Lightweight Aluminum Bridge Decks - 40+ Year History, 72 Examples

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A lightweight bridge decking that is reliable, long lasting and safe has been sought for decades if not longer. The reasons for the interest includes heavy movable bridge structures where the lighter the movable elements the better the design, and where the attributes of reduced dead load can mean an increase in bridge capacity and/or the potential to a widen bridge structure.

The original lightweight bridge decking is wood. It was used for centuries but its drawbacks are obvious. More recently fiber reinforced plastic has received a great deal of interest but there are others. Open steel grid, partially filled steel grid and other steel grating type systems are among the most used lightweight decks in this country. Typically these decks are not composite with the supporting superstructure but some decks are. This is true of the steel orthotropic decks, and for some of the latest efforts in aluminum bridge decking.

The most optimal attributes for a lightweight deck system include:

- Being lighter than what is customarily used. Concrete decks weigh 100 pounds per square foot if 8 inches thick.
- Being durable – concrete decks last 25 to 35 years when subjected to deicing salts with some intermediary work. Some of the other alternatives discussed previously last a little longer when subjected to deicing salt environments but most do not last this long.
- Being structurally sound or of structural significance.
- High fatigue strength (it should be designed to provide infinite fatigue life).
- Being safe by providing good skid resistance, not affecting the driver’s steering or by causing discomfort as a result of seeing through the deck.
- Low in maintenance.

So how does aluminum bridge decking measure up?

- Aluminum bridge decking systems are considerably lighter than concrete. They run from about 20 pounds per square foot up to about 32 pounds per square foot with the wearing surface. The aluminum bridge decks are also lighter than most steel deck alternatives even with the asphalt overlays.
- Aluminum bridge decking is durable. It is possible that the latest aluminum isotropic bridge deck system may last upwards of 100 years or more.
- Aluminum in structures? Aluminum’s structural characteristics in airplanes are exemplary yet they are not taken seriously in the infrastructure market. However they have proven themselves for decades in this situation as well.

Some notable examples of aluminum bridge structures include a portable aluminum bridge designed to meet the needs of Virginia Power in the early 1970’s. Pictures of the design follow.

VA Power Transformer and the portable aluminum bridge designed to carry it over inadequate bridges - Circa 1996

The problem that faced Virginia Power at that time was how to get some very heavy transformers to one of their new nuclear power plants. The existing bridges were too weak to carry the transformers so a portable aluminum bridge was developed that could be assembled at the bridge site, then placed over the existing bridge such that the aluminum bridge would carry the load over the bridge. The existing bridge never saw any of the transformer load.

Portable aluminum bridge being load tested just prior to transporting the transformer.

The pictures shown above is the same portable bridge about to be employed again for the same purpose. The pictures were taken circa 1996 as the bridge was load tested.

Another example of aluminum in US infrastructure includes the aluminum girder bridge over the Appomattox River. This bridge was developed by Reynolds Metals Company working cooperatively with the Virginia Department Of Transportation (VDOT) and was installed in 1961.

The bridge girder is made of aluminum alloys that do not require paint even when subjected to the ravages of deicing salts. The pictures that follow are of the bridge are as it appeared in March of 2009.

Petersburg aluminum bridge over the Appomattox River as it appeared in March of 2009. The bridge was installed in 1961 without paint.

Of special note is the photograph of the steel bearing at the abutment. What is shown in the picture that follows is the steel to aluminum connection after 48 years of service.

Steel bearing bolted directly to the tension flange of the aluminum girder. Note the absence of paint and lack of corrosion after 48 years of service.

It is clear that galvanic corrosion can be controlled. How? The lesson being provided is that galvanic cells are essentially batteries. In the case of the connection shown the aluminum is the anode, the steel the cathode and they are undergoing minimal corrosion as a result of the absence of an electrolyte. No water, no electrolyte, no battery, no problem.

Aluminum bridge decks have a continuous surface so you cannot see through them. The Swedish system uses a 1 to 2 inch asphalt overlay system that is field applied after the deck is installed. The asphalt is applied after a thin flexible bitumen membrane is flame applied to the aluminum. The purpose of the membrane is to ensure the mechanical joints in the deck are sealed and to prevent reflective cracking.

