A Sound Decision

Liquidmetal alloy in Musical Instrument Applications

Musical instruments have a rich and long history based on the successful use of traditional materials. This includes organic materials like wood and man-made materials such as various metals, fiberglass, various plastics, and even carbon fiber laminates. Each of these materials has been employed at various periods in time based on their availability, cost, durability, ease of manufacturing, and most importantly to the musician and listeners, the acoustic properties of the material being used.

The acoustic signature of even a single musical note and how that note is perceived within the range of human hearing is not simple to describe. There are six basic properties which define a sound: 1) the fundamental note being produced (frequency/pitch), 2) the audible volume produced by the instrument (amplitude/loudness), 3) how much time a projected note will last before it decays below audible range (duration), and 4) the "richness" of the sound being produced (spectrum/timbre). The last two properties are 5) the contour of the sound as it evolves over time (envelope) and 6) the placement of the sound relative to where it is heard (location), which are both important features - but less relevant to this study.

Audio volume and decay period are easy to understand and measure. “Richness” of tone is often the most difficult aspect to quantify and understand. An individual note produced by a musical instrument is rarely produced as a single frequency. Instead it typically comprises the fundamental frequency as well as harmonic notes often referred to as “overtones”. A note may both include octave based harmonics and non-octave interval harmonics such as “3rds”, “5ths”, “7ths”, “9ths”, and “11ths”. Where a single note is comprised of numerous harmonic frequencies the note may be described as “rich”, “warm”, “dark”, “brassy”, “bassie”, or “shrill” based on how the human ear interprets the combined frequencies. Over the years, increasingly precise measuring tools have been developed to help the musical instrument designer understand how changes in material and geometry will affect these harmonics and the resulting final sound.

The guitar is a musical instrument that has gained improvement and popularity since the 13th century with roots that date back to the time of Egyptian Pharaohs. Its construction utilizes components whose primary function are the facilitation of vibration in order to amplify sound or structural in nature to transmit vibration with minimal energy loss. In the case of an acoustic guitar, the soundboard is made from a lightweight and stiff wood such as spruce that can be caused to vibrate by the plucking action of a string though a structural transmitting member called a bridge. The conduit between the string and the bridge is commonly called a “saddle”. Various materials have been used for the saddle over the past 600+ years. These include dense hardwoods such as Ebony, Maple, and Rosewood, animal horn, bone, and ivory, various crystalline metals such as brass, bronze, aluminum, titanium and steel, as well as reinforced thermoplastics, resin/mineral composites, and even carbon graphite.

For many years, natural ivory was the default material choice for many guitar makers. It was readily available, easy to shape to the desired geometry, reasonable in cost, and had predictable acoustic properties. While known to develop cracks with age, ivory exhibited excellent resistance to taking a compression set where the string contacted the saddle. Today, use of ivory is limited in its use due to ethical reasons as well as international treaties such as CITIES which prohibits goods that utilize ivory from entering countries that have signed the treaty. Instead, guitar makers rely on saddles that are made from bones that are the byproduct of bovine meat production. The density and tensile strength of the saddles can vary widely depending on the donor species and the nature of the type of bone being used. Various commercial attempts have been made to make saddles using resin based thermoplastic molding and casting. These man-made materials often utilize the addition of pulverized bone, natural minerals and/or glass fibers to increase the tensile strength, hardness, and reduce elements such as compression set and creep.

Liquidmetal alloy is a new class of material (scientifically termed “bulk metallic glass alloys”) now available commercially to musical instrument designers for the first time. It offers the ability to allow instrument components to perform their acoustic purposes in enhanced ways, while offering unique and superior physical properties that are not available with traditional materials. Additionally, the molding process used in the Liquidmetal manufacturing process offers freedom of geometric design that would be unthinkable for traditional materials, and can be duplicated with unprecedented accuracy over and over. In combination with unique amorphous (liquid-like atomic arrangement) metallic physical properties, Liquidmetal alloys offer more than 10x greater compression strength than bone, and displays a magnitude of elastic resilience that is uncommon in other metals traditionally used in the musical instrument industry.

