LIGHTWEIGHTING WITH ALUMINUM: CORROSION APPS GUIDE LEADING DESIGN

Scientists at the National Research Council Canada (NRC) are using multiphysics simulation apps to minimize the risk of galvanic corrosion in new designs and advance aluminum adoption in vehicle lightweighting.

by **SARAH FIELDS**

FIGURE 1. A high-pressure die casting (HPDC) aluminum alloy.

Cars have been shedding pounds in recent years, as manufacturers and consumers increasingly prioritize efficiency and environmental protection. The reduction of a vehicle's weight by one tenth can boost the fuel efficiency of a vehicle by as much as 8%. To accomplish this, manufacturers know they must combine conventional materials for car structures and bodies, such as structural steel, with lighter materials. Aluminum (Figure 1) is a prime candidate for such efforts, as it is one third the density of steel, weather resistant, highly recyclable, and has excellent formability and crashworthiness.

However, developing a vehicle with both steel and aluminum alloys comes with many challenges. Among these are developing cost-effective mass production technologies; achieving multimaterial assembly using aluminum for parts originally designed to be made with other materials; and mitigating the risk of galvanic corrosion (Figure 2) due to dissimilar metals in contact in the presence of an electrolyte, such as de-icing salts applied on roads.

FIGURE 2. Top: Galvanic corrosion damage induced on a multimaterial overlap assembly made of a carbon-fiber-reinforced polymer (CFRP) and a 6000 series aluminum alloy after one year of in-service exposure on a vehicle. Bottom: Typical mounting of samples on a vehicle for in-service exposure testing.

From left to right: Richard Menini, Mario Patry, Sandy Laplante, Amélie Ruest, Marc-Olivier Gagné, Axel Gambou-Bosca, Philippe Tremblay, Stéphan Simard, Danick Gallant, and Alban Morel at National Research Council Canada, Aluminium Technology Center.

Danick Gallant, technical leader in corrosion activities conducted by the NRC's Automotive and Surface

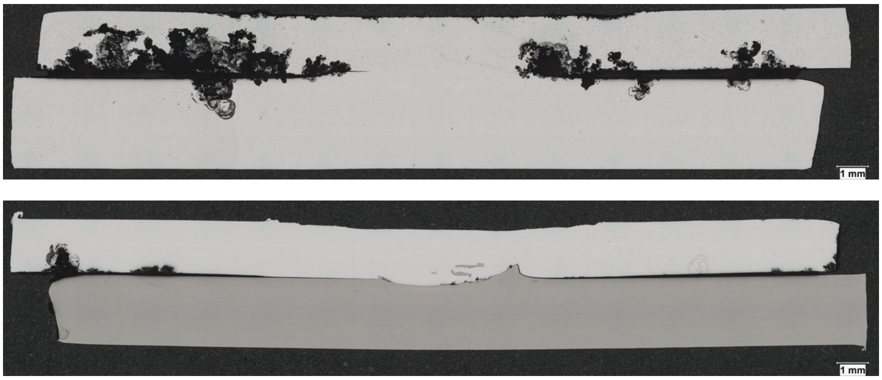

FIGURE 3. Cross-sectional view of multimaterial friction-stir welded (FSW) assemblies after a 100,000 km road exposure between a wheel and a mud flap. Top: Dominant crevice mechanism in a AA7000 series to AA6000 series FSW assembly, Bottom: Dominant galvanic corrosion in AA5000 series to stainless steel 300 series FSW assembly.

Transportation Research Center, supports companies in the development of corrosion-resistant components and assemblies. For a single joint geometry, the industry is currently facing different corrosion-related challenges, from crevice to galvanic corrosion (Figure 3). The NRC, through its ALTec multiclient aluminum R&D collaboration group (Figure 4), is working to advance aluminum in lightweighting and supports the transportation industry in understanding, mitigating, and implementing practical solutions to these issues.

Despite the variation in core business competencies of ALTec member companies, corrosion projects consistently rank highly in the priorities of members. The ability to predict the corrosion of an assembly is critical, as manufacturers of aluminum sheets need to ensure that their products are used correctly to maintain the desired requirements, such as reliability. Similarly, auto manufacturers need their products to perform well and hold up over time.

⇨ AVOIDING GALVANIC CORROSION

There are some general rules to which auto designers can adhere to in order to mitigate galvanic corrosion. These include (1) staying away from a large cathode-to-anode ratio, (2) following the galvanic compatibility chart, (3) avoiding any direct contact between dissimilar metals, and (4) painting both materials to be put in contact, or the cathode only, but never the anode only. However, in practice, applying each of these rules may be virtually impossible. An example is the difficulty in eliminating metal-to-metal contact when using mechanical fasteners, which are becoming more and more relevant in the context of dissimilar materials assembly.