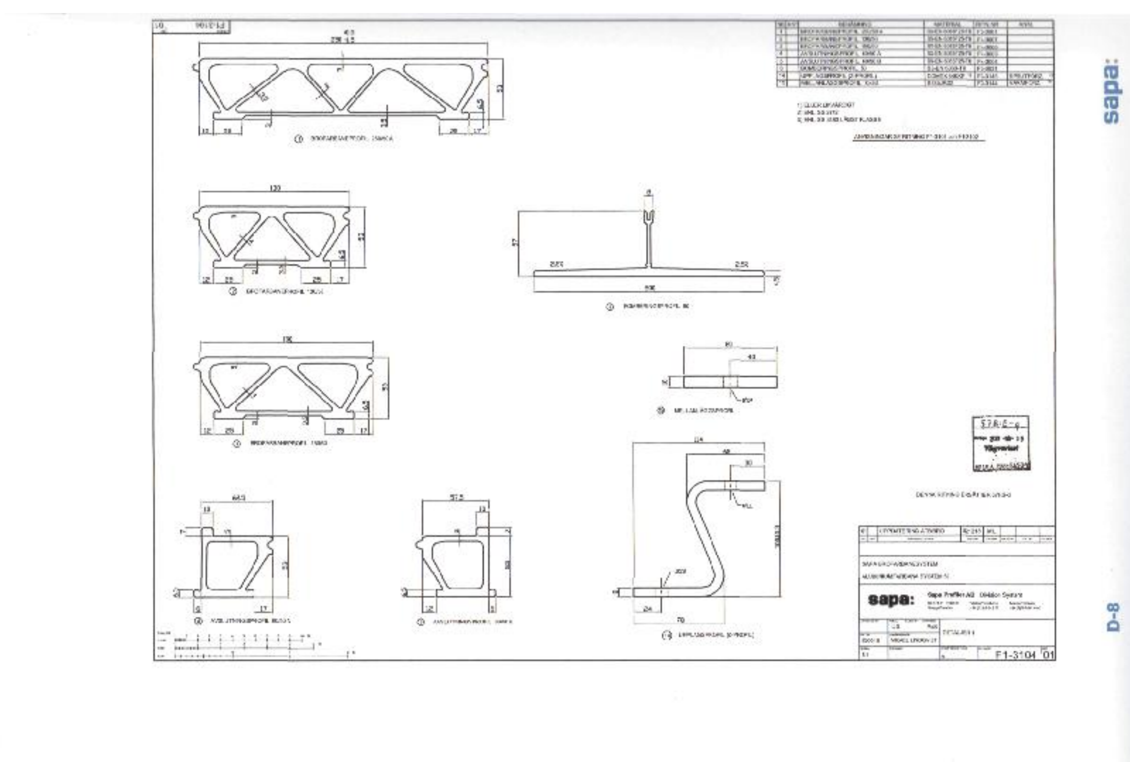
The all welded aluminum bridge decks use a 3/8” polymer concrete. The polymer concrete is nearly the same as the polymer concretes now employed by many DOT’s to seal concrete decks. The purpose of the thin polymer concrete over concrete is to seal the concrete to prevent the influx of deicing salts thereby protecting the steel and enhancing the life of the deck. It so happens that these wearing surfaces are polyurethane epoxies and getting polyurethane to adhere to aluminum is well understood. Thus far these polyurethane epoxy based wearing surfaces are performing well on the aluminum decks after 13+ years of use.

Since the wearing surfaces used are either asphalt or of polyurethane epoxy with a high skid resistance, the wearing surfaces employed on aluminum bridge decks are durable, provide good skid resistance and they do not affect the steering of a motor vehicle.

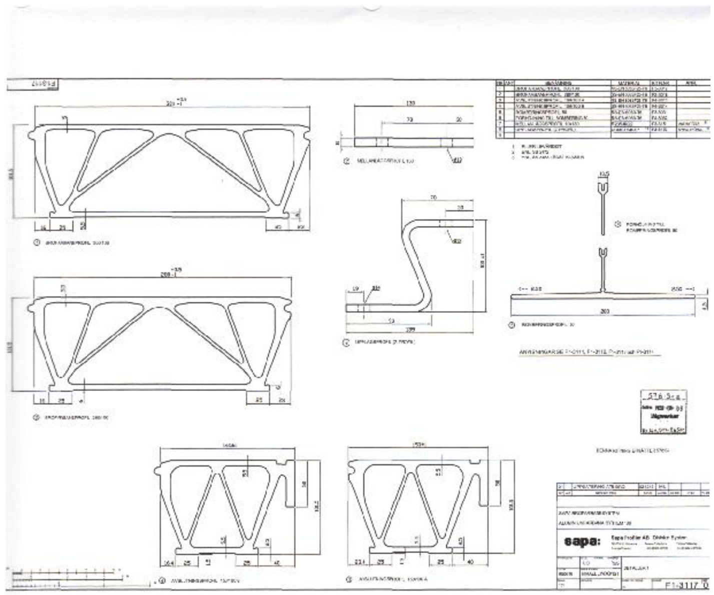
Aluminum bridge decks are made of aluminum alloy 6063. This alloy is composed of aluminum, magnesium and silicon. It is very corrosion resistant and does not require paint in order to have corrosion resistance. No paint means little or no maintenance is required.

