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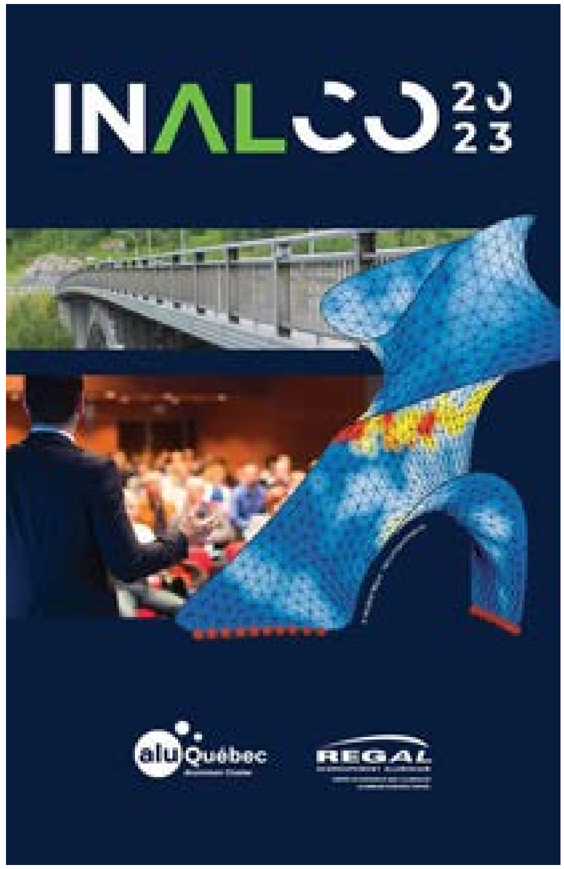

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Green transportation and infrastructure

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KEYNOTE | THE FUTURE OF RESPONSIBLE ALUMINIUM: CONNECTING THE ENTIRE VALUE CHAIN

Tao Wang[1]

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How can blockchain technology empower consumers to make more sustainable choices? Powered by blockchain technology, START provides transparency, traceability, and provenance across value chains so customers and end users can see key environmental, social, and governance (ESG) information. START tells the entire story—from mine to market—of sustainable materials from Rio Tinto, allowing users to prove to their stakeholders and customers that they share a commitment to sustainability.

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D2-3 | FRICTION MODELS FOR A BETTER PREDICTION OF MACHINING PERFORMANCE OF ALUMINUM ALLOYS PARTS

Sandrine Anicette Tcheuhebou Tina[1], Victor Songmene[1], Mohammad Jahazi[1]

[1]École de Technologie Supérieure

Aluminum alloys are widely used in transportation, household, and construction applications because of their many advantages: good strength-to-weight ratio, good corrosion resistance, good formability, and good electrical conductivity. The transformation of aluminum alloys into final consumer products involves forming processes such as machining, the effects of which, on the integrity of the part, are not always easy to predict without intensive and expensive testing. This surface integrity on which the in-service performance of finished parts largely depends, is conditioned by machining parameters and conditions, cutting tool geometry parameters, environment, and machining strategies. The relationships between these factors are complex to predict due to multiple interactions between them and indirect effects that are difficult to measure or estimate such as thermo-mechanical loads and the real friction coefficient during machining. In this paper, the Finite Element Method (FEM) is used in DEFORMTM 13.0 to predict friction coefficient models for aluminum alloys and these models are used to better predict the machining performance and surface integrity of machined parts. This study could help industries to better select machining conditions for cutting given aluminum alloys.

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S1-1 | WHY SURFACE TREATMENT MUST BE AN INTEGRAL PART OF MANUFACTURING? - AN OVERVIEW

Saleema Noormohammed[1]

[1]Réseau Trans-Al

In almost every sector of engineering and manufacturing, it is primordial for the materials, as aluminum, to undergo certain surface preparations prior to further processing and/or assembling. This may include cleaning, activation, functionalization, coating and texturing. All these essentially fall into one big terminology called surface treatment. Surface finishing is often a requirement for most parts produced by metal manufacturers for aesthetics and tolerance limitations for final applications. On the other hand, protection of the finished products is a major additional requirement to prevent any type of degradation including corrosion, abrasion and wear depending on the application and exposure of the product. In any case, surface treatment processes play a vital role in enhancing the performance, improve corrosion and wear resistance, increase service life under extreme conditions, and rendering a surface aesthetically pleasing. Among a panoply of existing surface treatment techniques, this abstract gives the audience an overview on the choice of methods based on the type of material to be treated, the kind of applications under defined or unprecedented conditions and based on how easy or difficult they are to perform and implement in an industrial set-up. These methods include mechanical abrasion (sanding), chemical modifications (etching, silanes) and physical processes (plasma, laser). This work also provides a brief overview on how to qualify and quantify the resulting surface to assure its intended function. This includes characterization techniques including wettability and chemical signature analyses.

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KEYNOTE | NOUVEL ALLIAGE ALUMINIUM-SCANDIUM POUR DES SKIS ALPINS DE HAUTE PERFORMANCE

Philippe Gosselin [1], Félix Lapointe [1]

In collaboration with Rio Tinto and the Centre de Métallurgie du Québec, Ferreol has succeeded in developing a new aluminum-scandium alloy that surpasses the properties of the industry's best performing materials. With this technology, the company hopes to revolutionize the alpine ski industry and create more efficient products, while minimizing the impact on the environment. Indeed, there has not been a major innovation in this sector for over 40 years. In addition, the alpine ski industry is currently plagued by major supply problems. What's more, the few materials that manufacturers are able to source do not meet the quality standards expected from the industry. Ferreol wants to change this with its new aluminum-scandium alloy.

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W3-2 | ACCELERATED OPTIMIZATION OF LASER CUTTING PARAMETERS USING A MACHINE LEARNING APPROACH

Volkher Onuseit[1], Max Hoßfeld[1], Tobias Menold[1], Andreas Michalowski[1]

[1]University of Stuttgart

Laser-based processes such as cutting, welding or laser milling with ultrafast lasers are widely used in the industrial processing of aluminum alloys. However, the large number of adjustable parameters and their interactions involved in these processes makes process development and optimization time-consuming and knowledge-intensive. Especially the physical interactions between different process parameters require a deep understanding of the process behavior to find the optimum parameter set using standard Design of Experiments (DOE). Alternatively, optimization algorithms can be employed during the experiments with a stepwise change of the parameters to minimize the number of trials required. This paper presents a practical method for optimizing the laser cutting process using Bayesian optimization that operators can use without prior knowledge of the process or additional measurement equipment installed at the processing system.

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E1-2 | ECODESIGN AND LIFE CYCLE ANALYSIS OF A REFRIGERATED VAN

Rodrick Levesque[1], Félix Rancourt[1], Christian Boily[1]

[1]Manac Inc.

Presenting the Life Cycle Analysis (LCA) of Manac Inc.'s new generation of refrigerated van through our product development process. Apply the best practices in eco-design techniques: - usage of aluminum extrusion to replace parts made of steel historically (also aluminum extrusion allowed to reduce the number of parts with the Design For Manufacturing and Assembly (DFMA) approach;- Innovative aluminum extrusion designs that allow the use of adhesives instead of welding;- Durable, low maintenance walls keeping the exterior aluminum skin design; Preservation of versatility; Preservation of structural integrity; Use of insulation material that limits water ingress, which allows the trailer to maintain its payload over its entire life time. This reduces fuel consumption for the carriers and lower GHG . The analysis was performed: transporting a 44,000 lbs payload refrigerated at 4°C or frozen at -20°C in a 53'' trailer between Toronto - Miami in winter and summer in 2022. This new design allows to reduce by more than 10%, at the limit conditions, the impacts on climate change. This work was carried out with the support of the CIRAIG (Le Centre international de référence sur l'analyse du cycle de vie et la transition durable) located in Montréal.

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E2-1

LIFE CYCLE ASSESSMENT ALONG ALUMINIUM VALUE CHAIN: REVIEW OF SEVERAL ENVIRONMENTAL STUDIES FROM BAUXITE MINING TO ALUMINIUM RECYCLING

Alban Pilard[1*], Hugues Imbeault-Tétreault[2]

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1 Key messages

According to several life cycle assessment (LCA) studies, the major environmental impacts of aluminium production and transformation are predominantly associated with energy consumption, direct greenhouse gas (GHG) emissions, and waste generation. Throughout the value chain, significant energy inputs are required for bauxite mining, alumina refining, and smelting processes. These energy-intensive stages contribute to the production of direct GHG emissions, primarily carbon dioxide, which significantly contributes to climate change. Furthermore, waste production during aluminium production, including red mud from alumina refining and dross from smelting, poses challenges in terms of disposal and potential environmental contamination.

The LCA studies also identified several opportunities for reducing the environmental impacts of aluminium production. By employing the LCA tool, decision makers and industry stakeholders can make informed choices and develop sustainable strategies to reduce the environmental footprint of aluminium products. For instance, increasing the energy efficiency of processes, adopting cleaner energy sources such as renewable electricity, and implementing recycling programs can help mitigate the carbon footprint associated with aluminium production. Additionally, optimizing waste management practices and exploring innovative techniques for utilizing waste materials can minimize environmental burdens.

2 Analysis

Primary ore: from bauxite mining to smelter's gate

Bauxite mining contributes to GHG emissions through the combustion of fossil fuels in mining equipment and transportation vehicles. Additionally, the mining process creates dust and particulate matter, which could cause respiratory problems for workers and nearby communities if exposed. However, opportunities for mitigation exist, such as improving energy efficiency in equipment and transportation, using alternative fuels measures.

The **transportation of bauxite ore** from mining sites to refineries also contributes to GHG emissions and particulate matter. Transoceanic ships rely on fossil fuels to carry the ore from bauxite exporting ports to alumina refineries. Opportunities for mitigation include improving the efficiency of transportation ships, using alternative fuels or electrification, and reducing the distance between mining sites and refineries to minimize transportation.

Alumina refining also contributes to GHG emissions, primarily through the combustion of fossil fuels during the calcination process and the use of electricity in refining equipment. The refining process also generates particulate matter and other pollutants such as sulfur dioxide and nitrogen oxides. Mitigation opportunities include increasing energy efficiency, switching to renewable energy sources, implementing scrubbers to capture pollutants, and using new refining technologies that generate less waste and pollution.

Primary aluminium: from smelting to casting

Anode production for primary aluminium smelting involves the combustion of fossil fuels to generate heat and electricity. Particulate matter and other pollutants are generated during anode production. Opportunities for mitigation include improving energy efficiency, using renewable energy sources, implementing scrubbers and other pollution control technologies, and developing new anode production technologies that generate less waste and pollution.

Electrolysis is the most energy-intensive step in primary aluminium production and contributes significantly to GHG emissions. The three main sources of emissions are electricity supply, direct anode consumption and anode effect. Electricity supply grid is crucial in the LCA. Particulate matter and other pollutants are also generated during electrolysis. Attenuation and reduction opportunities include improving energy efficiency, using renewable energy sources, implementing scrubbers and other pollution control technologies, and developing new

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Casting of primary aluminium into semi-fabricated products generates fewer GHG emissions and particulate matter compared to previous steps. Alloying compounds supply is potentially a very important contributor to the impacts. However, energy is still required for casting, and emissions may occur during the production of casting equipment. Opportunities for mitigation include improving energy efficiency, using renewable energy sources, and developing new casting technologies that generate less waste and pollution.

Manufacturing and use of aluminium products

Manufacturing steps (e.g. rolling, extrusion, forging, anodization …) require energy and generate emissions during the processes. Losses of aluminium at each stage is the main source of impacts. Opportunities for attenuation and reduction include improving energy efficiency, using renewable energy sources, and developing new manufacturing technologies that generate fewer losses and pollution. Aluminium is widely used in the **transport sector,** primarily in the production of lightweight vehicles and aircraft. The use of aluminium in transportation can reduce fuel consumption and emissions. Aluminium is also commonly used in **building applications**, including window frames, roofing, and cladding. Aluminium is also an excellent conductor of electricity, making it an essential material in **electrical applications.** Aluminium is used in a wide range of **consumer goods**, including packaging, appliances, and electronics.

The end of life of a product with aluminium is mostly caused by its design, the weakness of another component, like rubber gasket for tightness or refurbishment. But the aluminium is, most of the time, still functionable, namely its physical properties are not affected. Opportunities for attenuation and reduction include designing for repairability and reuse, improving the energy efficiency of vehicles and aircraft, using and developing new lightweight alloys that are less energy-intensive and have lower environmental impact.

