A History of Liquidmetal alloys:

You may have been reading about recent developments in metals technology from a diverse range of sources, including news articles, trade magazines, scientific publications, and investment publications. Many of the exotic metal alloys being described are actually the same material being referred to by different names. For example, Liquidmetal Alloys, Vitreloy, amorphous metal and metallic glass are basically synonyms for the same new class of metals which exhibit a non-crystalline atomic structure. To understand what these materials are, and more importantly, to understand how they are best utilized, one must first understand some basic principles of a field called “metallurgy.”

Metallurgy is an ancient practice which focuses on the development and processing of metal alloys for specific applications. Ancient metallurgists devised bronze and carbon steel alloys for weapons while modern metallurgists developed aircraft-grade aluminum and titanium alloys. Despite centuries of technological advancement, metal alloys have almost always shared the common thread of having a crystalline atomic structure; that is their atoms are arranged in naturally ordered patterns that represent the most stable form of the material (try shaking a glass jar full of marbles for a long time and watch the spheres settle into a closely packed arrangement). The crystalline structure of metals is both an advantage and a disadvantage when it comes to processing and mechanical properties. These materials exhibit broad trends that limit what can be done with them. For example, a metal’s melting temperature is usually proportional to its hardness and a material’s strength is usually inversely proportional to its ductility. This means that alloys with low melting points (which can be cast readily) are often soft and low strength while alloys with high melting points (which cannot be cast easily) are often hard, high-strength and brittle. These empirical rules have governed the development of metal alloys for centuries and it explains the competition between materials for specific applications. For example, if one were to desire a metal case there might be a competition between aluminum alloys, titanium and steel. Aluminum alloys can be cast into net-shapes, which would lower the production costs, but are soft and scratch easily. Steel sheets can be stamped and are very scratch resistant, but steel is much denser than aluminum, making a heavier case. Titanium alloys are low density and high strength but have high melting points and are not easily machined or cast, despite being more expensive than steel or aluminum. And such is the game of tradeoffs that must be played to use metal alloys in applications, a process called “materials selection for mechanical design.”

Now what if a metal alloy was developed that was not limited by the typical trends exhibited by crystalline metals? Such a metal would have low melting temperature, so it could be cast into net-shapes, yet would retain the high strength and scratch resistance of steel, while simultaneously exhibiting the mid-range density. The origins of such a material began in the 1960’s at Caltech, with the development of gold-silicon alloys that could be formed into a non-crystalline (also known as “amorphous”) microstructure at high cooling rates. By designing alloy compositions around deep melting points (also called “eutectics”), the alloy could be cooled from the liquid state (where no crystal structure exists) to room temperature without forming a crystalline structure (since the formation of crystals takes time, as with the shaking jar analogy). By rapidly cooling, one could trap the “liquid-like” atomic structure into the non-crystalline (or “amorphous”) solid creating a new class of metal alloys which can be called amorphous metals or liquid metals, synonymously. Early amorphous metals were limited to thin ribbons because of the high cooling rates required to form the non-crystalline structure. Nevertheless, low-cost commercial sheet fabrication of these thin ribbon materials lead to a very successful industry. Amorphous metal ribbons have been wound and used as transformer coils and anti-theft I.D. tags due to their magnetic properties.

So how does “metallic glass” fit with these amorphous or liquid metals? Another interesting trait is observed by rapidly cooling metal alloys from above their melting point to room temperature; they form a glass. Any metal can be cooled into a glass but most require impossibly high cooling rates. Only a select group of alloys can be cooled slowly and still form a glass. This is a property observed in many materials but is the most often misunderstood. There have been many erroneous articles about transparent airplanes and bridges made from amorphous metals because they are glasses. However, amorphous metals are conducting metals and not insulators, and by definition, cannot be optically transparent. The misunderstanding arises from the fact that glasses are not all transparent but rather are defined by a glass transition temperature, where their viscosity rapidly decreases and they start to flow. In amorphous metals, there is a temperature region between the glass transition temperature and the crystallization temperature where the materials start to transform back into liquids (with gummy consistency) and can be formed and rapidly cooled back into the glassy state. This property has been demonstrated by microprinting and blow molding amorphous metal alloys.