Aluminum bridge decks have been used in Europe since the late 1980’s. There are now 70 bridges employing aluminum bridge decks and they are non composite with the steel superstructure that supports the aluminum decks.

The design most used is out of Sweden. It was initially developed to replace wooden decking primarily on movable bridges. It even simulates wood in that it is a plank construction yet it is also very different. The Swedish system comes in two different sizes. The first is a plank that is called ‘System 50’ because it is 50mm deep.



The second is known as ‘System 100’ because it is 100mm deep.



This bridge deck system is known as the System 100 so named because it is 100mm deep. Note the tongue in groove system on each side of the extrusion.

Both aluminum planks are roughly 10 to 12 inches wide and employ a tongue in groove connection between adjoining aluminum planks. They are both engineered systems which use a well thought out and designed hold down system. The hold down system ensures that the tongue in groove connection is continuously forced together as traffic crosses it (it is oriented transverse to the direction of traffic) and provides adequate strength against vehicle dynamics, wind, and fatigue loads.

The System 50 with an inch of asphalt installed on a bridge will weigh approximately 22.75 pounds per square foot, and the System 100 with an inch of asphalt will weigh approximately pounds 32.75 per square foot.

As stated earlier, the Swedish bridge deck systems are now used on 70 aluminum bridge decks in Europe. With few exceptions they are doing well. The exceptions that did not do well include the very earliest installations installed prior to 1989 when it was learned that without a proper membrane beneath the asphalt the asphalt will develop reflective cracking over the tongue in groove joints leading to water leakage into the joint which causes a failure due to crevice corrosion.

Examples of movable bridges in Europe using the Swedish bridge decking system follow:

Movable Bridges in Europe that use one of the Swedish aluminum bridge deck systems.

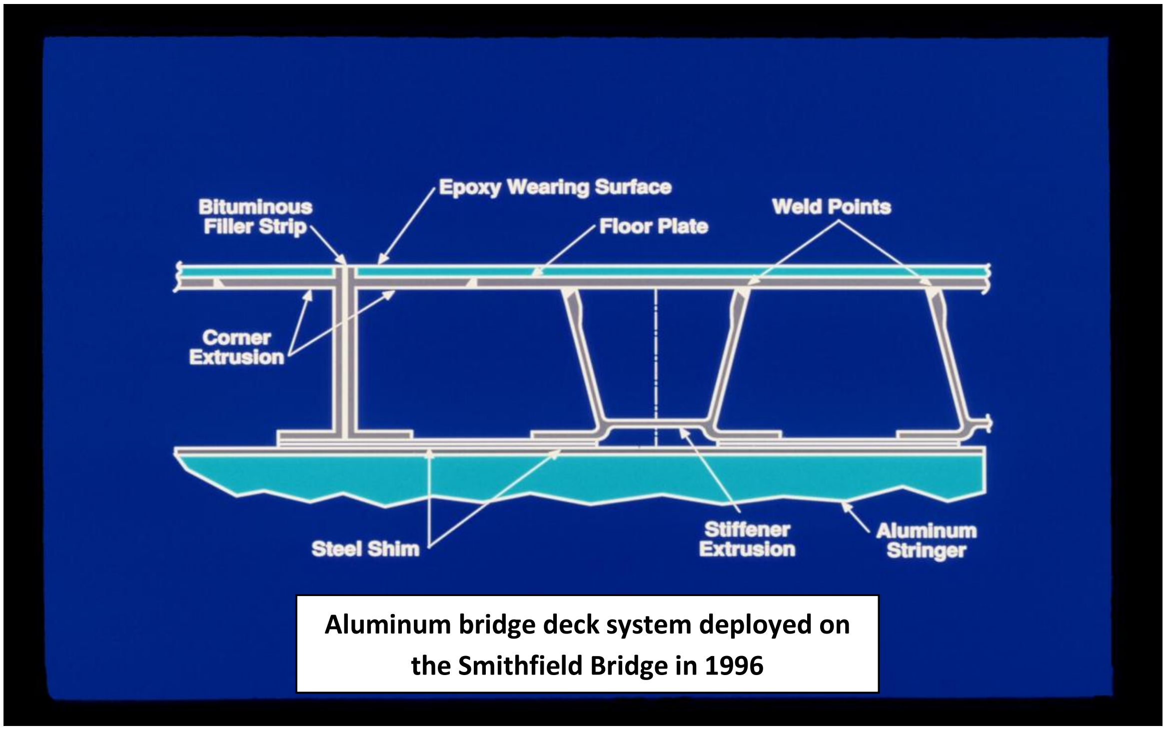
Europe is not the only place aluminum bridge decks have been used. The very first two aluminum bridge decks known to have been installed were deployed in the United States first. They were developed by Alcoa to fit a need to reduce the dead load on one of this country's oldest steel structures.