Physical testing, which includes in-service road exposure, cyclic corrosion, and electrochemical tests, is still needed though as it can help shed light on the behavior of more complex systems. Examining on-vehicle exposure is time consuming and expensive, standard cyclic corrosion procedures tend to overestimate galvanic corrosion risks, and electrochemical tests become difficult to interpret if several materials are involved in complex geometries.

Researchers have found that multiphysics simulation is the best strategy for combining and synergizing results from physical testing, resolving design challenges before full-scale physical prototyping, and accelerating the development of a corrosion-resistant design.

⇨ CORROSION MODELING OF MULTIMATERIAL ASSEMBLIES

Gallant and his team leverage the information gained from in-service,

FIGURE 4. Members (left) and partners (right) of the multiclient aluminum R&D collaboration ALTec group (as of March 19, 2018).

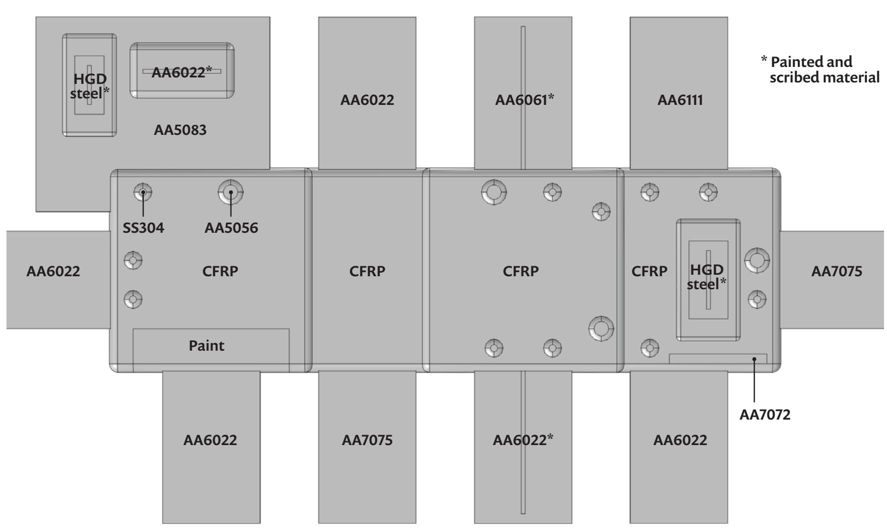

FIGURE 5. Multimaterial assembly built to demonstrate the relevance of using numerical simulation of corrosion to raise red flags for inappropriate designs.

cyclic corrosion, and electrochemical tests within the COMSOL Multiphysics® software to create flexible mathematical models capable of predicting corrosion behavior. "In order to build virtual prototypes that represent what happens in real life, the developed models are calibrated with a series of sensors mounted on vehicles," explains Gallant. The team has access to high quality data from which the most relevant information and knowledge can be extracted using advanced data analysis procedures and machine learning models. Each piece of data is taken into account, including the surface temperature under the vehicles, time-of-wetness, composition, conductivity of de-icing salts deposited on vehicles surfaces, vehicle speed, and GPS position.

At the beginning of the initiative, Gallant considered different software tools for the simulation of corrosion. He found that the COMSOL® software allowed him to specify and control all properties of the model, rather than operating as a "black box" with controlled inputs but unknown unchangeable internal calculations. "The corrosion modeling capabilities of COMSOL, combined with the ability to import geometries from other software is powerful because we can test different galvanic combinations. This information tells us which designs need a geometric change before moving on to building a physical prototype," Gallant explains.

As a case study and laboratory demonstration for potential NRC clients, Gallant and his team built a complex assembly made of more than 10 different materials and coatings (Figure 5). Corrosion damages experienced during an aggressive four-day laboratory procedure correlate well with the simulation results, illustrating the capability of the NRC corrosion models, built in COMSOL Multiphysics software, to predict the corrosion behavior of a complex multimaterial assembly.