Secondary aluminium: from dismantling to remelting of aluminium scrap

At the end of their life cycle, aluminium products must be **dismantled, collected, and sorted** for recycling or disposal. The main challenge to optimize aluminium recycling is to sort out the different alloys (e.g. Alu6xxx from Alu 1xxx) to then be able to reshape identical product and not downcycle the aluminium scrap by mixing it into a casting alloy. Opportunities for attenuation and reduction include improving the efficiency of dismantling and sorting equipment, using alternative fuels or electrification for transportation, and developing new technologies for recycling and disposal that generate less waste and pollution.

The **remelting of aluminium scrap** to create secondary aluminium products has generally a lower impact than primary aluminium production, due to a lower need for energy. However, remelting also generates GHG emissions and particulate matter, primarily through the use of fossil fuels. Opportunities for mitigation include improving the efficiency of remelting equipment, using renewable energy sources in production, and developing new remelting technologies that allow to recycle products in a loop, without downcycling.

3 Methodology

Life-Cycle Assessment (LCA) is a valuable tool used to evaluate the environmental impacts associated with the entire life cycle of a product or process. By considering all stages, from raw material extraction to final disposal, LCA provides a comprehensive understanding of the environmental footprint. In the case of aluminium, a versatile and widely used material across various sectors, LCA is particularly relevant in identifying its major environmental impacts. It also helps to evaluate impacts of mitigation strategies. Information in this article comes from several publicly available sources and Groupe AGÉCO work over the past few years.

The primary objective was to assess the environmental implications of aluminium production and explore potential opportunities for reducing its environmental footprint.

To conduct the LCA studies, a rigorous methodology was employed. Firstly, a detailed inventory analysis was performed, involving the collection of data related to energy consumption, raw material extraction, emissions, and waste generation at each stage of the aluminium value chain (including bauxite mining, alumina refining, smelting, manufacturing of primary and secondary aluminium, and recycling processes).

Data quality and reliability were ensured through robust data collection methods, including interviews with industry experts, and reliance on published data from reputable sources. The collected data was then subjected to a life cycle impact assessment, which involved evaluating the environmental implications of the identified inputs and outputs using established impact categories such as global warming potential, acidification, eutrophication, and resource depletion.

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E2-2

Aluminum fuel: the costs of a novel way to move and store clean energy in a decarbonized world

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1. Introduction

Chemical energy carriers will likely be needed to smooth out seasonal variations in renewable power generation, decarbonize hard-to-abate sectors and remote communities and industries, or to facilitate the exchange of clean energy on a global scale. As an alternative to widely discussed hydrogen-based energy carriers, some metals have been proposed as promising candidates, as they store energy in a compact and stable form for a long time [1]. These metals, such as iron, aluminum, magnesium, and zinc, are safe and can be easily handled and shipped to end-users. They can be stored cheaply and can eventually be either combusted in air to produce heat, or reacted with water to generate heat and hydrogen, both of which can be used for power generation. Solid oxide particles are also produced and must be collected, returned to the metal producer, and reduced back into fuel to ensure sustainable use of these resources. Provided that the reduction step is carbon-free, this creates a clean utilization cycle that could facilitate the use of renewable energy in some sectors difficult to decarbonize.

Among metal-fuel candidates, aluminum is a promising option due to its high energy density, safety, and abundance. However, to challenge other alternatives, clean aluminum fuel must not only be technically viable but, most importantly, cost competitive and sustainable. Previous work studying aluminum as an energy carrier employed a simplified approach when estimating production costs [2] or omitted some costs from the analysis [3]. This work aims to assess the cost of aluminum production based on an in-depth analysis of the reduction process. The production process is reviewed and the economic impacts of using novel carbon-free reduction processes are estimated to position aluminum against other energy carriers in terms of costs.

2 Aluminum as an energy carrier

Aluminum is of particular interest as a fuel, as demonstrated by its use in rocket propulsion. Without the need for a specialized tank, it can store 10 times more energy per unit volume than cryogenic hydrogen, and over 6 times more than liquid ammonia. It is inherently safe, as a thin oxide layer rapidly forms on its surface once in contact with air, making it effectively inert to water at ambient conditions.

To discharge the energy stored in aluminum, it can be oxidized with water, which releases half of its stored energy in the form of heat and the other half as hydrogen. The complete reaction of coarse aluminum particles has been recently demonstrated with the use of supercritical water [4]. This high-temperature reaction enables the production of heat that can be recuperated for power generation and, therefore, significantly increase the round-trip efficiency of this cycle. This is key for any energy carrier application, as storing electricity in any energy carrier leads to significant losses (and costs). It is necessary to maximize the conversion back to electricity to make any cycle viable.

3 Aluminum production cost

The Hall-Héroult electrowinning process is the main process of interest when assessing the cost and sustainability of the aluminum fuel cycle. Alumina is fed to a molten cryolite bath where it dissolves and is reduced using an electric current. Carbon anodes are consumed during the process, producing CO_2, and they need to be replaced every three weeks. The electricity consumption depends on the voltage requirement and the current efficiency of the cell.

Production costs can vary depending on the technology used, location, availability of cheap electricity and integration of supply chain operations, such as alumina refining or bauxite mining. Cash cost breakdowns from aluminum producers (Alcoa [5] and Hydro [6]) are compared to Rio Tinto's 2021 production cost of $1,162 per tonne for their Canadian smelters [7]. Based on this data, costs estimates are derived for the main cost categories: electricity, anodes and operational expenditures (OPEX). Since aluminum fuel would be used in a closed cycle, it is assumed that the alumina cost is negligible if a high oxide collection efficiency can be achieved for each cycle.

To get the total recharging cost, capital expenditure (CAPEX) must be added. This value is difficult to estimate since values found in literature vary widely [8,9]. This can be explained by regional differences in costs, mainly between western countries and China, but also from differences in the year of construction and the plant capacity. For this study, the capital cost was set to $5,000 per tonne per year of production. The annualized capital cost is calculated using an interest rate of 8% and assuming smelter life of 50 years.

4 Carbon-free aluminum production

If firmed renewable electricity is assumed to be available to power smelters and upstream alumina emissions are amortized to a negligible value over many utilization cycles, the only CO_2 emissions in the recharging process would come from the carbon anodes. These emissions are significant and need to be eliminated, as they represent around 180g of CO_2 per kWh of stored energy, which is comparable to that of natural gas.

Using inert anodes would cut all carbon from the electrolytic process, thereby eliminating CO_2 and PFC emissions. Research on the topic has gained momentum in the last few decades and such anodes are currently being developed by Elysis. The

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company hopes to reach commercialization by 2024 and has already built a pilot-scale demonstration cell [10].

5 Results

If produced using conventional carbon anode smelting, the resulting energy cost of aluminum, normalized using its specific energy, corresponds to the black dotted line in fig. 1. The resulting y-intercept represents the fixed production costs, while the slope provides information on the process efficiency.

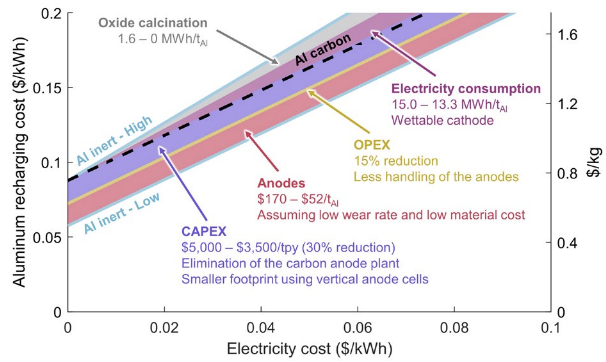

Figure 1. Aluminum cost of energy plotted with respect to electricity cost.

The cost of clean aluminum energy is presented as a range, showing the cost uncertainty of inert anodes. This technology could have the benefit of increasing cell productivity by 15% while reducing operating costs by 15% due to the reduced frequency at which anodes need to be replaced. Removing carbon from the process would, however, increase the energy requirement and therefore necessitate additional improvements to the cell design to keep the electricity consumption close to the current level [11]. Finally, inert anodes could be cheaper to produce and will eliminate the need for building a carbon anode baking plant for new smelters, which would impact CAPEX [12].

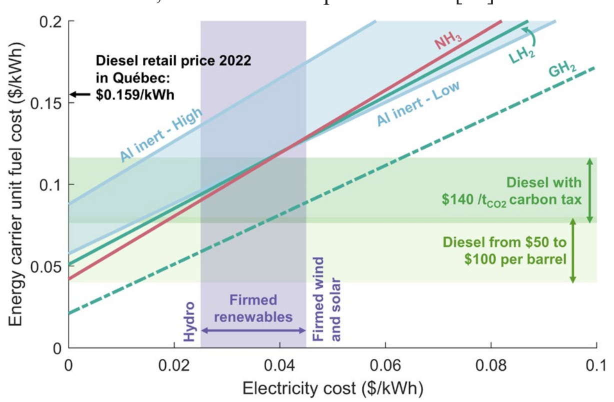

Figure 2. Comparison of the energy cost of various clean energy carriers with respect to electricity cost.

The cost of other energy carriers, such as gaseous hydrogen, liquified hydrogen, ammonia and diesel are compared to the aluminum cost range in fig. 2. These results show that aluminum is competitive on a chemical energy cost basis with ammonia, liquid hydrogen, and with diesel fuel if carbon emissions are priced at the intended rate for Canada in 2030 ($140/t$_{CO_2}$) and assuming an electricity price below $0.04/kWh. Gaseous hydrogen clearly appears to be the least expensive option, but this comparison only stands as a starting point to assess the competitiveness of an energy carrier in relation to any practical context. To correctly identify the best carrier for different application, storage, transportation, and conversion costs need to be considered, in addition to other practical issues, such as safety.

6 Conclusion

This study presents a comprehensive techno-economic analysis to assess the cost of aluminum as a sustainable energy carrier. A review of the potential impact of inert anode technology on production cost is also included to estimate the impact of eliminating CO_2 emissions from the process. Results show that aluminum cost could be competitive with diesel fuel, ammonia and liquefied hydrogen. Future studies should focus on assessing the entire metal-fuel cycle, including storage and power generation costs, to build specific case studies and identify the most promising application for aluminum as a fuel.

7 Acknowledgment

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E2-3 | DYNAMIC MONITORING OF ALUMINUM COMPANIES' CARBON FOOTPRINT

Florent Bouguin[1]

[1]OPTEL

Digital transformation now allows SMEs and large companies, such as those in aluminum transformation, to closely monitor the socio-environmental impacts of their value chains, all while guiding them toward making better business decisions. Better visibility and traceability in their supply chains are paramount to meeting regulatory requirements from legislative bodies and the customers they serve in the automotive industry and other sectors. We will explore several cases illustrating how Canada has positioned itself as a key player in the mining industry, both for its natural resources and its strong potential in sustainable practices. With OPTEL's strong presence in Germany, we will also discuss the opportunities and challenges for German businesses as they transform the supply chain towards greater sustainability and performance.

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D5-1

ASSESSMENT OF THE FATIGUE STRENGTH OF FRICTION STIR WELDED JOINTS IN ALUMINUM BRIDGE DECKS WITH NUMERICAL ANALYSIS

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1. Introduction

Friction stir welding (FSW) [1], a relatively new welding technique, has been widely used in the aerospace and manufacturing industries, showing superior mechanical and durability properties. However, its application in civil engineering is very limited due to the absence of appropriate standards and quality control guidelines. FSW appears to be a promising welding solution for the fabrication of vehicular bridge decks made from aluminium extrusions, with a potential to reduce distortions and improve fatigue properties. The fatigue behaviour of common FSW joint types such as the butt FSW has extensively been investigated and documented in literature. However, certain practical configurations such as the butt-lap joint used in the fabrication of extruded aluminium bridge decks have rarely been studied, especially in the area of fatigue performance. In this context, the present research provides first an overview on the welding process of typical aluminium friction stir welded bridge deck extrusions presenting the butt-lap configuration. Then, the fatigue behaviour of butt-lap FSW joints is assessed using the effective notch stress (ENS) approach.

2. Experimental work

Aluminium bridge deck extrusions made from AA6063-T6 were acquired and friction stir welded. The extrusions presented a butt-lap configuration. The welding occurred in the aluminium technology center of the National Research Council Canada NRCC. Friction stir welding is a solid-state welding technique where the tool first forges between the clamped extrusions flanges and rotates causing the flow and softening of the material. Then, it crosses the weld line while rotating until reaching the exit hole. First, the upper flange joint is welded, then the panel is overturned to weld the bottom flange joint. **Erreur! Source du renvoi introuvable.**1 illustrates the welding process and presents the final profile. The advancing side (AS) is the side where the rotational direction coincides with the welding direction while the retreating side (RS) is the side where the rotation direction of the tool is the opposite to the welding direction.