The Smithfield Bridge in Pittsburgh, Pennsylvania as it appeared in June of 2009.

The Smithfield Bridge is in Pittsburgh, Pennsylvania and was designed by Gustav Lindenthal. The bridge was opened to traffic in the early to mid 1880's. In the early 1930's Alcoa became involved to help reduce the dead load to allow the bridge to carry heavier vehicular traffic. Their aluminum design incorporated an aluminum orthotropic deck made of a 2000 series alloy mounted over similar 2000 series alloys for the supporting aluminum floor beams. The main alloying metal in the 2000 series is copper and it is very strong. Unfortunately, like steel the 2000 series aluminum alloys need painting to prevent corrosion and by the early 60's the 1930's vintage aluminum deck needed replacing.

In 1966 Alcoa working with the bridge owner again helped to rehabilitate the bridge using another aluminum bridge deck system. The old aluminum floor beams were repaired as needed and the new deck retrofitted to the floor beams. This new deck was made of a 5000 series aluminum deck plate reinforced with 6000 series trapezoidal aluminum extrusions with flanges designed to allow bolting to the top flange of the floor beams. The 5000 and 6000 series aluminum alloys are strong but not as strong as the 2000 series copper based aluminum alloys. The reason for their selection lies in the fact that these alloys are very corrosion resistant without the need for painting. Their bare surfaces protect the aluminum from corrosion even when exposed to chloride ions.

The details of the aluminum bridge deck system employed in 1966 is shown in the following diagram.



Aluminum bridge deck system deployed on the Smithfield Bridge in 1996

The method of construction was to leave a 6” opening between adjoining flanges to allow for welding access to make the partial penetration welds connecting the reinforcing trapezoidal ribs to the aluminum deck. This system remained in service for 26 years when again the Smithfield Bridge was renovated. This time the deck was replaced using a partially filled steel grid deck. The old aluminum deck was removed from the Smithfield Bridge in the summer of 1994 by Dick Enterprises and at that time Reynolds Metals Company was considering an effort to make their own version of the aluminum deck. Surprised and confused by the news that the deck was coming off the author went to the site with another engineer from Reynolds Metals Company to investigate. What was found was a both a good story and bad story.

The good story was that the aluminum deck had performed well structurally and that the aluminum alloy had done well without paint even though it had been exposed to deicing salts. The bad news was that where the aluminum laid upon the steel embedded in concrete at the Station Square abutment, a galvanic cell was created and that part of the bridge endured some severe corrosion problems. Nevertheless, even that area had not failed structurally.

The worst of what was found was evidence of wearing surface issues. Having found this very good story with difficulties it was decided on the spot to purchase 1200 square feet of the deck paying scrap value for the aluminum. Noting that Dick Enterprises had sliced the deck longitudinally into three segments to enable its removal, it was agreed that RMC would purchase one section from the upstream side of the bridge at 1/3 of the span, the center section from the center of the bridge and then the downstream segment from the downstream side of the bridge to represent what was found on 90% or more of the bridge deck. Then it was also agreed that RMC would purchase the entire width of the roadway (all three segments) at the Station Square abutment because that was believed to be the very worst portion of the bridge. Dick Enterprises was very accommodating and within a few weeks Reynolds had the requested samples to begin their forensic analysis.