EXPERIMENTAL SETUP

To prove the theory that Liquidmetal alloy can demonstrably enhance the acoustic performance of an instrument when compared with traditional materials, a simple test was designed and implemented. The test compared acoustic signatures (four of the six properties described previously) of a guitar played with saddles and bridge pins constructed from different materials. The saddle and pin components were chosen strategically because they are both critical transmission points for acoustic energy between the vibrating string and the guitar body which amplifies and conditions the sound by means of its construction. A high-quality luthier built folk-style steel-string guitar was selected for the test. All testing was done with the room temperature being between 70-72 F° and Relative Humidity of 45-50% to insure that Db output would not be affected significantly by changes in the moisture content of the wood used in the construction of the guitar.

The test guitar had been built utilizing a saddle made from bleached cow bone and typical plastic bridge pins. Both the guitar and the saddle were 10 years old, and were considered to be both mature and stable from a materials and structural point of view.

SADDLE SPECIFICATIONS

The Liquidmetal saddle was CNC milled from an LM105 rectangular bar stock to the same height, length, and top longitudinal radius as the original bone saddle. For comparison, a commercially available after market saddle made from a custom formulated engineering grade thermoplastic was modified to be dimensionally similar to the original bone saddle. Because Liquidmetal has a higher density than plastic or bone (though it is lighter than stainless steel at a mere 6.57 g/cc), seven "windows" were cut through the Liquidmetal saddle in order to make a more meaningful comparison (the mass of the three saddles being most similar). Between each of the windows a vertical support was integrated in order to provide an uninterrupted pathway for vibrational energy to be transferred from the string to the soundboard through the bridge. From a mechanical engineering perspective, this geometry would be unthinkable for use on a saddle made from bone due to the complex machining required and the strength limitations of bone itself. This geometry and other more complex geometries are easily reproducible at low cost thanks to the Liquidmetal manufacturing process.

BRIDGE PIN SPECIFICATIONS

Liquidmetal bridge pins were molded net-shape from LM105 on an Engel Liquidmetal Edition injection molding machine in a single-cavity prototype tool. The pins were removed from the runner assembly and buffed to a mirror finish as a final cosmetic step. The pin size most closely conformed to a slotted 2A .220” diameter design - about 1.1” in length. The pins were compared directly to typical plastic bridge pins. No special effort was made to reduce the mass of the Liquidmetal bridge pins at this time.

TEST APPARATUS & ELECTRONICS

A suitable test rig was developed that could repeatedly strike individual strings with a repeatable force and a uniform contact length of the pick against each string. The rig comprised a miniature linear slide, a plectrum holder attached to the moving portion of the slide and a height adjustable support on each side of the mounting bar for the slide. The slide was slowly pushed until the pick made contact with the desired string, and then until the picked flexed out of way the causing the string to be plucked. Using this method, it was determined that the results were highly repeatable and that three test samples for each string/saddle material combination would yield accurate and meaningful results.

The guitar was fitted with a K & K Sound Pure Mini Transducer System to pick up the vibrations directly from the maple bridge plate mounted on the underside of spruce top directly underneath the bridge. Analysis was made using the iPad app SpectrumView+, published by Oxford Wave Research based in Oxford, UK. The software was chosen to analyze and measure the comparative dBFS (Decibel Full Scale) output of the full frequency of fundamental and harmonic frequencies being tested, and was fully compatible with the passive K & K transducer pickups.

In the test procedure the guitar was fitted with new strings and the bone saddle and tuned to standard “E” tuning. With the SpectrumView+ software recording, each string was plucked once using the test rig with no attempt made to dampen the other strings. The recording continued until the software confirmed that the Db level of the produced tone was below that of ordinary human hearing in a close quiet setting and the test was repeated twice more before moving onto the next string. The test was repeated twice more for each of the “open” strings tuned to E, A, D, G, B, and E. The guitar was then de-tuned, the saddle swapped with the next saddle, then re-tuned to standard “E” tuning.

RESULTS

SADDLES

In the primary test using the bone saddle, the peak decibel level for each of the three test recorded tones was determined, logged, and averaged. The process was repeated for each for the remaining five strings. The test was then repeated for the thermoplastic saddle. Lastly, the test was repeated with the prototype saddle made from Liquidmetal. With regard to measured amplitude, the Liquidmetal saddle produced 2-7 dB higher output than saddles made from traditional bone or filled thermoplastic material. This confirms what the musician hears when playing a guitar fitted with a Liquidmetal saddle; the tones produced by the various strings of the guitar are not only louder, but more uniformly louder across the six open strings from low to high E. *Figure 1* shows the measured dBFS values for the three different saddle materials tested using the experimental setup described earlier.