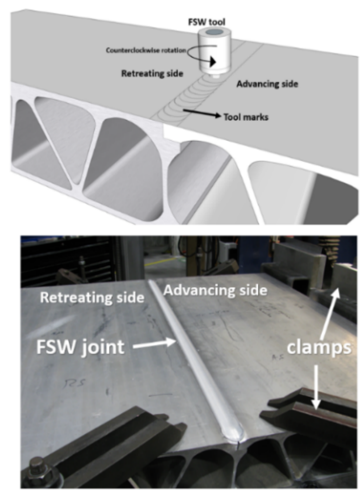

Figure 1: friction stir welding process of vehicular aluminium bridge deck extrusions [2]

Fatigue tests were conducted on both small-scale and large-scale specimens which were extracted from the welded pair of extrusions. The large-scale specimens were subjected to cyclic loading under a load ratio of R=0.1 and the small-scale specimens were subjected to tensile cyclic loading under load ratio R=0.1. Numerical approaches such as the notch stress approaches were used for the evaluation of the fatigue data.

3. Numerical analysis

The effective notch stress approach is a numerical method which assumes ideal elastic material properties. It is based on the calculation of the highest maximum principal stress at the weld root or toe which are geometrically idealized by a notch with a reference radius that depends on the plate thickness. The computed principal stress by means of finite element simulations at the notch represents the ENS. It is then evaluated and compared to the standardized notch stress S-N curve for aluminum alloys FAT-71 [3]. First, ENS is used to predict the fatigue failure mode of small-scale specimens. Then, it is performed to reassess the fatigue failure mode of the joint in Guo et al. [4] which present the fatigue results on a typical A6061-T6 butt-lap configuration. Finite element simulations were conducted on Abaqus to compute

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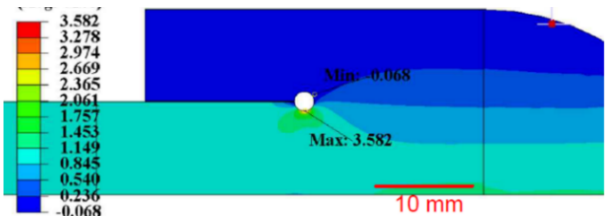
as 1 mm because the thickness of the joint was greater than 5 mm as recommended by the international institute of welding (IIW) [3] (see figure 2).

Figure 2: Principal stress distribution in the FSW area under a unit



applied nominal stress range [2], specimen geometries and experimental data was extracted from Guo et al.[4]

Numerical results showed that the stress concentration was located at the root of the butt-lap FSW joint. The stress concentration location also corresponded to the actual fatigue initiation location. The fatigue failure initiated from the weld root. Such a fatigue failure mode was associated with a degraded fatigue strength (category D according to the American design manual ADM, 2015 [5]). Numerical analysis based on the ENS approach showed capability to estimate the fatigue failure initiation location and thus may be used to optimize the structural configuration of the butt-lap FSW joints and thus improve their fatigue strengths.

4. Conclusions

The present research aimed at characterizing the fatigue behaviour of a uniquely designed butt-lap joint used in the fabrication of aluminium vehicular bridge decks using both numerical and experimental analysis. Also, technical insight on the friction stir welding process of thick extrusions for vehicular bridge deck application was presented. In summary, the following major conclusions are drawn:

- The ENS method well predicted the fatigue failure mode for butt-lap FSW joints reported in the literature. It was also applied to predict the fatigue failure mode of a butt-lap joint used in the fabrication of a typical aluminium vehicular bridge deck.
- The ENS approach could be used both to assess the fatigue behaviour of butt-lap FSW joints (comparing the fatigue data based on the ENS approach versus the design S-N curve provided by the IIW based on the ENS approach) and also estimating the fatigue initiation location which further controls the fatigue failure mode and subsequently the fatigue strength of the welded joint.

5. Acknowledgment

The authors acknowledge the financial support provided by the Fonds de recherche du Québec: Nature et Technologie (FRQNT) and the Natural Sciences and Engineering Research Council of Canada (NSERC). The welding of the extrusions was carried out at the Aluminum Technology Center of the National Research Council of Canada (NRCC). The authors extend their thanks to Mr. François Nadeau and Mr. Mario Party for their assistance. Furthermore, the authors appreciate the financial support and practical insights from Mr. Michel Toupin of Proco Inc. and Dr. Rachik Elmaraghy of SAFI Inc. The support of the Aluminum Research Center (REGAL), Québec, is also gratefully acknowledged. The authors recognize the contributions of Professor Mario Fafard (AluQuébec) and Dr. Sofiene Amira (CQRDA).

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W5-1 INFLUENCE OF ENVIRONMENTAL CONDITIONS ON THE MECHANICAL PERFORMANCE OF AL 5052-H36 ADHESIVELY BONDED JOINTS

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1. Introduction

The recreational vehicle (RVs) industry, including off-road and marine vehicles, significantly impacts the Canadian economy. The activities generated by this industry are considerable and highly varied. Consequently, the transportation industry is experiencing growing pressures with regards to greenhouse gas emissions, fuel consumption of motorized vehicles, and associated costs. To respond to society's exigence to have access to more energy-efficient vehicles, it appears urgent, among others, to develop lighter vehicles. Currently, the chassis of these vehicles are assembled mainly by welding, riveting, and screws. However, compared to conventional fastening methods, adhesive bonding offers several advantages as a desirable joining technology. These advantages include the ability to bond dissimilar materials with varying thicknesses, create continuous joints with uniform stress distribution, and reduce vibration while simultaneously reducing the weight of the structure. Throughout their lifespan, RVs are exposed to different loading and environmental conditions. As a result, the vehicle structures must withstand various environmental factors like moisture and temperature. In general, adhesives absorb water in a humid environment causing long-term degradation of the bonded joint. The effect of environmental aging on the mechanical properties of the bonded assembly is pronounced depending on the hygrothermal conditions and the exposure time in the humid environment and temperature. If specific properties (stiffness and strength) are diminished, aging may seriously compromise the fatigue life and durability of the joint in the long term. The objective of this study is to examine the influence of hygrothermal conditions, specifically moisture, and temperature, on the strength and fatigue life of aluminum bonded joints.

2. Environmental conditioning

This study will focus on aluminum-bonded joints made from Al 5052 and a methacrylate adhesive. Three categories of samples were studied. The first group of samples is in a pristine state, without any exposure to degradation conditions. The second category was degraded using the Cataplasma test procedure (JNS 30.03.35) recommended by Jaguar [1]. Cataplasma treatment is a standardized testing method that employs accelerated conditions, high and low temperatures (70°C and -20°C), moisture exposure, and thermal shock to assess the extent of degradation in bonded joints. The third batch of samples was immersed in tap water at samples was continuously monitored until they reached a fully saturated condition, which is referred to as "fully saturated."

3. NDT and Mechanical Characterisation

Two non-destructive testing methods were conducted to assess the level of degradation before the mechanical tests, contact ultrasound pulse-echo technique and immersion C-scan testing. The ultrasound pulse-echo test measures the travel time for ultrasonic lamb waves to propagate between two fixed piezoelectric sensors on the samples. This NDT technique enables comparing the ultrasonic wave flight time in the pristine reference sample to that in degraded samples. A dedicated test bench was constructed to guarantee the positioning of transducers on the specimen. The ultrasonic C-Scan mapping method was the second NDT technique used to visualize and localize defects in bonded joints and adhesive degradation associated with environmental exposure. A dedicated test bench was designed and positioned within a water tank to ensure coherent repetitive ultrasonic measurements. A robot arm coupled to an ultrasound probe with a 20MHz resonance frequency was employed over the overlap area to scan the desired region. For each category, twelve samples were prepared. The initial three samples were subjected to shear loading until rupture, utilizing an MTS Test frame 322 hydraulically controlled machine. The test speed was set to 0.5 mm/min. After mechanical testing, SEM images of the fracture surfaces were captured to analyze the developed failure modes. For fatigue testing, nine samples from each category were tested on the same machine using a 0.1 load ratio and a cyclic frequency of 5Hz. S/N curves were generated from three loading levels for each series. Three specimens were tested per loading level to evaluate fatigue data dispersion and investigate result repeatability. Acoustic emission monitoring was employed to detect damage initiation during the static test and fatigue crack initiation using AE piezoelectric sensors and the Vallen multi-channel AE measurement system (AMSY-6)

4. Analysis

Non-destructive tests results

The measurement of the time delay of the ultrasonic pulse, which travels between the transmitter and the piezoelectric receiver, made it possible to estimate the speed of propagation of the picked guided wave mode. Preliminary ultrasonic calibration

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sensitive to defects and microstructural degradation related to environmental exposure. Therefore, shear waves were used to assess the bond joint's damaged state, and the collected signals were analyzed to process time delay and velocity variations. Generally, the wave traveling velocity decreases if it interacts with created defects in the bonded area over time under degraded conditions. The obtained results show that the velocity of the considered wave mode decreases by 1.5% and 7% for Cataplasma degraded condition and fully saturated bond joint samples, respectively. This reduction confirms that the hygrothermal conditions create physical and microstructural damage in bonded joints. However, the fully saturated samples seem more damaged than the Cataplasma ones.

Joint strength and durability

Generally, both hygrothermal degradation conditions affect the adhesive joint's principal mechanical properties (rigidity, resistance, and ductility). However, the performance reduction is more severe for fully saturated bond joint samples. This drastic drop in mechanical properties is justified by the prolonged exposure to hot water for the fully saturated samples, favouring a significant humidity absorption by Fick law diffusion [2] in the adhesive layer. The absorbed water molecules cause swelling of the adhesive, decreasing stiffness and mechanical strength. The AE results confirmed that the fully saturated samples have a lower resistance to damage initiation, meaning that damage onset occurred in lower load levels than in Cataplasma conditioning. The fracture surface of SLJs showed a cohesive failure for pristine samples, while there is a combination of adhesive and cohesive failure for environmentally degraded samples. The SEM images show the border between interface failure at the edges and cohesive failure away from the edge for degraded samples. A good coherence exists between the C-scan images of interfaces, SEM images of the failure surface, and adhesive texture. Generally, Water molecules can hydrolyse chemical bonds, forming weaker chemical bonds. In addition, the absorbed water molecules act as plasticizers, and this plasticization effect makes the adhesive softer and less rigid. As a result, the adhesive loses its ability to effectively transfer loads and distribute stress, decreasing joint strength and resistance. Under mechanical fatigue testing, the results show that joint fatigue resistance to crack initiation (Figure 1) under constant amplitude cyclic loading has decreased by 97% for fully saturated samples and 64% for Cataplasma degraded samples. The total number of cycles to failure has been decreased by 80% and 30% for fully saturated and Cataplasma degraded samples respectively. Water absorption weakens the bond between the adhesive and the substrate, reducing the interfacial adhesion. During cyclic loading, this weakened bond is more susceptible to crack initiation and propagation. In the case of Cataplasma degradation condition, the rapid freezing of the absorbed water within the adhesive layer can introduce swelling, creating internal pressure within the adhesive and leading to the initiation of microcracks. However, the adhesive layer may experience compressive residual stress around the frozen water pockets or between the adhesive and substrate, reducing the probability of crack propagation compared to fully saturated samples.

5. Conclusion

- This study shows that the environmental conditions reduced the joint resistance, and durability and changed the fracture surface from pure cohesive failure to a combination of adhesive and cohesive failure.
- The main reasons for decreasing adhesive bond mechanical properties are swelling, plasticization and softening, and chemical reaction between the adhesive and absorbed water.
- The exposure time of SLJ to hot water showed more severe degradation than those with less exposure time but experienced high and low temperatures.

6. Acknowledgment

This work was financially supported by PRIMA and by the Natural Science and Engineering Research Council (NSERC). The research team acknowledges the Centre des Technologies Avancé and Gilbert Lefrançois, Eng., for the technical assistance and counselling.