Part of the 1200 square feet purchased by Reynolds Metals Company in the summer of 1994. The samples shown were typical of the entire bridge except for the abutments.

In the late summer and fall of 1994 Reynolds Metals Company started their aluminum bridge deck program. In essence, the experiences of the bridge deck deployed on the Smithfield Bridge from 1966 until 1994 is the forerunner of the modern aluminum isotropic deck. What was learned from that forensic study was used to correct the problems associated with the aluminum deck installed by Alcoa and the first iteration of a new design was deployed on a 300 foot suspension bridge in Huntingdon, Pennsylvania.

The first iteration from the lessons learned on the 1966 vintage aluminum bridge deck used on the Smithfield Bridge was another orthotropic deck. It was designed and developed by a very strong group of consultants working with the Research and Development staff at Reynolds Metals Company. Some of the consultants working on the team included:

John Ahlskog – retired Assistant Chief Bridge Engineer for the Federal Highway Administration Bridge Division in Washington, DC

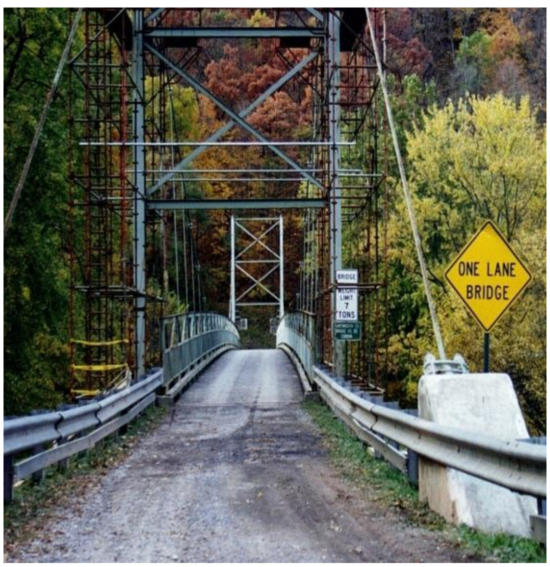
Dr. John Kulicki of Modjeski and Masters out of the Harrisburg, Pennsylvania office, renowned bridge engineer and many of his staff.

Randy Kissell of the TGB Partnership - an aluminum structures engineer and structures code writer.

Roman Wolchuk – renowned steel orthotropic bridge deck expert and consultant.

Working together this team combined with Reynolds Metals R&D welding knowhow developed the design used on the Corbin Bridge. Within a short period of time RMC R&D proved they could weld aluminum ¾ inches thick in a single pass with a removable backer system held in place with a mechanism powered by an inflated fire hose. The removable backer bar also featured a machined groove to receive the aluminum weld melt providing a reinforcing bead that allowed the design to assume a category C weld detail according to AWS D1.2. These developments led to the first isotropic aluminum bridge deck and that system is now on US Route 58 East over the Little Buffalo Creek. This design has been deployed since June of 1997 and it is performing very well.

It is important to note the accomplishments of the two bridge decks Reynolds Metals Company produced. The first is that the dead load reduction enabled by the orthotropic deck employed on the 300 foot suspension bridge coupled with strengthening the bridge's stiffening truss significantly increased the capacity of the bridge. By also replacing the steel stringers with aluminum the combined dead load allowed the bridge that was posted at 7 tons to have its capacity raised to 24 tons.



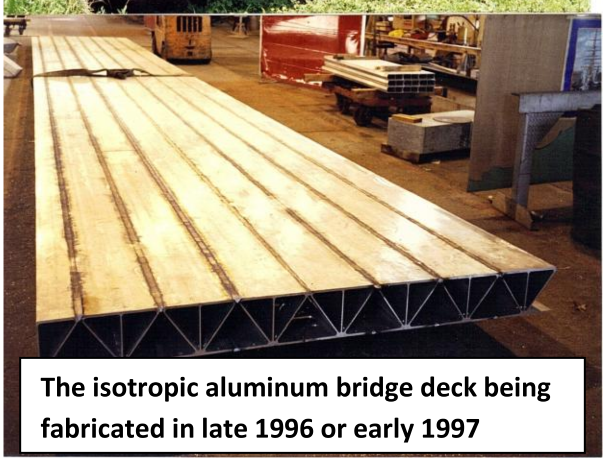
Corbin Bridge – posted at 7 tons before renovation and at 24 tons after renovation.