In some metal alloys, the formation of the crystalline structure is very slow and the alloys can be cooled at moderate rates to form a glass (as low as 1℃/s vs. 1,000,000 ℃/s with quenched ribbons). The slower critical cooling rates of these alloys allows for thicker parts to be fabricated (i.e., as long as the center of the part can be cooled faster than the critical rate). Developed at Caltech, centimeters thick amorphous metals were fabricated by exploiting the atomic structure and eutectic temperatures of these alloys. When a glassy part can be developed in a thickness greater than 1mm, it is called a “bulk metallic glass” or BMG, and these alloys are what make up the revolutionary commercial product known as Liquidmetal® alloys. Since the early 1990’s, Liquidmetal Technologies has been the world’s leading producer of amorphous metal technology and is currently the only company offering commercially available Liquidmetal products. So to conclude, while it is complicated, amorphous metals, metallic glasses and liquid metals, are actually all the same fundamental classes of materials. However, what makes Liquidmetal alloys remarkable is not what you call it, but rather what you can do with it!

Mechanical Properties of Liquidmetal:

What makes Liquidmetal a fundamentally different material than all of its crystalline counterparts are its truly unique combination of processing and mechanical properties. Much like aluminum, magnesium and zinc alloys, Liquidmetal can be readily cast from the liquid into extremely complex net-shapes. Unlike those alloys however, cast Liquidmetal parts are hard, high strength and can have a lustrous surface finish. Owing to its glassy (amorphous) structure, Liquidmetal alloys have strength similar to high carbon steels (1.9 GPa, 270 Ksi compressive yield strength), extremely good corrosion resistance (due to a robust passivation layer), high hardness (Vickers 550, HRc 51), and moderate density (6 g/cm^3). It is these combination of properties that makes Liquidmetal alloys remarkable; they can be cast like plastics into complex net-shape parts and simultaneously have mechanical properties similar to the best titanium alloys right out of the mold. Crystalline steels and titanium alloys cannot be easily cast, due to their high melting temperatures, and must be machined at great expense to form a complex net-shape. Liquidmetal Technologies, and its Certified Liquidmetal partnership with Visser Precision Casting (VPC), has developed a casting process by which high-tolerance parts with a high glossy metallic finish can be fabricated in a single high-tonnage process, opening the door for a myriad of potential commercial applications.

In what Applications do I use Liquidmetal?

Although Liquidmetal alloys represent a paradigm shift in the way that metal alloys can be used, they have a particular subset of applications where they are best suited. There is virtually never a single materials solution to a particular engineering problem but every application has a material which is the best combination of cost, properties, and processing. Identifying applications where Liquidmetal alloys are superior to alternative materials due to their processing or mechanical properties is the key to making a successful product. In contrast, it is also important to understand their weaknesses. After all, there is never a single material which can be used for all applications.

The most common request of Liquidmetal alloys is for high-temperature applications, such as in engine components, for example, due to their high-strength and net-shape casting ability. This is a common demand for new high-performance materials but is fundamentally flawed for Liquidmetal alloys because they are designed to have as low a melting temperature as possible to form the thickest glasses. Liquidmetal alloys can never be used at service temperatures near their glass transition, otherwise they will begin to flow and eventually crystallize. Although there is some variation from alloy to alloy, Liquidmetal alloys are typically only used in continuous service below 250 °C (482 °F).

The next thing to consider when selecting applications for Liquidmetal alloys is the size or amount of material required. As with high-temperature applications, the mechanical properties of Liquidmetal are alluring for structural components as well. There are many articles about making bridges, cars and even buildings out of amorphous metals, for example. The most important thing to consider is that these alloys are not replacements for steel and aluminum in high-performance structural applications, both due to their cost and their limitations in scale. Liquidmetal can only be fabricated into parts that are several millimeters thick. Large-scale structural members, like architectural I-beams, are not possible. It is fundamentally possible to make large panels or sheets out of Liquidmetal with millimeter thickness, but this technology is currently under development. Car bumpers, aircraft panels and energy absorbing structures for ships, for instance, are all great applications that are not possible with currently available technology.

The best applications for Liquidmetal alloys are discovered by considering (1) small plastic parts that could benefit from being replaced with metal, (2) machined metal parts that could be replaced with net-shaped cast parts, (3) mechanical properties that cannot be obtained with crystalline metals or plastics, and (4) high-value added parts. Because Liquidmetal alloys are similar to crystalline titanium alloys in density and strength, it is helpful to consider replacing titanium with parts that can be cast, instead of machined.