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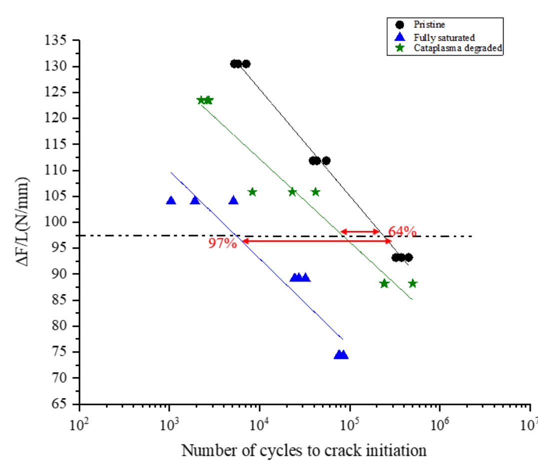

Figure 1. Fatigue curve of SLJs

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W5-2 | ADVANCES IN ADDITIVE FRICTION EXTRUSION DEPOSITION

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Laser-based processes such as cutting, welding or laser milling with ultrafast lasers are widely used in the industrial processing of aluminum alloys. However, the large number of adjustable parameters and their interactions involved in these processes makes process development and optimization time-consuming and knowledge-intensive. Especially the physical interactions between different process parameters require a deep understanding of the process behavior to find the optimum parameter set using standard Design of Experiments (DOE). Alternatively, optimization algorithms can be employed during the experiments with a stepwise change of the parameters to minimize the number of trials required. This paper presents a practical method for optimizing the laser cutting process using Bayesian optimization that operators can use without prior knowledge of the process or additional measurement equipment installed at the processing system.

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A2-2 | THERMAL ANALYSIS FOR ALUMINUM CASTING TECHNOLOGY TRANSFER

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Thermal analysis is the study of the temperature during the solidification of a sample of molten metal. Traditionally, the temperature versus time curve is used to define reactions which has its limitations. In aluminum foundries, thermal analysis has been used since the late '80's to measure the grain refinement and the eutectic modification of Aluminium-Silicon alloys. Recently, the use of the cooling rate curve and the upper derivatives allowed to obtain more detailed information on the solidification characteristics of aluminum alloys. Thanks to mathematical filters and data processing algorithms, most of the exothermic and endothermic reactions occurring during solidification are detected and measured on the shop-floor. The calculation of the zero curve makes it possible to measure the relative energy coming from the different phases. Recent development used the cooling rate curve, the zero curve, the relative energy and the higher order derivatives.

Applications in R&D:

Technology transfer tool between the laboratory and the foundry; After developing new alloy, method or treatment; The laboratory furnaces is much different from production furnaces; Between different plants of the same corporation; Measurement tool of the non-equilibrium phases and the solidification for alloy development to compare with the simulated phase transformation temperatures; Hot tearing evaluation for long freezing range alloy; Study for metal treatment and solidification for process development.

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A2-3

MODELING PRECIPITATION EFFECTS ON MECHANICAL CHARACTERISTICS OF AL-CU ALLOY

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1. Introduction

Microstructure evolution plays a crucial role in determining the mechanical properties of age-hardenable aluminium alloys [1]. The presence of nano-sized precipitates within the microstructure hinders the movement of dislocations, thereby increasing the critical resolved shear stress (CRSS) required for their motion and enhancing mechanical strength. The size, shape, and volume fraction of secondary phases are key factors in determining the level of hardening during the aging process, affected by time and temperature. Understanding the strengthening of aged aluminium alloys requires awareness of the influence of the complex microstructure evolution process, which includes thermo-mechanical principles and kinetic phenomena. However, it is worth noting that many precipitation models fail to adequately incorporate kinetic considerations.

A notable example is the precipitation of Al-Cu alloy, extensively studied for over a century, given the following sequence of precipitation: (SSSS) →GP zones→ θ''→ θ' → θ [2, 3]. To explain the formation of phases in this sequence, previous research has examined classical nucleation theory. The involvement of precursors in the nucleation of each phase, which is commonly referred to as one of the plausible kinetic pathways, is considered, but experimental evidence is lacking. Challenges arise in understanding the plate-shaped θ'' transformation with high Cu content as a possible descendant of monolayer spherical-shaped GP zones, or in explaining the direct transition from θ'' to θ' [4, 5]. Moreover, the intermetallic secondary phases exhibit solid covalent bonding, resulting in a significantly slow transformation between them during aging due to low atomic mobility and diffusion within the intermetallic structure. It further complicates the dominant role of precursors in solid-state transformation.

The absence of a comprehensive theory explaining the kinetic pathway and microstructure evolution during precipitation hinders the analysis of precipitation hardening. This study aims to address this gap by employing a multidisciplinary computational model to investigate the role of kinetics in precipitation hardening based on complementary theories and analytical approaches. The computational analysis provides detailed insights into the precipitation evolution and the contributions of secondary phases to the strengthening process. In addition, the work hardening of the aged material is considered using FEM models that account for the effects of precipitation on the material's plastic deformation.

2 Scope of study

This study investigates the kinetic pathway and the involvement of interfacial mobility in the evolution of secondary phases using the complementary theory of solid-state precipitation and nucleation [6]. Instead of considering a predetermined sequence and precursor roles, it focuses on a collective phenomenon where different phase embryos interact intensively, highlighting the role of interfacial mobility in solid-state precipitation. During incubation, "winner" embryos grow at the expense of dissolved "loser" embryos, with their growth rate limited by the driving force. From the early stages of nucleation, all phase embryos are present and grow at the expense of the matrix, and the competition among embryos is driven by their favorable kinetics.

The study utilizes the mixed-mode regime to model the growth and dissolution rates of competing phases [7, 8]. Phases' shape, size, and spatial distribution are assessed to determine their CRSS and equivalent initial yield stress. It is worth noting that at a more advanced level, it would be accessible to calculate those parameters for different cluster sizes with the unified theory of nucleation and coarsening based on this "winner-loser" phenomenon [9]. The study also examines the impact of secondary phases on work hardening through FEM simulations. The initial yield stress and the contribution of secondary phases are considered in determining dislocation hardening, which impacts the accumulation of geometric and statistical dislocations in plastic deformation.

This study employs a multidisciplinary approach, including theoretical modeling, computational analysis, and FEM simulations, to enhance the understanding of precipitation hardening in age-hardenable aluminium alloys. It provides practical insights that can improve industrial applications and lead to more efficient manufacturing processes for optimized alloy components.

3 Methodology

This study utilizes a microstructural computational analysis based on established theories outlined in references [6, 9]. It employs mixed-mode regime analytical approaches to model the growth and dissolution of shape-preserving ellipsoidal precipitates [7, 8]. Following the analytical approach found by Nie et al. in reference [10], the evaluation of critical resolved shear stress (CRSS) for different phases involves calculating values based on microstructure evolution and considering other phase characteristics, such as shearability, orientation variants,

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favorable slip systems, etc. Furthermore, it employs adapted deformation plasticity and hardening laws proposed by Ashby [11] and Kocks [12] to provide models for FEM simulations.

To implement the relevant codes and perform FEM simulations, the "Multiphysics Object Oriented Simulation Environment" (MOOSE) [13, 14] is utilized, which is an open-source, parallel finite element framework. Standard C++ codes for MOOSE are developed to implement microstructure evolution, CRSS and yield stress computation, and the work hardening model. MOOSE-based applications are used to analyze precipitation evolution at the microstructure level, calculate initial yield, and perform FEM simulations. These MOOSE-based applications are linked together, and data is transferred between them in a multi-apps manner within the MOOSE framework, providing the required parameters for FEM simulations based on microstructure evolution and yield computation.

In this study, a fully saturated Al-4wt%Cu alloy is considered, undergoing isothermal precipitation at 423 K for 300 hours of aging. The evolution of different phases, including θ'', θ', and θ are assessed. The computational analysis incorporates the interfacial mobility and equilibrium solubility of these phases that the research team was able to obtain from MatCalc and DSC analysis results. Moreover, relevant experimental tests are conducted to verify the model and simulations.

4 Analysis

Microstructure

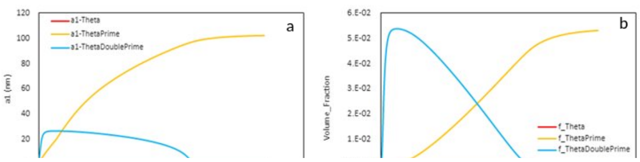
Fig. 1 illustrates the evolution of size and volume fraction for different phases during the aging process. θ'' demonstrates rapid growth in the early hours, reaching a maximum size of 50 nm within 10 hours (a_1 in the figure is the radius), followed by gradual dissolution up to 200 hours. In contrast, the growth rate of θ' is slower compared to θ'', attributed to its lower interfacial mobility ($M_{\theta'} = 5.23\ e^{-23}\ m^4\ J^{-1}s^{-1}$, and $M_{\theta''} = 1.03\ e^{-20}\ m^4\ J^{-1}s^{-1}$). Notably, during the initial stages of aging, a small size of θ' phase with a low volume fraction is observed, emphasizing the role of the kinetic pathway considered in this model. After 220 hours, θ' reaches its maximum size of approximately 200 nm. Remarkably, the size of θ undergoes minimal changes due to its extremely low interfacial mobility ($M_{\theta'} = 2.39\ e^{-29}\ m^4\ J^{-1}s^{-1}$) at this temperature.

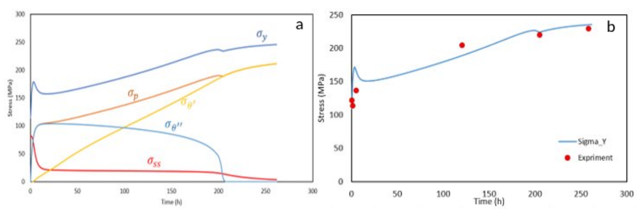
Mechanical Properties

The development of yield stress, σ_y, based on equivalent precipitation hardening, σ_p, offers comprehensive insights into the mechanical characteristics at various stages of precipitation, as illustrated in Fig. 2a. The constant contributions of grain boundary and dislocation hardening effects in aged aluminium, accounting for ambient temperature conditions, are reflected in the difference between σ_p and σ_y. This graph not only showcases the individual contributions of θ'' and θ' phases to precipitation hardening but also provides valuable information for optimizing manufacturing processes and understanding their implications on work hardening during plastic deformation. Furthermore, Fig. 2b demonstrates a close agreement between computed yield stress values and experimental results from mechanical tension tests, thereby validating the model's reliability across different precipitation times. The calculated initial yield stress, combined with microstructural values and coefficients obtained from microstructure analysis, provides the necessary data for performing von Mises yield surface calculations in Finite Element Method (FEM) simulations during plastic deformation. This approach facilitates a comprehensive understanding of the material's mechanical behavior under varying loading conditions and enables predictions of its response to the applied stresses.

Fig. 1. a) Size and, b) volume fraction evolution of θ'', θ', and θ during aging time

Fig. 2. a) Contribution of different parameters on yield computation, b) Comparison of experimental and computational analysis.





5 Conclusion

In conclusion, this study emphasizes the significance of incorporating kinetic considerations and interfacial mobility in the evolution of secondary phases during the precipitation process in age-hardenable aluminium alloys. The multidisciplinary approach, encompassing computational analysis at the microstructure level and FEM simulations at the engineering level, enhances understanding of the collective phenomena involved in precipitation evolution and the distinct influence of different phases on mechanical properties and material behaviours. The utilization of MOOSE-based applications provides practical insights for developing efficient industrial simulations that account for the coupled thermomechanical impacts of microstructural changes on manufacturing processes. By integrating theoretical modeling, computational analysis, and FEM simulations, this study contributes to advancing the understanding and optimization of precipitation hardening in age-hardenable aluminium alloys.

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KEYNOTE | ALUMINIUM LONG SPAN SUSPENSION BRIDGES - AMBITIONS, OPPORTUNITIES AND CHALLENGES

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Aluminium bridges in Norway are about non-existing except for some aluminium bridge decks for shorter bridges as replacement decks. However, in recent years the interest for aluminium in long span bridges has grown among the road authorities, industry and the municipalities and counties as bridge owners. A number of concepts have been developed and especially the Langenuen suspension bridge, with a span between the towers of 1200 meters, has been thoroughly investigated with regards to global stability, weight optimization, fatigue properties and manufacturing. This presentation will guide the audience through the concept, ambitions, opportunities and challenges.

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W6-2 | MECHANICAL PROPERTIES OF RESISTANCE SPOT WELDED JOINTS OF ALUMINUM CASTINGS AND WROUGHT ALLOYS

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In recent years, automobiles have been required to have lighter bodies in order to reduce CO2 emissions and increase cruising range due to electrification. The application of aluminum alloys, which are lighter than steels that have been widely applied in the past, is expanding, and aluminum wrought alloys and castings are increasingly being applied to structural members of car body.

Mechanical fastening such as SPR is used to join aluminum alloys together, but joining by resistance spot welding is also possible, in which case additional materials such as rivets are not required, therefore the weight reduction effect of aluminum alloy application can be maximized.