Photos of the Corbin Bridge

From to top left and moving clockwise – the Corbin Bridge prior to renovation, opening ceremony in the Fall of 1996, and as the bridge appeared in June of 2009.

The second accomplishment is that the US 58 East Bridge over the Little Buffalo Creek was widened from a 23 foot roadway to a 28 foot roadway reusing the existing foundations and most of the substructure.

The Route 58 East over the Little Buffalo Creek as it appeared in 1996



The isotropic aluminum bridge deck being fabricated in late 1996 or early 1997

US 58 East over the Little Buffalo Creek Bridge under construction in the Spring of 1997.

These developments and accomplishments required and investment of over $5,000,000 not including funding that RMC was able to leverage from the Department of Energy's Oak Ridge National Laboratory (ORNL). The leverage came as a result of a Cooperative Research and Deployment Agreement (CRADA) between ORNL and RMC. In essence, ORNL performed work with RMC as long as RMC put in equal amounts of work and/or money. At the rate Reynolds was spending, the requirements of the CRADA were easy to meet.

The Federal Highway Administration (FHWA) was also notified of the RMC effort, and the FHWA Turner-Fairbank Research Center became interested. For numerous reasons the FHWA decided to test a full scale sample of the deck at their Turner-Fairbank Research Center. They published their results in their

Spring Edition of 1997 'Public Roads' magazine and to quote the author William Wright "It took two wheel loads of 77 metric tons to produce failure in the deck section. That is equivalent of balancing four fully loaded tractor-trailers on two wheels. Clearly the strength of the deck is more than adequate for highway use."

> http://www.tfhrc.gov/pubrds/spring97/alum.htm FHWA article written by Bill Wright and published in Public Roads Magazine – 1997 Spring Edition.

As a result of this early study and interest, the FHWA contracted with the Virginia Transportation Research Council (VTRC) division of the Virginia Department of Transportation (VDOT) to evaluate the deck. The results of these studies indicated that the deck's structural attributes and capabilities can be predicted using the AASHTO design guide and that commercially available FEA software can be used to accurately model the deck's behavior. The final recommendation from the VTRC's first of three reports on the bridge deck system was to proceed with the construction of the bridge.

The remaining two reports published by the VTRC can be found at the following websites.

> http://www.virginiadot.org/vtrc/main/online_reports/pdf/99-r22.pdf The article written by the Virginia Transportation Research Council (VTRC) of VDOT regarding the tests performed on deck used on The Little Buffalo Creek Bridge and in support of Bill Wright's article.

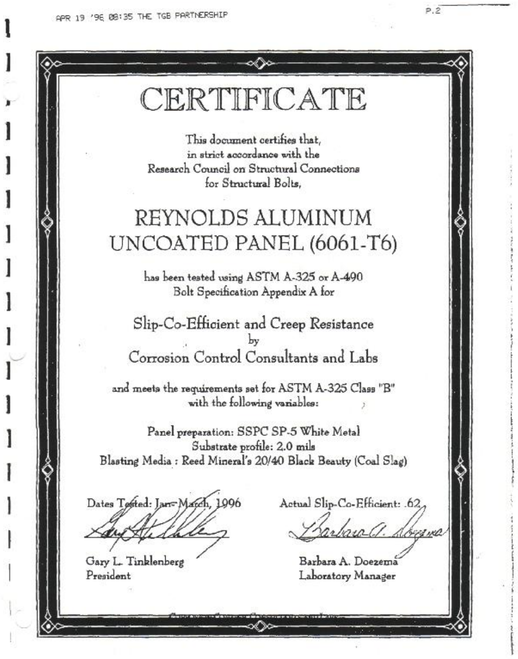
> http://www.virginiadot.org/VTRC/main/online_reports/pdf/00-r5.pdf says it is the "FINAL article" on aluminum bridge decks by RMC written by VTRC.

Sometime in mid 1996 the design of the Little Buffalo Creek Bridge renovation began. Modjeski and Masters of Harrisburg, Pennsylvania became the bridge engineer of record, the drawings were issued, the project was bid, then awarded to the D. W. Lyle Construction Company of Clarksville, Virginia. By mid June of 1997 the bridge was completed and opened to traffic.