(1) Replacing small plastic parts with Liquidmetal: For plastics to be replaced with metal there must be a reason. Plastics are cheap, extremely easy to cast, and are fairly durable. Unfortunately, there are many applications where the plastic is too soft, low strength, and not durable enough to survive normal use. Moreover, the finish of plastic can never be as lustrous as a polished piece of metal in a consumer part, which gives the metal part the illusion of superior internal construction. Electronic casings (cell phones, laptops, cameras, video games, among others) are perfect examples where plastics may fall short in mechanical properties. Liquidmetal alloys can be cast with extreme precision, just like plastics, but with the added benefits of metal durability and lustrous finish. However, there is a tradeoff in cost that must be considered. If the part is being sold for much more than its cost of materials, then it may be beneficial to have a slick metallic finish on the part than a standard plastic. However for low cost parts, like plastic children's toy, Liquidmetal is not the correct selection.

(2) Machined metal parts that can be replaced with cast Liquidmetal: These applications should be used when a metal part (such as a hinge, fastener or small electronic component) must be machined from a piece of metal. Steel stamping technologies excel at making complex metal parts but often they are not capable of reaching the tolerances necessary for small parts. This is also true where the metal part requires threaded holes, flanges or contours that cannot otherwise be stamped. If a metal part must be machined, it is a good candidate for replacement with Liquidmetal alloys, as long as the working temperature is relatively low.

(3) Mechanical properties with Liquidmetal that cannot be obtained otherwise: The best applications for Liquidmetal alloys are the ones that take advantage of both the unique mechanical behavior of the alloys and their processing ability. Take the golf club, for example. A Liquidmetal golf club can be cast in a single processing step and yet has elasticity and strength that exceeds all competitors, including steel and titanium. The "bouncing ball" demonstration found at www.liquidmetal.com is a good demonstration of this property. Ruggedized cases are another ideal application where properties and processing merge. A Liquidmetal case can be cast into a net-shape with a perfect surface finish but is also scratch resistant and durable. To identify such an application for Liquidmetal requires a complete understanding of how a particular metal or plastic part is manufactured as well as its intended use. If the metal part is difficult to machine, requires a high polish, needs to be scratch resistant, has complex features, is subjected to a corrosive environment, or requires high elasticity, then the part is a good candidate for replacement with Liquidmetal.

(4) High-value added Liquidmetal parts: This refers to when the cost of the product greatly outweighs the cost of the materials (which generally requires some sort of exceptional craftsmanship or unique application). There have been many successful applications for Liquidmetal in this arena, including in watches, jewelry, high-end cases, and dental devices. Liquidmetal alloys can be combined with other high-performance alloys to form exceptional parts, such as the Omega Planet Ocean Liquidmetal watch, which relies on the look of the material more than its function. In another application, dental implants cost far more than the materials from which they are fabricated. If some cost or processing advantage exists for Liquidmetal compared to conventional materials, then it is well-suited.

These four rules offer a general guideline of how Liquidmetal alloys can be integrated into a wide variety of products, ranging from consumer hardware to missile components. By understanding the underlying science of Liquidmetal alloys, many applications may be possible that have not even been considered. After years of discussions with potential customers, there are some general properties of Liquidmetal alloys that must also be considered during design. Compared with their crystalline metal counterparts, Liquidmetal alloys have low stiffness (Young's modulus of 75-100 GPa). Even though they have among the highest strength-to-weight ratio (i.e., specific strength) of any metal alloy (300 kN·m/kg), they are very flexible and not stiff.

The applications for Liquidmetal alloys are growing significantly and hopefully this article will begin to explain the breadth of uses for this truly novel materials innovation. There are many applications for Liquidmetal that are already under investigation and prototyping but the true impact of this material is yet to come. In time, the use of glassy metals will be as ubiquitous as plastics in our everyday lives. If you have a potential application for these materials, the staff at Liquidmetal Technologies has more than 15 years of experience with prototyping and commercially casting products. Now in a relationship with a high-performance metal supplier, Materion Brush, Injection Molding Machine experts Engel, and a precision casting company, Visser Precision Casting, Liquidmetal is ready and willing to quickly develop your product and bring it to market. Moreover, with headquarters and partners located in the United States, working with Liquidmetal Technologies not only supports the U.S. workforce, but is also a perfect for defense-oriented work. Please contact us by using our Contact Us page on our website for more information. We will be happy to discuss your application and how Liquidmetal can help you.

- Liquidmetal Staff