However, in general, castings are more difficult to join by resistance spot welding than wrought alloys because they have lower melting temperatures due to higher amounts of added elements, more defects such as blowholes, and inconsistent thicknesses compared to wrought alloys.

In this study, the characteristics of resistance spot welds of aluminum castings and wrought alloys were clarified using the nugget shape, hardness distribution and microstructure results. In addition, strength properties such as tensile shear strength and cross tension strength were evaluated to clarify the relationship between the characteristics and the strength.

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A3-1

EFFECTS OF AN OSCILLATING LOAD ON SUPERPLASTIC DEFORMATION AND MICROSTRUCTURE OF AA5083 SHEET SPECIMENS

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1. Introduction

Aluminium alloy AA5083 is commercially available as a fine-grained sheet. This alloy is commonly used in the automotive and aerospace industries to produce complex-shaped parts in a process called superplastic forming. Superplastic forming consists of slowly shaping Aluminium sheets up to very large deformations at temperatures between 450 - 550°C [1], producing parts that are lightweight, have good strength and stiffness, good weldability and superior corrosion resistance. The automotive industry is increasingly using this process to form very large parts (e.g. body side panels) so as to reduce the need for welding, hemming and other joining operations. Nevertheless, the very slow deformation required for superplastic forming leads to long forming times, increased manufacturing costs and limits its application to low-volume production.

However, in the last few years, research & development has achieved some improvements in the superplastic production process. For instance, Jarrar redesigned gas pressure profiles which have helped to reduce cycle times without jeopardizing the integrity of the manufactured parts [2]. And Mauduit et al. introduced infra-red heating lamps into the process to cut down heating time and production costs [3]. The investigation of the effects of oscillations on the superplastic deformation of aluminum was not reported in the literature prior to this work, however, the benefits of oscillations have been shown in other applications. Padhy et al. [4] compared friction stir welding of aluminum with and without ultrasonic vibration and observed that there was increased material flow and softening with the ultrasonic vibration. Metallographic analyses performed revealed that the thermo-elastic energy generated by the vibrations helped soften the material and reduce forming stresses [4, 5], and thus improve plastic deformation.

2 Scope of study

Considering the beneficial effects of superimposed oscillations in other applications, the objective of this work is to determine its effects on superplastic forming. Therefore, this study consists of experimentally applying a small oscillating load on AA5083 sheet specimens that are monotonically loaded in uniaxial tension at 450°C and at various strain rates. Finally, the microstructural changes that occur during superplastic deformation will also be observed under the microscope.

3 Methodology

Testing equipment included a well insulated 2 zone furnace that works in accordance with the ASTM E21-17 standard, a pair of electro-magnets, an MTS tensile testing machine, and a data acquisition (DAQ) system. A proportional-integral-derivative controller was used to regulate the temperature, the electro-magnets were used to induce a sine wave oscillating load on the specimen, the MTS machine was used to apply a monotonic tensile load, and the DAQ system collected the data.

The tensile tests were conducted in accordance with the ASTM E2448-18 standard. First, the oscillation was calibrated, then the furnace was preheated to 450°C. Before testing, the dimensions of each specimen were measured and recorded. After the furnace reached the desired temperature, it was raised to fasten the specimen in the holding fixture of the MTS machine, then the furnace was lowered again around the specimen and sealed. Once the furnace temperature stabilized at 450°C, the specimen was left to soak for 5 minutes in accordance with industrial practice, then an oscillating load was generated, and the tensile test was started. On average, the preparation for each test took 11 minutes. After the test was conducted and fracture occurred, force and displacement data were exported and processed with MATLAB to determine the true stress and true strain behaviour. For each test condition 3 repeats were performed. Below is the test matrix of tensile tests performed for this study showing strain rates, amplitudes, and frequencies tested.

Table 1: Test Matrix

Amplitude (N)	Frequency (Hz)	Strain rates (s^{-1})	Temperature (°C)
0, 0.02, 0.08, 0.5	5	0.001 - 0.4	450

4 Analysis

Microstructural Analysis

The main deformation mechanism in superplastic forming (SPF) is grain boundary sliding (GBS), as seen in the literature [6]. The high elongation in SPF is facilitated by GBS, and failure is accompanied by void nucleation, void growth, and void coalescence, which then leads to fracture. SEM images of tested specimens showed deformation in the grains, cavitation development, and GBS.

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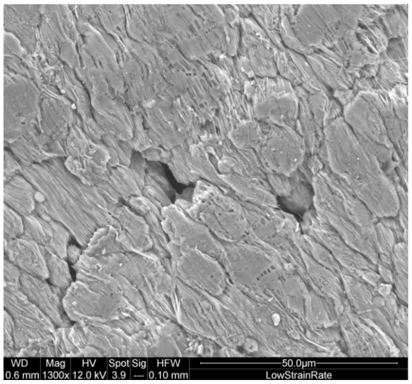

Figure 1 SEM images of post formed AA5083 samples deformed at 450°C and $1x10^{-3}$ s^{-1} strain rate.

Figure 1 clearly shows evidence of GBS and grain elongation, as expected from such high-strain deformations, and the grain boundaries have been stretched along the tensile axis (the tensile axis is at an angle of 45°from the vertical).

Tensile Test Results

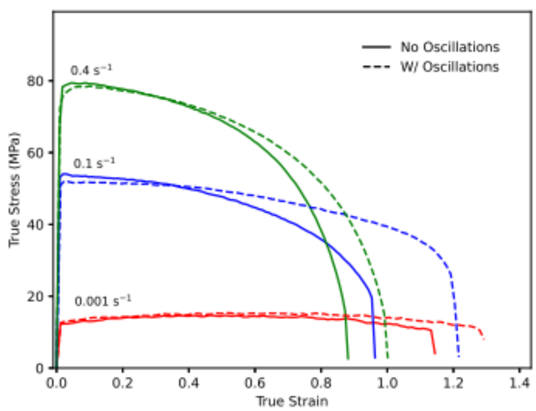

Figure 2 True stress-strain curves with and without oscillations at different strain rates.

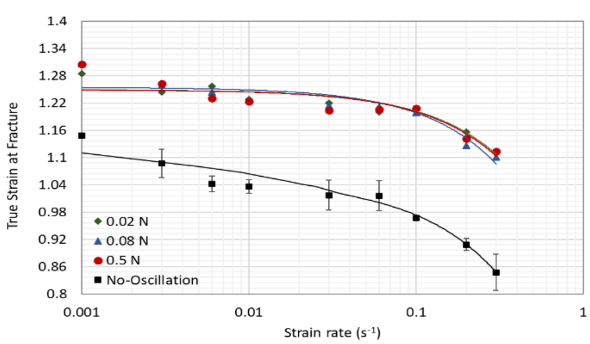

Figure 3 True strain at fracture as a function of strain rate with and without superimposed oscillations

The results of the tensile tests, shown in the figures above, indicate there was significant improvement in true strain at fracture when a minor oscillating load was superimposed during tensile testing. This was observed for every load amplitude tested (0.02 N, 0.08 N, 0.5 N) and across all the strain rates tested (0.001 – 0.3 s^{-1}). The percent improvement in true strain at fracture ranged from 12 to 31 %. This shows that superimposed minor oscillations have a significant effect on the superplastic forming of AA5083 sheets. This could be a result of improved GBS. As mentioned already, GBS is the main deformation mechanism in superplastic forming and the minor oscillation appears to facilitate GBS, leading to higher strains at fracture. Also, oscillations may help to reduce local stresses, which in turn would reduce void coalescence and delay the onset of fracture.

5 Conclusions

AA5083 specimens were tested in uniaxial tension at 450°C and at multiple strain rates. There were significant improvements in the true strain at fracture for specimens tested with a superimposed oscillating load compared with samples tested without the oscillating load. Tested specimen were observed under the SEM and showed evidence of grain boundary sliding with the grains visibly elongated along the axis of deformation. The minor oscillations are thought to facilitate grain boundary sliding, thus leading to increased deformations even at higher strain rates. It is anticipated that oscillation-induced enhancement of superplastic forming could significantly improve industrial SPF processes because of more uniform thinning of formed parts (i.e. improved part quality), reduced scrap rates and also reduced cycle times (i.e. improved productivity).

6 Acknowledgments

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KEYNOTE | ALUMINIUM IN A CIRCULAR ECONOMY

Rosa Galvez[1]

Sénat du Canada[1]

Aluminium is more than just a resource; it is an absolutely critical component of human society and it will only grow in importance as we accelerate the transition towards a low-carbon economy. The Honourable Rosa Galvez, a pollution expert and Canadian Senator since 2016, will provide context surrounding her life experience as a woman from Peru practicing engineering and now politics in Canada as well as how Canada fares in the global fight to reduce greenhouse gas emissions. This presentation aims to provide insight on aluminium as an invaluable part of our life and economy in the context of climate change, environmental stewardship, a circular economy, and the UN Sustainable Development Goals.

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A4-2 | MODELLING OF PROCESS-MICROSTRUCTURE-PROPERTIES RELATIONSHIPS IN ALUMINUM COMPONENTS WITH ADVANCED MICROSTRUCTURAL CHARACTERIZATION AND MACHINE LEARNING

Marc-Olivier Gagné[1], Siyu Tu[1], Alexandre Gariépy[1], Phuong Vo[1], Ghazal Farhani[1]

[1]National Research Council Canada (NRC-CNRC)

Microstructural characterization, especially using optical microscopy, has been an important part of process development and process operation of aluminum components during the last decades. At the era of digitalization and artificial intelligence, manufacturing processes are pushed to move toward a new paradigm where data intelligence and machine learning are fully integrated. This work presents a novel approach for optical microscopy and show how it can be integrated into a digital process data workflow and leveraged to gain critical insight on the process-microstructure-properties relationships with the help of machine learning. High Pressure Vacuum Die Casting (HPVDC) of Aural™-2 alloy and Cold Spray for Additive Manufacturing (CSAM) of AA6061 alloy, both in a research environment, are taken as example to illustrate the approach. It is demonstrated that with a proper database structure, advanced image analysis methods and a custom easy-to-use machine learning tool, it is possible to automate and speed up a large part of the workflow and improve the overall value of the characterization on one hand by gaining insight on the process to microstructure relationships which can help to understand and improve the process and on the other hand, by developing a predictive model for the mechanical properties using the microstructure data as inputs for the model.

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A4-4 | ALULIBS - EFFORTLESS AUTOMATED MOLTEN METAL SAMPLING

François Audet[1]

[1]Solutions Fonderie Services Métallurgiques Inc.

For an aluminum alloy manufacturer to be competitive they rely on recycled aluminum in which the elemental composition may or may not be known. To utilize this material successfully requires constant monitoring through continuous and frequent sampling of the melt to ensure it meets specifications. The sampling process is time-consuming, labor intensive, and a safety risk due to the amount of interaction with the melt.

The Alulibs streamlines the aluminum alloy production by automating sampling by providing 24/7 real-time multi-element chemistry readings in molten aluminum. It enables operations to react faster with additions by understanding how the melt is changing and without the need for sampling, it will provide a safer work environment and increased man hours.

The Alulibs will benefit facilities by enabling them to produce the same high-quality aluminum alloys more efficiently and safely, helping to meet customer demands and remain competitive.

This presentation will focus on the technical aspects of the Alulibsenabling chemistry monitoring below the surface of the melt.

ISBN: 978-2-9815930-6-1

S2-1 | ATMOSPHERIC PLASMA PROCESSES AS POTENTIAL ALTERNATIVE TO THE CONVENTIONAL ANODIZATION OF ALUMINUM ALLOYS

Jacopo Profili[1]

[1]Laboratoire d'ingénierie de surface, Centre de recherche sur les matériaux avancés, Université Laval

In the last years, anodization of aluminum alloys is facing new challenges because of the increase of strict regulations. Alternative solutions are already studied in different research laboratories to develop eco-friendlier alternatives to Cr(VI) baths or similar conventional anodization methods. In this context, plasma processes have already demonstrated many advantages concerning functionalization and coating of surfaces when compared to the other conventional methods. More specifically, plasma at atmospheric pressure overcome the limitations inherent to wet-chemical treatments in terms of the amount of material consumed, environmental impact and could be easily integrated in-line productions. More recently, plasma-transferred arcs (PTAs) have been studied to modify the surface of metallic surfaces. These systems generally consist of an electric arc formed between a biased electrode and a sample. The formation of such plasma-transferred-arcs is usually associated with an uncontrolled modification of surfaces, a quick increase of the temperature and the melting process. For this reason, PTAs have been extensively used in welding applications. This work focuses on the fine analysis of the surface melting and re-solidification dynamics to better control the anodization processes for the aluminum (Al). This novel alternative process employs a plasma-jet system at atmospheric pressure (APPJ) working in air or nitrogen. The modification of the chemical and physical properties was obtained tuning the interaction between the arc and the surfaces. The characterization of the plasma source obtained by optical emission spectroscopy (OES), highlighted the etching processes of the substrates. Scanning electron microscopy (SEM), stylus profilometry and X-ray microtomography measurements were also used to clearly study the increase in the surface roughness with treatment time. Confocal microscopy and ATR-FTIR were employed to examine the morphology as well as the chemistry of APPJ-treated surfaces. Finally, because this type of preparation remains very important for the adhesion of suspension plasma sprayed coatings (SPS), the modified surfaces were also used to evaluate the adhesion of ceramic coatings on Al samples. The metallic surfaces were covered using a Mettech Axial (III) system from Al2O3 powders. The adhesion strength of the coatings was evaluated by the ASTM C-633 pull test protocol. Grit blasting was employed as a benchmark technique to compare different surface preparations.