US 58 is a major highway that links Norfolk, Virginia at the sea coast with Bristol, Virginia/Tennessee at the western tip of Virginia. It is not an interstate highway but it is heavily traveled. It sees significant vehicular traffic including trucks. The small, 55 foot long, two lane Little Buffalo Creek Bridge has been a huge success story. Very little has been done to keep the bridge in service although there were some wearing surface repairs needed over the field applied wearing surface over the splices. The repairs were needed in the few locations soon after the bridge opened. It is now understood that 85 to 95 percent of the original wearing surface is still on the bridge and it appears the repairs have held up well too. The major success story associated with the wearing surface is where installed correctly it lasts and if it develops problems they can be repaired with an expectation the repairs will also last. In essence, the bridge with its wearing surface is sustainable.

Pictures of the Little Buffalo Creek Bridge as it appeared in November of 2009. The bridge was opened in June of 1997.

During the design and installation of the Little Buffalo Creek Bridge meaningful work was still being developed by RMC through their CRADA agreement with ORNL. Two years after the deployment of the Little Buffalo Creek Bridge came the fruits of that effort. ORNL at RMC's request investigated, evaluated and then documented that aluminum to aluminum friction connections are achievable and so too are aluminum to steel friction connections. The investigation also went as far as to prove that the same turn of the nut method used to tension the high strength bolts used in steel friction connections causes the same tensioning of the high strength bolt in the aluminum related connections. As a result of concerns expressed by evaluators that aluminum's coefficient of expansion is twice that of steel and that the tension in the friction connection could be lost with sub zero temperatures, ORNL performed another evaluation checking the sensitivity of the joint with falling temperatures. The results of this study indicated that aluminum friction connections are no more sensitive to this falling temperature concern than steel friction connections. In essence, friction connections in aluminum are now part of the aluminum bridge deck's tool box to help with the design's implementation and that was not true when the Little Buffalo Creek Bridge was deployed. For reference purposes, the certificates issued by Corrosion Control Consultants and Labs follow.



APR 19 '96 08:35 THE TGB PARTNERSHIP P.2

CERTIFICATE

This document certifies that,
in strict accordance with the
Research Council on Structural Connections
for Structural Bolts,

REYNOLDS ALUMINUM
UNCOATED PANEL (6061-T6)

has been tested using ASTM A-325 or A-490
Bolt Specification Appendix A for

Slip-Co-Efficient and Creep Resistance
by
Corrosion Control Consultants and Labs

and meets the requirements set for ASTM A-325 Class "B"
with the following variables:

Panel preparation: SSPC SP-5 White Metal
Substrate profile: 2.0 mils
Blasting Media : Reed Mineral's 20/40 Black Beauty (Coal Slag)

Dates Tested: Jan-March, 1996

Actual Slip-Co-Efficient: .62

Gary L. Tinklenberg
President

Barbara A. Doezema
Laboratory Manager

APR 19 '96 08:34 THE TGB PARTNERSHIP P.1
TO: ADAM MATTEO FROM: JRK Pretty nice, eh? I've got full reports – 4/19/96

CERTIFICATE

This document certifies that,
in strict accordance with the
Research Council on Structural Connections
for Structural Bolts,

REYNOLDS ALUMINUM
UNCOATED PANEL (6061-T6)
BETWEEN ZINC COATED PANELS

has been tested using ASTM A-325 or A-490
Bolt Specification Appendix A for

Slip-Co-Efficient and Creep Resistance
by
Corrosion Control Consultants and Labs

and meets the requirements set for ASTM A-325 Class "B"
with the following variables:

Panel preparation: SSPC SP-5 White Metal
Substrate profile: 2.0 mils
Zinc Coating: Carboline CZ11 at 6 mils DFT
Blasting Media : Reed Mineral's 20/40 Black Beauty (Coal Slag)