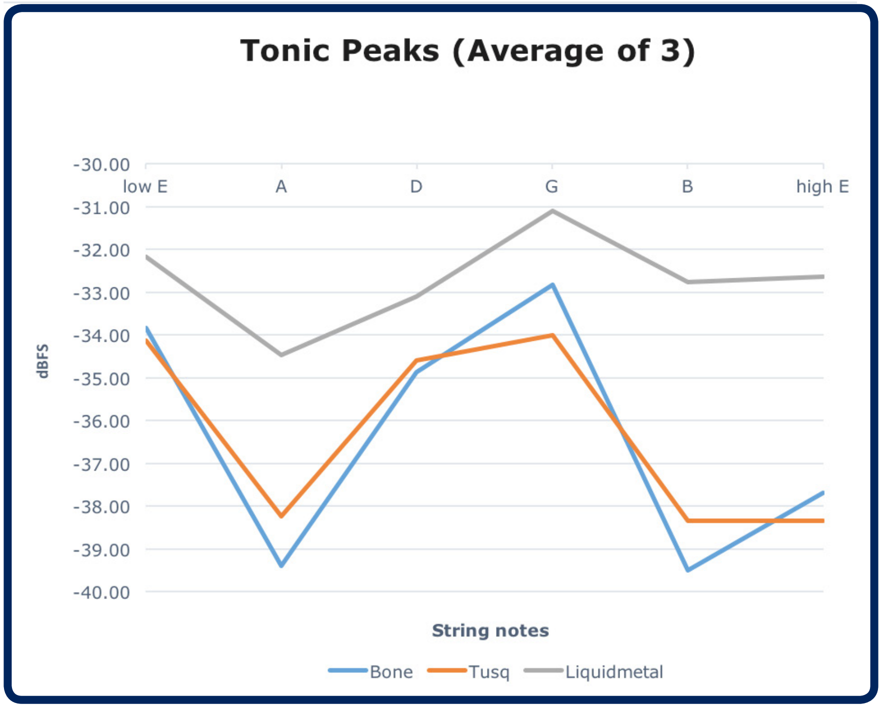

Figure 1: Measured amplitudes in dBFS for each of the six guitar strings shown when played with bone (dashed line), Tusq (dotted line) and Liquidmetal LM105 (black solid line) saddles.

In a secondary evaluation, each of the saddles were tested to gain an understanding of how the switch to Liquidmetal would affect the harmonic properties of the note being produced. The results show that the use of Liquidmetal alloy enhances desirable harmonics and overtones, and does not bias the tone in any undesirable way.

The chart in *Figure 2* shows a harmonics study conducted on a single string (B) comparing the results of the Liquidmetal saddle to those of the bone saddle. Significantly, the fundamental frequency and 6 of the 7 harmonics are all louder and contribute to a richer overall sound.