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S2-2 | NANOSTRUCTURED SUPERHYDROPHOBIC THIN FILMS AGAINST CORROSION OF ALUMINUM ALLOYS

Dilip Sarkar[1], X. Grant Chen[1]

[1]Université du Québec à Chicoutimi, Aluminum Research Centre - REGAL

Superhydrophobic surfaces have rising demands in various industrial sectors including consumer electronics, optical, transportation, medical, electrical and home appliances. A one-step electrochemical method was initially developed in our research group to fabricate superhydrophobic copper surfaces. In this process, surface of copper was modified to copper stearate with micro-nano two-tire roughness in the ethanolic stearic acid solution providing enhanced corrosion protection of copper. However, this process was found not effective for the fabrication of superhydrophobic aluminum surfaces. A new one-step electrochemical process was developed to fabricate superhydrophobic aluminum using modified electrolytes of SA adding metal ions. Metal stearates superhydrophobic thin films ware formed on the aluminum surfaces by electrochemical modifications using these new electrolytes. The corrosion properties of these superhydrophobic thin films on aluminum were evaluated in 3.5 wt.% NaCl aqueous solutions. The results demonstrate that the superhydrophobic thin films on aluminum display better anti-corrosion properties than the original aluminum.

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S2-3 | ECOFRIENDLY SURFACE TREATMENT METHODS IN MANUFACTURING

Saleema Noormohammed[1]

[1]Réseau Trans-Al

Whether it is to bond surfaces with adhesives, coat, prime, print, or seal, adhesion becomes an extremely important criterion. This means that the chemical product used in any of these processes needs to create a strong bond with the surface of interest. If there is no adhesion, the whole system fails. Therefore, Surface Treatment (ST) becomes crucial for successful and durable products. ST allows modification of surfaces to a few molecular layers, which is the basis of forming chemical bonds with a foreign material (ex. adhesives). It isn't new that manufacturing gets more complex with demands of complex geometries, innovative and efficient light materials as aluminum, and of automated processes, all in accordance with health and safety measures and be ecofriendly. Several existing ST techniques deal with modifying texture, chemistry, and functionality of a surface to favor adhesion. Conventional methods using solvents, etchants, or abrasives are not entirely clean and may leave chemical or abrasive residues after treatment interfering with adhesion. Aiming on achieving high adhesion using clean and simple processes, this paper addresses two major physical ST methods - Atmospheric Pressure Plasma (APP) and Laser Ablation (LA). APP alters the surface chemistry and reactivity to create strong chemical bonds by interacting with air or gas plasmas created under atmospheric pressure. LA precisely cleans and textures surfaces by removing atomic layers of material with focused pulsed laser beam, which, depending on the energy, can also alter the surface chemistry. Both methods are easy to implement in industrial setups.

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KEYNOTE | ELYSIS A KEY PLAYER IN THE ALUMINUM DECARBONIZATION

Vincent Christ[1]

[1]ELYSIS

ELYSIS is a joint venture between Alcoa and Rio Tinto formed in 2018 with a mission to transform the aluminium industry with breakthrough technology where environmental and financial performance meet. Aluminium is a key material part of the transition to renewable energy. It is therefore important to develop breakthrough solutions enabling the decarbonization of the aluminium production and replacing carbon dioxide emissions by oxygen. ELYSIS is progressing at a fast pace towards this goal and is excited to provide an update of its journey.

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KEYNOTE | ALUMINUM AUTO BODY SHEET IN NORTH AMERICA AFTER THE 2015 FORD F-150

Laurent Chappuis[1]

[1] Light Metal Consultants, LLC

The presentation will explore some of the forces both driving and limiting the use of aluminum auto body sheet (ABS). Some of the topics will include the competitive situation, the manufacturing environment, the impact of scrap recycling, and some considerations on potential differences between EV start-ups and established OEMs. It will follow with a short review of current applications, both won and lost. Finally, the presentation will conclude by offering some thoughts about the future, using the same parameters outlined in the introduction.

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D8-4 | REVOLUTIONIZING 6G AND AEROSPACE WITH ALUMINUM-BASED ROCKOON ENABLED HIGH ALTITUDE PLATFORM SYSTEMS: THE VERTEX JOURNEY

Abdo Shabah[1]

[1]Solutions Humanitas

The REHAPS project aims to address critical environmental challenges in telecommunication and aerospace by leveraging the multifaceted properties of aluminum. Serving as the backbone in the design of Rockoon Enabled High Altitude Platform Systems (REHAPS), aluminum offers unique attributes—light weight, high strength, corrosion resistance, and thermal and electrical conductivity—that make it integral to the system's architecture. The project's objectives are four-fold: 1) to design, manufacture, and test an aluminum-based REHAPS structure that enhances efficiency and robustness; 2) to investigate the long-term sustainability, machinability, and cost-effectiveness of aluminum in REHAPS; 3) to study the thermal properties of aluminum during rocket launching from REHAPS, focusing on thermal expansion and its influence on long-term space exposure; 4) to examine the suitability of aluminum in the fabrication of 5G antennas, leveraging its conductive properties for lightweight and efficient design. The REHAPS vehicle designed in this project functions as a 'flying space train,' capable of high-coverage 5G deployment, innovative energy-payload transfer, and swift operational readiness. The comprehensive approach to aluminum application in REHAPS aims not only to elevate the technological boundaries in aerospace and communication but also to create an environmentally responsible alternative to current systems. This investigation seeks to maximize aluminum's potential in these fields, balancing efficiency, sustainability, and cost-effectiveness.

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W7-1 | APPLICATIONS OF FRICTION STIR WELDING TO IMPROVE THE THERMAL MANAGEMENT AND TO REDUCE THE COST OF LIQUID COLD PLATES

Laurent Dubourg[1], Antoine Pras

[1]Stirweld

This presentation describes the combination of aluminium Liquid Cold Plate (LCP) and Friction Stir Welding (FSW).

A liquid cold plate is a device designed to cool electronic equipment. It consists in a housing in which a channel is machined to allow coolant to pass through (for example water), and a cover over the channel. Generally, liquid cold plates are made in aluminium. The advantage of using aluminium is its high thermal conductivity and lightness.

The challenge: the assembly of the aluminium cover to the aluminium housing. On one side, conventional techniques as MIG/TIG welding lead to porosities into the joint and waterproof defects. On the other side, vacuum brazing result in high operating cost, limited LCP size capacity and poor mechanical resistance.

FSW consists in a solid-state welding process that has many advantages for LCP manufacturing:

- Improvement of thermal conductivity by mixing different aluminium alloys (AA 1050 / AA 6061 T6) and aluminium alloys with copper alloys;
- Cost reduction (up to 10 times less expensive than conventional techniques);
- High pressure resistance (up to 250 bar);
- 100% waterproof.

This presentation describes:

- A short introduction to FSW;
- The golden rules to design LCP for FSW;
- FSW key points and associated quality control procedures for developing LCP;
- Applications of FSW on different LCP for railway, space, aeronautics, data centers and military.

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W7-2

NOTCH STRESS APPROACH TO ASSESS THE FATIGUE STRENGTH OF FRICTION STIR WELDED JOINTS IN ALUMINUM BRIDGE DECKS

Mahmoud Trimech[1,2,3*], Charles-Darwin Annan[1,2,3*], Scott Walbridge[4]

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1. Introduction

Extrusions made from aluminum alloys have been used in different structural applications, including the fabrication of roadway bridge decks [1–4]. Aluminum bridge deck panels are fabricated by the welding of extrusions into larger panels. Fusion welding techniques have traditionally been used to join the extrusions. However, these techniques have been known to adversely affect the mechanical properties of aluminum, especially in the heat-affected zones, and have resulted in the introduction of significant defects in the joints. A relatively new welding technique, friction stir welding (FSW) has shown potential in minimizing these issues associated with fusion welding techniques. Friction stir welding is a solid-state joining process invented by the International Institute of Welding (IIW) in 1991 [5]. During the process, the joint surfaces are 'stirred' due to plastic work and heat generated by the friction of a non-consumable tool with the work assembly. The temperature reached in the FSW process is significantly lower than in the conventional fusion welding process. Volumetric defects, distortions, and residual stresses seem to be better managed with FSW compared to the use of fusion welding techniques, and FSW joints have, in general, shown superior mechanical and fatigue properties than fusion welds [6].

Although the benefits ensured by FSW, the fatigue strength of these joints have not yet been documented yet in the corresponding design codes and standards. Also, the literature focused mainly on the fatigue behaviour of butt FSW joints. However, the butt-lap configuration, most recently used to fabricated aluminium bridge decks has not been studied thoroughly in the literature and scarce data on the fatigue strength of such configuration is available. Thus, this study aims to provide insights into the fatigue strength and fatigue failure mode of butt-lap FSW joints in aluminium bridge decks through experimental and numerical analysis based on the notch stress approach.

2 Experimental work

Large-scale specimens extracted from real AA6063-T6 butt-lap FSW aluminum bridge decks have been fabricated. Subsequently, the fatigue test setup was designed to provoke the fatigue failure from the butt-lap FSW joint to enable the study of the fatigue behaviour and fatigue failure mode of the welded joint. A total of 10 large-scale fatigue tests were performed using a servo-hydraulic MTS testing machine equipped with an actuator of 5000 kN load capacity at 1.4 Hz cyclic frequency under force. control mode. The load ratio R, defined as the minimum over the of the fatigue tests are detailed in [6]. It is worth noting that the number of cycles to failure was computed using the deflection measurements given by the LVDT. The deflection curve during the fatigue test was analyzed and the number of cycles to failure corresponded to the peak deflection after which a constant deflection response was observed. That peak corresponded to the propagation of the initial fatigue crack to the weld toe causing breakage. No instantaneous brittle fracture occurred after the initiation of the fatigue crack. The fatigue life of all specimens was mainly consumed in the fatigue propagation phase rather than the fatigue initiation phase which was expected since welded joints in general exhibit a dominant fatigue propagation phase due to the presence on inherent internal microcracks and flaws prone to fatigue initiation under the effect of cyclic loading.

3 Numerical analysis

The assessment of the fatigue data was done using the effective notch stress (ENS) approach because the nominal stress approach has been shown to lack accuracy in assessing the fatigue performance of complex geometrical joints such as butt-lap FSW joints. The ENS numerical approach consists of first idealizing the weld root and weld toe with rounded shapes. Then, the effective notch stress, which corresponds to the highest elastic stress at the weld root or toe is computed by finite element analysis, assuming ideal elastic material behaviour. This method allows the assessment of the actual fatigue data by comparing it with the S-N curve of welded aluminum details provided by the international institute of welding (IIW) [7].

Numerical results showed that the S-N curve derived from the ENS approach was above the FAT-71 design S-N curve provided by the IIW for the fatigue assessment of aluminium welds using the ENS approach. Therefore, the fatigue strength of the investigated butt-lap FSW joint in this study showed greater fatigue performance than conventional fusion welded joints.

4 Conclusions

Large-scale specimens extracted from real-sized welded aluminum extrusions were obtained and tested to properly characterize the fatigue behaviour of FSW butt-lap joints under realistic loading conditions for highway bridge applications. A three-point bending test set-up was designed to provoke the fatigue failure in the FSW area. The fatigue test results were assessed using the effective notch stress (ENS) approach. The

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following conclusions are drawn from the experimental and numerical analysis:

- The test results showed that the fatigue failure initiated from the weld root, then propagated diagonally towards the load application point.
- The deflection data can be used to accurately determine the number of cycles to fatigue failure when visual observation becomes impractical. This approach presented consistent data used to derive the S-N curve.
- The effective notch stress approach based on the IIW recommendations was used for the assessment of the fatigue behaviour of the tested butt-lap FSW joint. Results showed that the IIW FAT-71 design curve can be used conservatively to assess the fatigue behaviour of the butt-lap FSW joint investigated in this study.

