One of three GuarDeck bridges installed at the Parc national des Îles-de-Boucherville in Quebec, Canada, which spans 212 ft (64.5 m).

Deploy-Ready Aluminum Bridge Decking

Addressing the Challenges of Aging Infrastructure

Introduction

Roads and bridges are the backbone of society infrastructure, ensuring the efficient movement of people and goods through the world. Steel and concrete are the most common materials used for the construction of new bridges, however, aluminum should be considered as a viable and beneficial solution for bridges because of the number of advantages that it provides. Aluminum offers versatility, good aesthetics, and high corrosion resistance, which reduces maintenance costs compared to steel.[1] Costs are also reduced over the lifetime of the bridge. A 2008 Canadian study showed that older projects using aluminum decking instead of concrete, steel, or wood have stood the test of time.[2] Between 1946 and 1963, nine bridges were built with aluminum beams and girders and six still exist.

With its combination of light weight and high strength, aluminum reduces dead load and provides an opportunity to design bridges with increased widths and load capacity without the need for supporting bridge elements to provide strength. This is especially important for load-restricted bridges, historic bridges, movable bridges, and bridges with narrow roadways requiring expansions for bicycle paths or walkways. Overall, aluminum bridge decks are 70-80% lighter than concrete and most other metals (about 10 psf – 0.5 kPa), which also makes handling and installation easier.

Over the past few years, aluminum has seen improved properties and advances concerning its mechanical behavior, along with much-improved alloys and tempers. This structural engineering knowledge combined with the wide variety of cross-sectional shapes provided by aluminum extrusion manufacturing, has lead to increased use of aluminum in bridge construction. Domestic demand for extruded products was up 5% over 2017, the ninth consecutive year that demand has increased,[3] with bridges, streets, and highways counting among the significant sectors that are on the rise.

Many successful vehicular bridge projects have been carried out in North America, such as deck retrofits, pedestrian, lift (or bascule), floating, and temporary bridges. The most frequent and successful applications have included sidewalk, sign and bike path support structures, light fixtures, and bridge rails. Gradually, more governments and municipalities are recognizing the advantages of aluminum. In keeping with this growing trend, MAADI Group Inc. in Canada has developed a new aluminum-based product called GuarDeck®, which is for a pedestrian payload that is capable of carrying up to 33,000 lbs (15 tonnes) and allows for occasional maintenance and other vehicles. In particular, this concept would provide a solution for replacing heavier and aging decks or for rapid or temporary repair of bridge deck damage.

The Challenge of Aging Bridge Decks

The North American system of bridges is in a critical state. The vast majority of the approximately 603,000 public roadway bridges in the U.S. and over 56,000 in Canada were built between the 1950s and 1970s. Many of these bridges are or will soon be structurally deficient. According to the latest data from the Federal Highway Administration, there are about 56,000 structurally deficient bridges in the U.S. A report by the American Society of Civil Engineers (ASCE) estimates that it would cost some $123 billion to fix the damaged or deficent bridges in the U.S.[4]

Over the next two decades repair and rehabilitation of these bridges will significantly add to state infrastructure costs. The majority of older bridges are steel and concrete, with more recent bridges being primarily made from reinforced concrete. Investing in bridges, roads, and other

transportation infrastructure that connect cities and rural communities is key to local economies, navigating the future, and our overall quality of life.

MAADI Group provides a viable solution for addressing this issue of aging bridge decks. "I see very strong potential for this product to be used in retrofit applications," said Scott Walbridge, associate professor of Civil and Environmental Engineering at the University of Waterloo, Ontario, Canada. "The upside to this is that you can make the bridge lighter at the same time the aging deck is replaced, thanks to the strength and the material's lightness. Not only will the product be useful for replacing slowly aging decks, but it may also have value for use in emergency situations, such as for rapid or temporary repair of bridge deck damage due to extreme events."

Figure 1. Deflection test of the aluminum bridge deck at MAADI's facility.

Development

Although aluminum provides many advantages for structural applications, it also faces several challenges, including its lower elastic stiffness and fatigue strength compared to steel, the reduction in the local yield strength when it is welded, and its higher initial material cost. MAADI Group has had years of experience meeting these challenges through the use of fusion welding and the selection of alloys based on application. The company has designed and built hundreds of aluminum structures—such as Make-A-Bridge, a weld-free interlocking aluminum pedestrian bridge—in the U.S., Canada, the Caribbean, and Asia for the marine, civil, industrial and architectural sectors. The company is now applying this knowledge to develop its aluminum bridge decks for vehicles up to 33,000 lbs (15 tonnes).

MAADI Group has been working with the University of Waterloo on the development of the GuarDeck concept. Both Alexandre de la Chevrotière, ceo of MAADI Group, and Walbridge were involved in the formulation of new standards for the Canadian Standards Association (CSA) in 2011. They worked as part of a technical committee writing a chapter on aluminum structures for the Canadian Highway Bridge Design Code (CSA S6). Shortly after, de la Chevrotière donated a 75 ft long (22.9 m) Make-A-Bridge sample, which Walbridge's team at the university used for a research project, through which they performed vibration and crowd load testing.