Dates Tested: Jan-March, 1996

Actual Slip-Co-Efficient: .57

Gary L. Tinklenberg
President

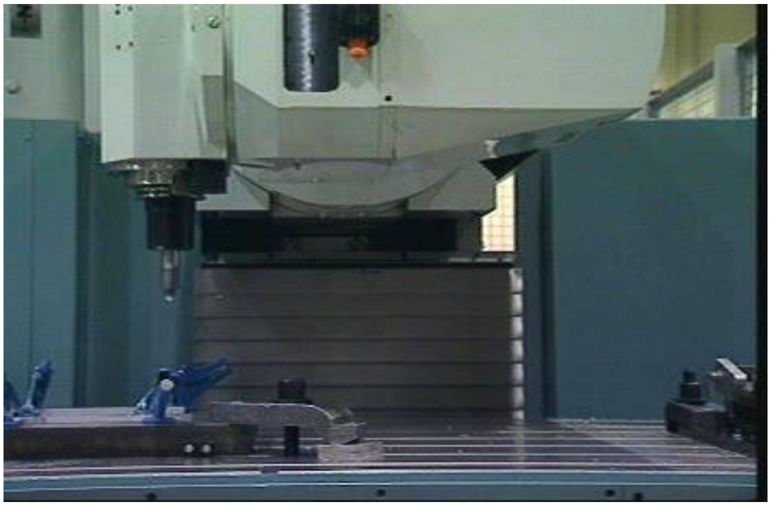
Barbara A. Doezema
Laboratory Manager

CORROSION CONTROL CONSULTANTS AND LABS

Subsequent to the deployment of the aluminum bridge decks in Virginia and Pennsylvania, Kentucky implemented aluminum bridge decks on two bridges in their state. The two bridge decks are used on Pony trusses to reduce the dead load. The first bridge was installed in 2006 and the latest bridge went into service in 2009. Not a lot is known about the bridge deck systems but at least one of them uses a very similar attachment system that the Swedish system employs so these decks are likely non composite with the girders. These decks also use an asphalt overlay that is well over an inch thick so it is likely they weigh around 40 or more pounds per square foot. As a result of contacts with the Kentucky Transportation Cabinet it is known they are pleased with the performance of these two bridge decks.

In recent years the research, development and engineering behind the technology deployed on the Little Buffalo Creek Bridge has been passed on from Reynolds Metals Company to Alcoa and finally to Sapa of Sweden as a result of corporate sales. Alcoa bought Reynolds Metals Company around 2001 and Sapa acquired the rights to the technology when it purchased Alcoa's soft alloy extrusion plants.

Since the recent acquisition by Sapa (January of 2009), the isotropic bridge deck system developed by RMC is undergoing a new evolution. Although the system has performed well the new evolution seeks to learn from the past lessons from the Swedish efforts in Europe and the lessons learned in the US. The effort also makes use of the friction connections that can now be counted upon as a result of the work done at ORNL. The new isotropic deck employs essentially the same aluminum profile as that used on the Little Buffalo Creek Bridge and evaluated by the FHWA but has undergone a quantum leap in regard to how it is fabricated. The design has been altered to accept a new way of welding known as friction stir welding. This method of welding is a mechanical method of joining aluminum without the use of an electric arc. No shielding gases are needed and the heat with its associated distortion has been significantly reduced. The new system of welding provides improvements in welding stability, welding speed, reduced distortion, fabrication quality and reduced fabrication costs.



Friction Stir Welding Machine at rest. Note the similarities to a milling machine.

The deck design has also undergone improvements to enhance the design's accelerated bridge construction capabilities by making use of high strength bolted connections to achieve slip critical friction connections. These improvements include moving the longitudinal splice to coincide with a girder location and using a bolted connection to connect the deck to the girder instead of a grouted connection. These improvements also enhance the design in numerous other ways.

Summarizing what has been said and established:

- Aluminum bridge decks have been evolving for over 44 years now (nearly 80 years if you include the lesson learned to use an alloy that does not require paint).
- Seventy bridges are in Europe using a plank design with an asphalt wearing surface.
- Two bridges are in the US using an all welded design that also use a long lasting polymer concrete wearing surface. This wearing surface can be expected to last well over one decade if not longer with minor or no repairs. It is repairable if needed and the repairs likewise can be expected to perform.
- The lessons learned are about to start a new wave of aluminum all friction stir welded isotropic decks. The first deployment is likely to be in Massachusetts in late March or early April of 2011.
- The system will weigh about 25 pounds per square foot including the wearing surface and attachment system.
- The system will be prefabricated in panels 14 feet wide or wider and 60 feet long or longer.
- The wearing surface will be pre-applied to the panels which mean the wearing surface will have been applied in an environmentally controlled situation to promote quality and adhesion.
- The panels will be unsurpassed in durability and longevity and they may well be reusable. The design is for infinite fatigue life so why not reuse it if the bridge is to be relocated.
- The panels will have a high scrap value if not reusable.
- Aluminum bridge decks are likely the lowest life cycle cost alternative available on most bridges particularly movable bridges.
- Aluminum bridge decks that are friction stir welded together may be new and emerging technology, but it is also clear it is a time proven alternative.