5 Acknowledgment

The authors acknowledge the financial support provided by the Fonds de recherche du Québec: Nature et Technologie (FRQNT) and the Natural Sciences and Engineering Research Council of Canada (NSERC). The welding of the extrusions was carried out at the Aluminum Technology Center of the National Research Council of Canada (NRCC). The authors extend their thanks to Mr. François Nadeau and Mr. Mario Party for their assistance. Furthermore, the authors appreciate the financial support and practical insights from Mr. Michel Toupin of Proco Inc. and Dr. Rachik Elmaraghy of SAFI Inc. The support of the Aluminum Research Center (REGAL), Québec, is also gratefully acknowledged. The authors recognize the contributions of Professor Mario Fafard (AluQuébec) and Dr. Sofiene Amira (CQRDA).

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E2-1

ADAPTING AN ALUMINIUM MODULAR TOWER STRUCTURE FOR FRICTION STIR WELDING

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1. Introduction

Friction Stir Welding (FSW) can be an interesting alternative to conventional fusion welding. It can be particularly relevant in applications where heat-treated or strain-hardened high-strength aluminium alloys are used. Since FSW is a solid-state welding process, the heat input required for welding is much lower compared to traditional fusion welding (M. Thomas 1992). Hence, the degradation of the mechanical properties of the base metal is lower than with fusion welding. Another important advantage of FSW is the possibility of automating the welding process using widely available CNC machines. In the current context of labour shortage, including welders in Quebec, Canada (M&EQ, 2021), automation of welding is essential to reduce dependence on skilled labour.

However, FSW presents many challenges. Due to its fundamentally different nature compared to fusion welding, converting an existing product to FSW often means completely rethinking its design and manufacturing sequence. Some examples of converting riveted assembly to FSW have been performed successfully, namely, in the aviation industry. However, few products conversions from GMAW to FSW have been documented in detail, especially outside the aviation industry. Hence, this work is intended to share the process of this conversion being made on an existing product, the SBB aluminium tower module, and highlight the improvements it made possible.

2. Scope of study

The scope of this work is to share our experience in adapting an existing product from GMAW to FSW. Since this is an ongoing project, this study will cover everything from the feasibility analysis stage to the design validation stage. The product to be converted is the main structural component of the SBB modular tower, the mast module. These towers are used by electrical utilities worldwide for emergency restoration of damaged transmission lines. The mast module is an assembly of 6061-T6 aluminum extrusion measuring 412mm x 412mm x 2900mm. The module geometry is shown in *Figure 1*.

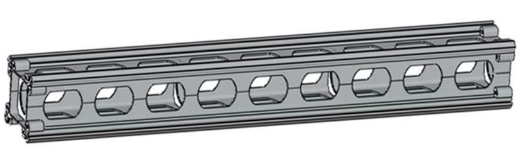

Figure 1 Current GMAW welded mast module

3. Methodology

The methodology used to adapt the mast module to FSW can be divided into two main steps, as presented below.

Feasibility Study

A preliminary cost analysis was performed to estimate the manufacturing cost of the FSW module and compare it to the current module. Since we do not know the exact manufacturing sequence of the new module at this stage (highly dependent on final design), this study will look at improvements regarding welding speeds and possible simplification of assembly operations. Welding tests were performed to determine adequate welding speeds and other parameters for this application. FSW joints mechanical properties were then measured via tensile testing of the resulting samples. Samples were made using the same 7.94mm thick 6061-T6 aluminium extrusions that are used for manufacturing the GMAW modules.

Design and Validation

The following design constraints must be respected in the new module design: External dimensions must be maintained at 412mm x 412mm x 2900mm. Extruded profiles thickness (7.94mm) and corner rail design must remain the same to ensure compatibility of equipment's used for the modular tower construction and usage. The weight of raw aluminium extrusion must be less than or equal to the current weight. Final weight of the module (after machining) must be less than 100kg. The bending strength and rigidity of the module must be equal or superior to those of the current module. Welding and machining must be performed on a 4-axis CNC machine. All FSW welds should therefore preferably be in a 2D plane on each face of the module to minimize welding tool entry and exit points. The modules installation must remain safe, fast, and easy for the users. Following those constrains, a viable design was created, and its mechanical properties were validated using FEA. Two functional prototype modules, each 0.7m long, were made using FSW. Current module extrusions were re-used and adapted to ensure that the prototype section geometry is as close to the FEA validated design as possible. An ultimate bending test was then performed to verify the strength and overall rigidity of the prototypes. Note that, since the prototypes are shorter than the full-scale modules (0.7m instead of 2.9m), deflection of the GMAW module has been interpolated to obtain equivalentresults for a 0.7m length module.

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4. Analysis

Feasibility Study

The feasibility study revealed that manufacturing costs of the FSW module would be comparable to the GMAW module. Preliminary welding tests confirmed that welding speeds of at least 0.5m/min can be achieved for this specific application, which is 20% faster than the speed of the GMAW robot. Further speed increases could be possible after full optimization of FSW parameters. In addition, several potential cost reductions were identified regarding handling during assembly of the modules. Since assembly of the modules is currently made over 3 different stations (manual welding, robot welding and CNC machining), centralizing all assembly operations into one CNC station would greatly simplify production logistics and reduce floor space requirements. Another improvement is the replacement of manual acid cleaning of GMAW soot by a simple machining operation after FSW.

Design and Validation

Figure 2 and *Table 1* below presents the new FSW module design in comparison of the current GMAW design.

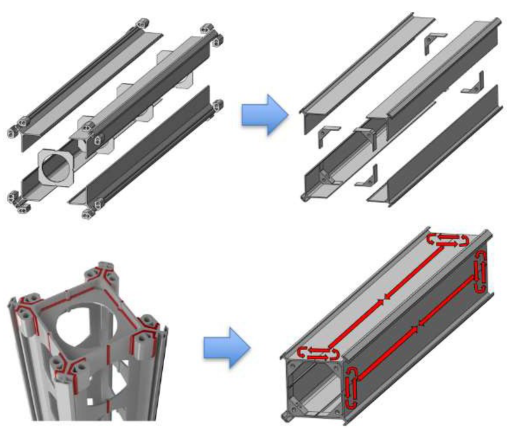

Figure 2- Current Design (Left) vs New Design (Right)

Table 1: Current GMAW design VS new FSW design

Characteristic	Current Design (GMAW)	New Design (FSW)
Number of parts	24	12
Raw Extrusion weight (kg)	134	124
Final module weight (kg)	100.5	93.5
Qty of manual welds	24	0
Qty of automated welds	4 (Robot)	8 (CNC)
Total welding time (min/module)	80	35
Deflection at 74kN-m bending moment (mm)	15.3 (Interpolated)	16.0
Bending Strength (kN-m)	230kN-m	225kN-m
Fasteners	8 x 3/4-10	4 x 1-8

As shown in *Figure 2* and *Table 1*, the newly developed FSW module suggests substantial improvements compared to the current design. The most important change being the replacement of the 8 outside bolting blocs by 4 inside blocs. This change enables complete assembly of the module with 2 welds performed on each face of the module. This type of weld is made possible by the ability of the FSW tool to weld through the outside extrusion surface to reach the inside blocs underneath, effectively joining the two surfaces together. Welds are represented with red arrows in *Figure 2*. Also note that the number of welds passes required to join the outside extrusions to the inside blocs can be increased until the required joint resistance is obtained. Because bolting blocks are now inside the module, its internal square cage has been widened without increasing the total width of the module. The practicality of inside bolting instead of outside bolting has been tested and validated using the prototype modules. However, mechanical testing of the prototype has shown that bending strength is slightly lower (~2.5%) than the current module design. Bending rigidity is also lower (~4.5%) than the current module design. Those results are acceptable considering manufacturing improvements made possible by this new design. Prototype testing results are also in line with

5. Conclusion

FSW was successfully applied to the SBB modular tower module previously welded with GMAW. The newly developed FSW module design enables complete automation of the assembly process. It could also greatly reduce the complexity of the design and manufacturing. FEA and Prototype testing has proven the validity of the design. Although slightly lower bending strength and rigidity were observed during prototype testing, further refinement of the final design could be able to bridge that gap. The next steps of the project will be focused on detailing the manufacturing sequence of the final product and designing a welding/machining jig for a full-scale module.

6. Acknowledgment

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LIST OF POSTERS ABSTRACTS

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ON THE DEPENDENCY OF COEFFICIENT OF FRICTION ON CUTTING CONDITIONS DURING ORTHOGONAL TURNING OF AA7075-T6

Sandrine Tina[1,2], Victor Songmene[1,2], Mohammad Jahazi[1,2], Yahia Younsi[1]

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Aluminium components are widely found in transportation (airplanes, boats, electricity conductors, bikes, automobiles, etc.), construction (structure), and engineering. Aluminum families are well known by the very interesting properties. However, their shaping comes with many challenges. Friction occurring during machining in one of such challenge that can impact the tool performance, surface finish of machined parts, residual stresses, or accuracy of simulated machining results. The friction produced throughout a manufacturing process is evaluated by the coefficient of friction (COF), the value of which depends on the surface condition of the bodies in contact. In machining, this can also be influenced by other factors such as tool geometry and machining parameters. This dependence, very important for a better numerical prediction of machining responses, is not available in the literature for most materials. In this poster, machining friction models for AA7075-T6 are established based on tool rake angles and cutting parameters (cutting speeds and feeds) using statistical analysis and surface responses.

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STUDY OF THE DEGRADATION OF ORDINARY REFRACTORY BRICKS IN AN ALUMINUM REDUCTION CELL

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The lining of aluminum reduction cells employs layers of refractories to maintain thermal equilibrium and safeguard insulating bricks beneath from high temperatures and chemical attacks. These materials, crucial for cell longevity, are susceptible to corrosion from the electrolyte bath. This study investigates the breakdown and/or degradation of ordinary refractory bricks (ORB) located on sidewalls and beneath cathode blocks during industrial autopsies following cell failures or planned shutdowns. Characterizing the behavior evolution of ORBs contingent on their contamination level is vital. To achieve this, an analysis campaign involving contaminated ORBs was conducted during autopsies on electrolysis cells of varying ages at the Aluminerie Alouette. The campaign quantifies the contamination concentration range experienced by ORBs through Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy, X-ray Fluorescence, X-ray Powder Diffraction, and Differential Scanning Calorimetry analyses. Subsequently, ORB samples will be exposed to electrolytic bath contamination at different temperatures and duration. Both uncontaminated and contaminated samples will undergo dilatometry, high-temperature uniaxial and room-temperature triaxial compression tests, alongside evaluations of the thermophysical properties. A comparative study will then juxtapose laboratory-contaminated ORBs with post-mortem ORBs acquired from autopsies. The aim is to meticulously examine the contamination history endured by ORBs within an aluminum reduction cell.

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IMPACT OF ANODE STACKING ON PITCH SQUEEZING OUT OF ANODE DURING BAKING

Nafiseh Shadvar[1,2], Guillaume Gauvin[1,2], Simon Laliberté-Riverin[1,2], Julien Lauzon-Gauthier[3], Houshang Alamdari[1,2]

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The baking process is an integral part of carbon anode production for aluminium smelters, contributing to the most important microstructural evolution in the anode structure. However, this process occasionally faces some challenges while after baking, either anodes stick together or surrounded packing coke adheres to the anode surfaces, a phenomenon known as “Anode sticking”. Given that three anodes are stacked in industrial furnaces, one possible reason is pitch squeezing out of the bottom anodes during baking owing to the mechanical stress generated by the top ones. This work aimed to verify pitch outflow by tracking its distribution in the anode using a tracer. Lab-scale anodes were fabricated with an optimized pitch ratio containing 1 wt. % Bi2O3 as a selected indicator. The anodes were then baked under compressive stresses of 0 kPa, 25 kPa, and 50 kPa, corresponding to the stresses exerted on different vertical positions in the industrial furnace. XRF analysis of the anode cross-sections revealed homogenous pitch distribution in green anodes, whereas pitch had a tendency to extract from all baked anodes. The impact of stresses, however, was not straightforward due to Bi evaporation during baking.