"Since then, Alexandre and I have had numerous conversations about developing a weld-free aluminum vehicular bridge deck product," said Walbridge. He explained that his research team at Waterloo has been working in the development stages of GuarDeck by carrying out structural analysis of prototype designs to confirm stress levels and providing opinions on the concept as it evolved. Walbridge's team at the university also provides assistance in testing its limits in terms of fatigue life and ultimate strength. In addition, the team is investigating how decisions made at the design stage have an influence on the durability and maintenance-related lifecycle costs of metal structures.

"We have enjoyed the opportunity to help MAADI Group with this effort," said Walbridge. "A number of other aluminum deck products exist on the market or are currently in development, yet most involve welding extrusions to each other to make a large deck panel." He explains that this creates challenges with distortion during fabrication and long-term fatigue performance. "By developing a deck product that doesn't have welds in it, many of these problems can potentially be avoided."

MAADI Group's team of in-house engineers produced prototype bridge decks, which were evaluated in-house at the company's facility. The engineers performed deflection tests (Figure 1), and friction tests to evaluate friction force (e.g., resistance to motion of a panel relative to the steel I-beams) using a 178 kN press. Support during the research phase of this project came from the Centre québécois de recherche et de développement de l'aluminium (CQRDA), an organization dedicated to developing new applications for the aluminum industry.

Aluminum Bridge Deck

All the components for GuarDeck are manufactured from custom aluminum extrusions and processed on a large scale 5-axis CNC machine with very tight tolerances—for example, 0.020 of an inch (0.5mm) over the length of a 39 ft 9 inch (11.5 m) panel. The deck panels are extruded on large 5,000 ton extrusion presses using structural aluminum alloy 6061 to provide both strength and improved corrosion resistance. Each panel has tongue and groove slots on either side providing interlocking joints. Since aluminum expands twice the amount of steel due to temperature change, the tongue and groove method provides leeway for thermal expansion between the aluminum and steel I-beam. The extruded panels can be treated with transparent or durable anodizing or baked paint and are further treated with an anti-slip epoxy to prevent the automobile tires from sliding on the surface. Optional guardrails and curbs for additional safety can also be installed (Figure 2).

With environmental concerns in mind, MAADI Group has reduced the carbon footprint of GuarDeck by using 20% recycled aluminum. Where recycled aluminum is not used, the company implements renewable energy and employs innovative, energy efficient technology in the manu-


Figure 2. A 3D rendering of a GuarDeck bridge showing optional guardrails.

facturing process in order to further reduce emissions. Also, the aluminum bridge components are 100% recyclable and potentially reusable.

Of particular importance is the accelerated bridge construction (ABC) technique, which enables work crews to quickly install or replace bridges with minimum disruption to traffic. GuarDeck is prefabricated in the factory and shipped in bundles as part of a kit and then assembled onsite. Depending on the bridge width, individual panel weight is approximately 120 lbs (55 kg). Workers place the panels in increments of 13 inches (330 mm) over the entire bridge span. The panels are joined to the main I-beams using custom hollow extrusions with special stainless steel fasteners designed to prevent corrosion, damage, or theft of the aluminum parts. A special torque is used on each fastener, which provides 134 kN of slipping force resistance per panel. The most complex step required for installation is achieving proper alignment of the panels perpendicular to the axis of the main girders. This is important since cumulative tolerances may result in misalignment over larger spans. "GuarDeck represents a huge advantage over other types of bridge decks which require special considerations to attach to the main girders," said de la Chevrotière.

Since no welding and no heavy equipment is required, installation time is kept to a minimum. Workers can install a panel in about 10 minutes, replacing a 100 ft (30 m) span bridge deck in about one day. "Whether permanent or temporary, this product fits well into most environments and situations where durability and rapid installation are top priority," said de la Chevrotière. It is built to international standards, including to American and Canadian codes designated by the CSA, the ASCE, and the American Association of State Highway and Transportation Officials (AASHTO).

Further Development

In the coming months, MAADI Group will be scaling up the GuarDeck technology in order to enable it to span larger distances and carry heavier loads. "Research is planned on the fatigue performance and thermal effects between the aluminum deck and main steel girders," said de la Chevrotière. If the continued research on fatigue performance proves successful to ensure the greatest possible versatility of the product, then many more applications beyond bridges are possible.

MAADI Group will continue to work closely with the University of Waterloo's structural lab to carry out specific tests to improve GuarDeck using precision equipment. The university's structural lab and graduate students are involved in MAADI Group and are part of the next generation of professional engineers helping to promote the sustainable use of aluminum and to explore its untapped potential.

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