, Kazakhstan and Turkey. New plants have been built in Malaysia, South Korea and Iran, and pilot plants for future operations have been constructed in Australia and Canada.

"In the 1980s China accounted for about 15 percent of global production, yet at the present time China produces 90 percent of the world's magnesium. The state subsidizes the industry, even in the private sector. There is a problem, however, in that China runs its magnesium smelters with coal, which harshly impacts their air quality," said Barela. "In preparation for China's hosting of the 2022 winter Olympics, China curtailed its production of magnesium to improve the air, thereby causing a supply chain shortage and rapid increase in prices. This, in turn, affected steel, aluminum and titanium production in a true domino effect."

Although extrusion, stamping, and diecasting processes account for the vast majority of automotive magnesium parts, forged parts of magnesium alloys are drawing increasing interest from designers and suppliers because of their superior wrought microstructure and properties as compared of those of cast magnesium components. Steven Barela puts it this way: "The forging process maximizes the properties of a metal by eliminating porosity, converting grain structure, and tailoring the grain structure to part geometry."

A 17.5-in x 7.5-in. magnesium wheel blank (MA 14 Mg alloy) (Courtesy of Terves, Inc./Magnesium-USA)

Although interest is growing, magnesium forgings have found only limited application in the non-OEM automotive industry, that being relatively minimal forged wheels for race cars and motorcycles (F1, AMA super bikes) and some high-performance cars where its lightness optimizes acceleration and braking efficiency because of rotational mass considerations. Research at the University of Waterloo in Canada is exploring the development of magnesium suspension components (see the sidebar in this article).

Conclusion

The lighter forging metals of aluminum, titanium and magnesium are of great interest to the forging community for their high specific strength. Alloys of aluminum and titanium are common in aerospace, automotive and other durable goods applications. Magnesium is a forgeable material that is being studied for future forging applications. It has found some applications in wheels for high-performance vehicles and other limited use.

All of these lightweight metals stand to benefit from growing global demand by the industries that consume them, most notably the aerospace and motor vehicle industries. Each of the metals is subject to global supply chain discontinuities, depending on geopolitical conflicts, international economic factors, tariffs, consumer preferences and other market forces.

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