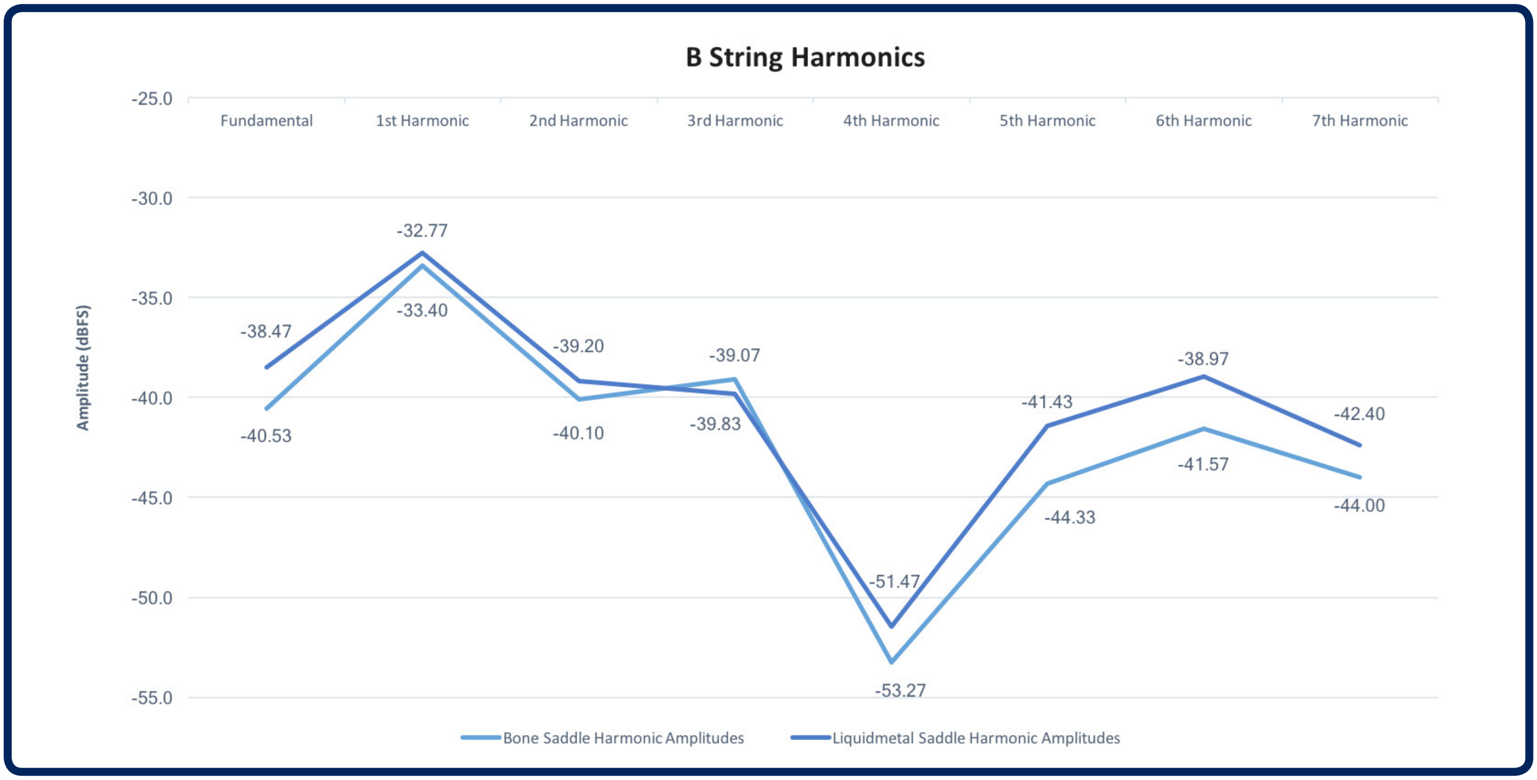

Figure 2: Measured higher order harmonic amplitudes for the guitar B string when played with a bone saddle (blue trace) and Liquidmetal LM105 saddle (orange trace).

BRIDGE PINS

Liquidmetal also performed acoustically superior to traditional plastic bridge pins when tested using the same experimental setup. As can be seen in *Figure 3* when compared with plastic, the Liquidmetal pins produced an average increase of 3.6 dB across all six guitar strings when plucked individually. The same chart shows an increase in sustain for each of the six strings, with each note lasting an average of over 3 seconds longer. This is a remarkable result for a simple change of bridge pin material.