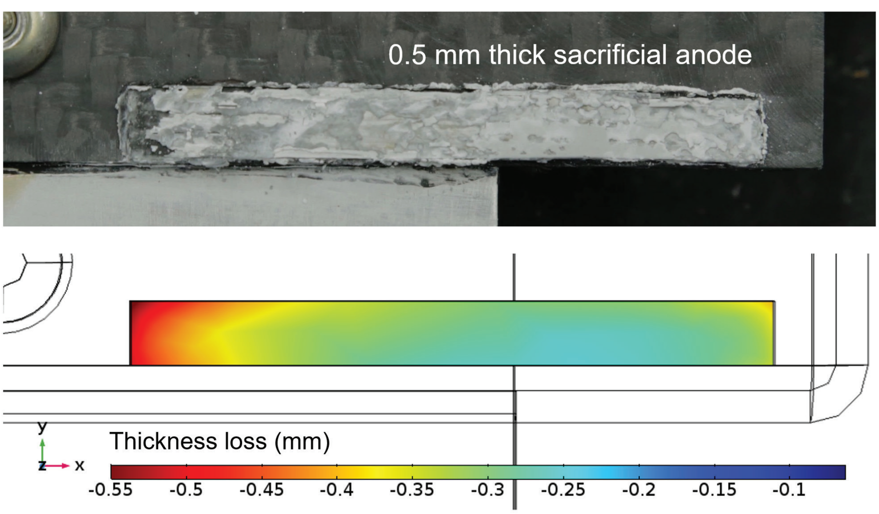

FIGURE 6. Time-dependent analysis (bottom) used to determine the thickness loss of a sacrificial component throughout the laboratory corrosion exposure (top) period.

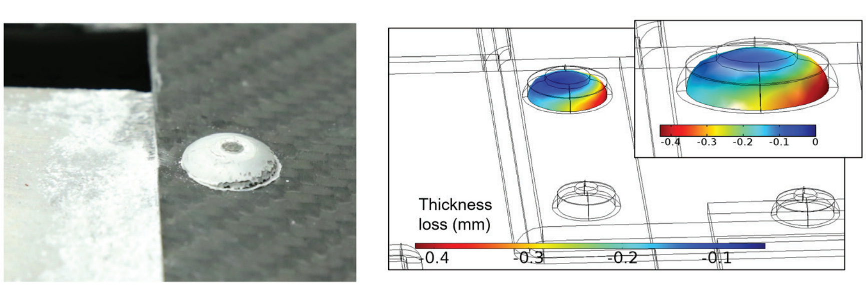

FIGURE 7. Time-dependent analysis (right) used to determine the dissolution of the aluminum rivet (left).

Time-dependent studies in the COMSOL Multiphysics software were carried out to determine the thickness loss of a sacrificial anode throughout the laboratory corrosion exposure period (Figure 6). The experimental and simulation results are in good agreement. As observed from both experimental data and simulation results, the dissolution of the aluminum rivet is inhibited on its left side, since a larger and more active aluminum components in located next to it (Figure 7). On its right side, the rivet corrodes due to the presence of the noble CFRP material. Again, the team found that the simulation describes the experimental observations well.

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>
> — DANICK GALLANT, TECHNICAL LEADER IN THE AUTOMOTIVE AND SURFACE TRANSPORTATION RESEARCH CENTER

⇨ APPS SUPPORT LEADING DESIGN

After creating the numerical model, Gallant uses the Application Builder tool in the COMSOL Multiphysics software to create a simulation app that can be shared with colleagues at NRC and ALTec members. Using a local installation of the COMSOL Server™ product (Figure 8), he can quickly deploy apps through a web interface, administer users, apply customized branding, and share updates when needed.

His colleagues and clients can access the apps at any time using their web browser and provided login information.

An example of a simulation app used to calculate the galvanic corrosion that will occur in a complex multimaterial assembly is shown in Figure 9. The user of the app can select the components of the assembly and define the electrolyte thickness, convection, and temperature. When running the app, the user can visualize the electrolyte potential, current density, and the electrode thickness change. Customized results files can also be exported for further data analysis with MATLAB® or RStudio® scripts written by the NRC and adapted to clients' specifications.

Apps are also facilitating the communication between the engineer responsible for the performance of the entire vehicle and the corrosion engineer. Before apps, the former might not see the merit in switching to a different geometry or changing out a material if it deviates from what they've done in the past or is more expensive. But with the arrival of apps, the corrosion engineer can provide a more concrete rationale to the design engineer and clearly demonstrate where and why corrosion will occur.

"Our next steps are to give ALTec members the ability to select the assembly location on the vehicle within the app, which will give them a better representation of the electrolyte in the model and give them an even better prediction tool. Possibilities offered by the COMSOL Server are almost infinite and its flexibility makes it easily adaptable to specific clients' requirements," Gallant explains.