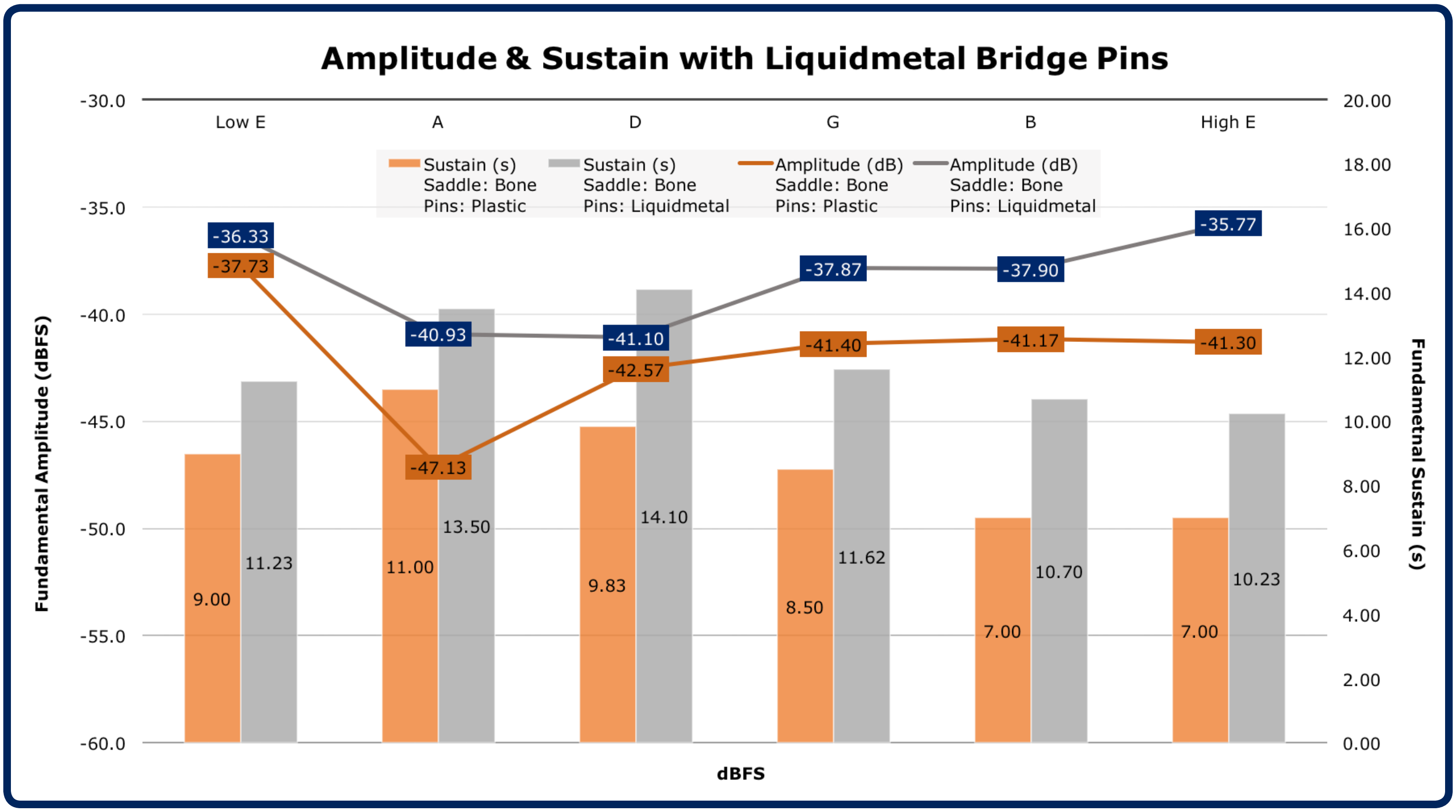

Figure 3: Measured amplitude and sustain on the six strings of a guitar played with Liquidmetal (gray) and plastic (orange) bridge pins. Each string was measured independently and the fundamental frequency measured. The left-hand vertical axis indicates the decibel level of the note, and the right-hand vertical axis the length of the audible note.

QUALITATIVE DISCUSSION

How does it sound? A few accomplished guitar players had the opportunity to play the guitar with saddles made from traditional materials and Liquidmetal. They were not told that the Liquidmetal saddle had any different or better physical properties. When asked for comments, they commented that the Liquidmetal saddle sounded louder, clearer, and richer than either the bone or filled thermoplastic saddles. They told us that the guitar seemed more responsive and was easier to play softly while still having full-bodied tone. The guitarists were able to clearly articulate what their ears were telling them and the test results confirm that their ears are indeed highly perceptive to the changes in volume and tone. In summary, the Liquidmetal saddle produced greater acoustic volume and richer harmonics than traditional materials, and skilled guitarists could hear and appreciate the difference.

CONCLUSIONS

In summary, this study shows that Liquidmetal is an acoustically intriguing material with the ability to conduct sound energy efficiently and uniformly across a wide range of audible frequencies. We have shown that when thoughtfully applied to instrument design, Liquidmetal can elegantly enhance tone amplitude, sustain, and timbre. Additionally, it can also be molded into complex geometries, has better corrosion resistance than stainless steel, can be produced with the repeatable dimensional accuracy of precision CNC operations, and can exhibit cosmetic quality appearance quality visual appearance.

Talk to the experts.

Wondering how Liquidmetal alloys might work for your application? We invite you to download our design guide and speak with Liquidmetal scientists and engineers. We are challenging everything you know about metal parts processing. Why not challenge us?

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(949) 635-2100