⇨ WINNING THE LIGHTWEIGHTING RACE

With multiphysics simulation and apps, it is easier to select the right materials and geometry throughout the design process, greatly aiding the implementation of aluminum in new lightweight designs. The team at National Research Council Canada and their industrial partners will continue to pave the way for more innovation in aluminum manufacturing, supporting to the game-changing movement of aluminum adoption in automotive lightweighting. ❖

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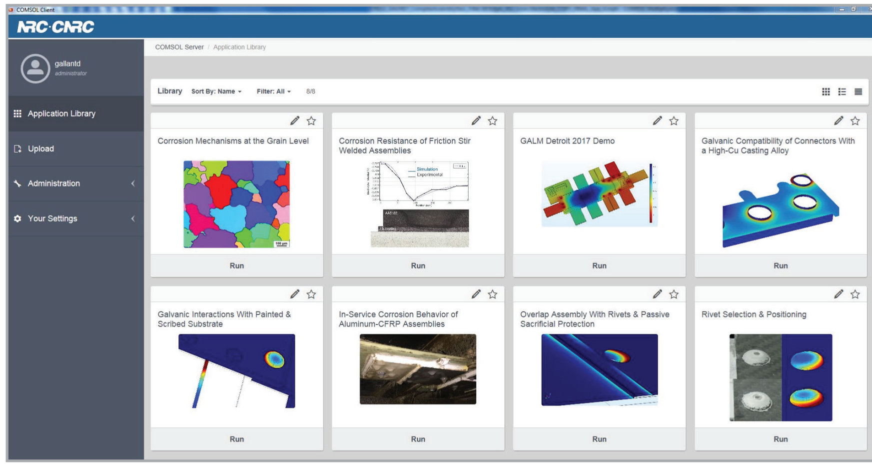

FIGURE 8. View of NRC-branded COMSOL Server™ accessed from a web browser.

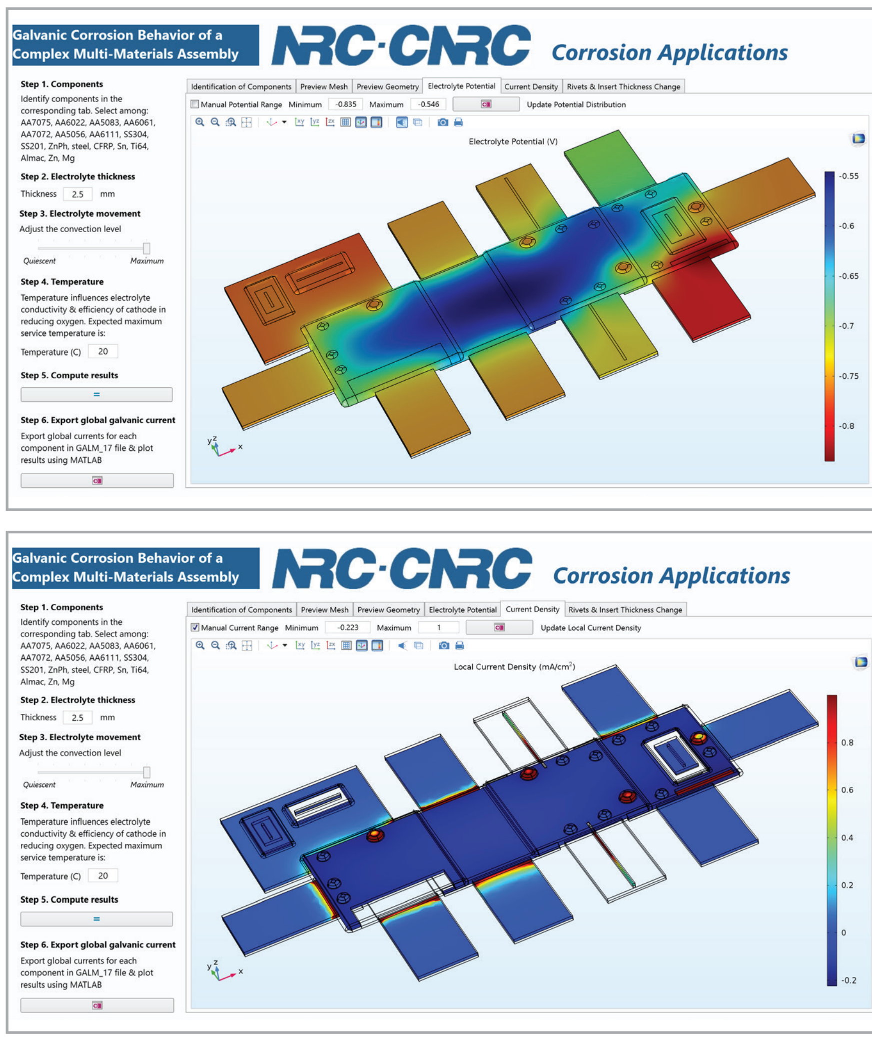

FIGURE 9. Simulation app for determining the galvanic corrosion behavior of a complex multimaterial assembly. Top: Visualization of the electrolyte potential across the assembly. Bottom: Visualization of current density throughout the assembly.