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EFFECT OF FINE CALCINED PETROLEUM COKE ADDITIVES TO BIO-PITCH FOR CARBON ANODES

Marie Aimée Tuyizere Flora[1,2], Guillaume Gauvin[1,2], Simon Laliberté-Riverin[1,2], Julien Lauzon-Gauthier[3], Thierry Ollevier[1,2], Houshang Alamdari[1,2]

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Coal-tar pitch (CTP) releases polycyclic aromatic hydrocarbons (PAHs) during anode baking, which are carcinogenic. Bio-pitch (BP), a solid carbonaceous material extracted from biomass oil, has demonstrated interesting properties and low PAHs emissions to become a sustainable binder for carbon anode. However, high mass loss of BP during baking causes important shrinkage and porosity in the baked anode. In past experiments, a hybrid bio-binder (HBB) was developed by heating bio-oil in air up to 180 °C with 0.5 C/min heating rate, and 1 h soaking time. The aim was to increase the coking value of BP by adding fine calcined petroleum coke (fine CPC), which was achieved. This study aims to determine the rheological properties and the chemical composition of the same HBB with X-ray fluorescence spectroscopy. The HBB viscosity decreases by adding fine CPC between (5-18) wt.%, compared to BP. Sulfur in fine CPC and HBB decreases after pyrolysis compared to sulfur in fine CPC and BP before mixture. These results indicate possible interaction of fine CPC and bio-oil during pyrolysis which could contribute to BP improvement.

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EFFECT OF VIBRATION ON PARTICLE SETTLING IN SHEAR-THINNING NON-NEWTONIAN FLUIDS

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Vibro-compaction of anode paste generates density gradients that compromise cell performance. Given that in this stage, numerous coke particles vibrate within the pitch, we aim to understand particle behavior in various vibrating fluids, primarily focusing on the effect of vibration amplitude on the settling time of 3.2 mm diameter glass particles with a 2.38 g⁄cm3 density in the Carbopol gel. To do this, we compared three cases: one without vibration and two with 9 Hz vibration, the amplitude being twice as large in the high-intensity case. The settling time decreased by about 22 % and 36 % in low-intensity and high-intensity vibration cases, respectively, compared to no vibration. The underlying reason is that the viscosity of shear-thinning non-Newtonian fluids, such as Carbopol gels, decreases when subjected to vibration. This reduces the drag force acting on suspended particles according to Stokes' law, allowing the particles to settle faster through the liquid. Moving forward, we will use these insights to analyze the behavior of particles in a fluid that represents the rheological characteristics of anode paste across a range of vibration times, frequencies, and amplitudes to improve aluminum production efficiency by producing anodes with more uniform density distributions.

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EXPERIMENTAL AND NUMERICAL EVALUATION OF THE STRUCTURAL PERFORMANCE OF A NOVEL HYBRID DENSIFIED WOOD FILLED-ALUMINIUM TUBE DOWEL FOR STRUCTURAL TIMBER CONNECTIONS

Gotre Bi Djeli Bienvenu Boli[1,2], Marie-Gabrielle Tétreault[1,2], Marc Oudjene[1,2], Daniel Coutellier[3], Hakim Naceur[3]

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Structural performance of a novel hybrid dowel, made of densified wood filled aluminium tube, for structural timber joints was investigated experimentally and numerically, for the first time. Three-point bending tests have been conducted on both hybrid densified wood filled aluminium tube dowels and densified wood dowels in order to evaluate their strength and stiffness characteristics as well as their ductility and failure modes. The developed hybrid densified wood filled aluminium tube dowels were, then, used and tested in the context of slotted-in aluminium plate timber connections and the obtained load-slip curves as well as the failure modes were analyzed and compared to their equivalent connections made with conventional steel dowels. In addition, a comprehensive and predictive finite element model, using LS-Dyna software, has been developed to thoroughly investigate the basic mechanisms and optimize the design of the hybrid densified wood filled aluminium tube dowels. The results showed that this hybrid densified wood filled aluminium tube dowels can be a potential substitute for conventional steel dowels.

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MEASUREMENTS OF PERFLUOROCARBON EMISSIONS DURING ALUMINUM PRODUCTION

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Perfluorocarbons (PFCs) are greenhouse gases generated periodically during aluminum production during specific events called anodic effects. While two main components are usually generated (CF4 and C2F6) during these events, CF4 emissions are dominant in a 10:1 ratio. The purpose of the work presented is to quantify the accuracy and behavior of an innovative monitoring device for continuous measurement of PFC emissions in electrolysis cells. This high-precision device uses a quantum cascade laser technology to evaluate the concentration of CF4 across the gas flow. In order to interpret the data logically, the data analysis first uses a moving average crossover strategy for the estimation of the trend variation and defining the optimal segmentation strategy for proper analysis of the signal. For this purpose, an algorithm has been developed and optimized for this segmentation. Detection time and an amplitude of detection were used as metrics for the optimization of the algorithm's parameters. Ultimately, the segmented data will be coupled with the corresponding process conditions for a deeper analysis of the correlations between cell indicators and PFC emissions.

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FATIGUE BEHAVIOUR OF BUTT-LAP FRICTION STIR WELDED JOINTS IN HOLLOW EXTRUDED PROFILES FOR ALUMINUM BRIDGE DECK APPLICATIONS

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This research focuses on understanding the fatigue behavior of butt-lap Friction Stir Welding (FSW) joints, an emerging technique in the aluminum bridge deck industry. Traditional welding, often used in these structures, introduces defects impacting the fatigue resistance. However, FSW offers better control over these defects, though its application is hindered by limited standardization in current codes. This research characterizes the fatigue behavior of FSW joints, determines tolerance levels for fit-up defects, and introduces numerical tools for predicting the fatigue life of large-scale FSW specimens. Experimental tests on these specimens revealed that fatigue failure often begins from the "hooking" defect in the weld root. Numerical simulations, in line with the International Institute of Welding's recommendations, confirmed the experimental findings. Further experimentation on fit-up defects and variations in welding conditions showcased the hooking defect's role in fatigue failures. The research also introduces a numerical framework, based on finite element models, effectively predicting fatigue initiation and life, validated against experimental data.

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EFFECT OF MIXING AND PRESSING PARAMETERS ON THE PROPERTIES OF BIOMASS-BASED LAB-SCALE CARBON ANODES

Nooshin Baastani[1,2], Simon Laliberté-Riverin[1,2], Marie-Aimée Tuyizere Flora[1,2], Guillaume Gauvin[1,2], Julien Lauzon-Gauthier[3], Thierry Ollevier[1,2], Houshang Alamdari[1,2]

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Biopitch (BP) is a candidate to replace coal-tar pitch (CTP) in carbon anodes. Since the softening point (SP) of BP is lower than CTP, the mixing temperature could possibly be lowered, not only to save thermal energy but also to optimize the mixing parameters, as the pitch demand and the other mixing parameters may be affected by the low SP. The goal of the current study was to investigate the effect of mixing and pressing variables on anode properties. The pastes were made via four different parameters according to a 2-level full factorial design of experiments: BP/Coke ratio (16-20) %, mixing temperature (160-180) °C, mixing time (8-12) min, and pressing temperature (130-150) °C. The pastes were compacted in a mold at a pressure of 60 MPa. The green anodes were baked at 1100 °C. Then, the apparent green density (GAD), the apparent baked density (BAD), and the specific electrical resistivity (SER) of the baked samples were measured. Improved production parameters are suggested to achieve high GAD, BAD, and low SER.

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EFFECT OF COMBINED ADDITIONS OF MN AND ZR ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF EXTRUDED 6XXX ALLOYS

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The influence of the combined additions of Mn and Zr on the microstructure and mechanical properties of extruded 6xxx alloys was investigated. Two homogenization treatments (400°C/24h and 550°C/2h) were applied followed by the extrusion at 500°C and aging at 175°C for 8h. The mechanical properties were evaluated using tensile and bending tests, while TEM and EBSD were used for microstructure characterization. The results showed that compared to an individual addition of Mn, the coexistence of the finer Mn and Zr-bearing dispersoids resulted in higher recrystallization resistance. However, comparable tensile properties were observed in the T5 condition, regardless of the homogenization conditions owing to the significant impact of precipitation hardening. Meanwhile, a significant improvement in the bending anisotropy was noticed after the combined addition of Mn and Zr. Notably, the alloy with the combined addition of Zr and Mn homogenized at 550 °C and extruded at 500 °C, exhibited the best combination of yield strength and bendability, owing to a higher dispersoid number density, smaller peripheral coarse grain thickness, and more fibrous grain structure.

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NUMERICAL REPRODUCTION OF CONSTANT HEATING CONDITIONS USED FOR MEASURING THERMAL PROPERTIES OF GRANULAR MATERIAL

Maxime Guéguen[1,2], Lukas Dion[1,2], Thomas Roger[1,2], László Kiss[1,2], Sébastien Guérard[3], Jean-François Bilodeau[3]

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Identifying the thermal properties of granular materials presents several challenges due to the nature of the material (grain heterogeneity, contact resistance, impurities, etc.). The use of a monotonous heating furnace allows for the measurement of the conductivity, diffusivity, and specific heat of different materials. However, at high temperature ranges, the results become more sensitive, and the degree of uncertainty associated with the measurements obtained becomes more significant. A numerical model has been created to better understand this sensitivity increase and provide potential solutions to improve the quality of results. This model is based on an adaptation of the discrete element method with thermal equations related to the granular characteristics of the material considered. The discrete element method presented relies on the interpenetration of grains to calculate interaction forces and create a grain scheme. The thermal equations used also rely on the interpenetration of grains to adapt the interaction within their neighborhood and solve the thermal balance for the entire system. Through this methodology, it is possible to consider the influence of the gas present between the particles. Consequently, studying the sensitivity of input parameters such as particle size distribution or compound nature becomes easier, ultimately reproducing the observed behaviors with the experimental setup.

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DILUTE AL-SC-ZR ALLOY FOR THE RETARDATION OF GRAIN COARSENING IN 1XXX ALLOYS DESIGNED FOR BRAZED HEAT EXCHANGERS

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Brazed aluminum heat exchangers have an important role in the emission reduction and cost saving in refrigeration and air-conditioning systems. The industrial manufacture route of Al tubes consists of homogenization, extrusion, sizing, and brazing. The combination of sizing and brazing could result in abnormally coarsened grains that have negative impacts on the in-service performance of the heat exchanger. One of the numerous beneficial effects from the Sc addition to Al alloys is its retardation effect on grain growth. In this work, a diluted Al-(0.07Sc-0.09Zr) alloy was assessed with respect to the hot deformation and the post-brazing grain structure, and compared to a base AA1xxx alloy. After hot deformation, the microstructure of the Al-(0.07Sc-0.09Zr) alloys showed an improvement in the resistance of dynamic recovery compared to the base AA1xxx alloy. After the simulated high-temperature brazing the base AA1xxx alloy suffered from a severe grain coarsened microstructure. The Al-(0.07Sc-0.09Zr) exhibited a recrystallized microstructure, and no severely coarsened grains were observed, indicating an improvement in the resistance of grain coarsening due to the microalloying additions of Sc and Zr.

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IMPACT OF HOT ROLLING TEMPERATURE ON THE MECHANICAL PROPERTIES AND MICROSTRUCTURAL EVOLUTION OF AA5083 WITH SC AND ZR MICROALLOYING

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The impact of hot rolling temperature on the evolution of microstructure and mechanical properties of AA5083 alloy containing Sc and Zr was studied. The results revealed that samples subjected to low hot rolling temperatures (LHRT) exhibit enhanced tensile properties compared to samples deformed at high hot rolling temperatures (HHRT). Specifically, the yield strength (YS) of LHRT samples reaches 450 MPa (H18-temper) and 291 MPa (O-temper), representing 20% and 39% improvement relative to HHRT samples, respectively. The rolling temperature has a profound impact on the dispersed particle's characteristics and recrystallization resistance. By increasing the hot rolling temperature, the size of Mn-dispersoids and Al3(Sc,Zr) precipitates increased by 118% and 82.5%, respectively, while density decreased by 91% and 78%. Conversely, the coarsening rate of dispersed particles was significantly reduced by lowering the rolling temperature, resulting in an enhanced recrystallization resistance. These findings indicate that optimizing the rolling temperature can effectively control the mechanical performance and microstructural stability of the AA5083 alloy. This offers a strategic approach for tailoring the properties of the AA5083 alloy for specific engineering applications.

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HOT DEFORMATION BEHAVIOR AND PROCESSING MAPS OF AL-MG-SI-ZR-MN ALLOY

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Isothermal compression tests of homogenized Al-Mg-Si-Zr-Mn alloy were carried out on a Gleeble 3800 thermomechanical simulator ranging from 400 °C to 550 °C and strain rates varying from 1 s-1 to 0.001 s-1. The hyperbolic-sine constitutive equation was used to find the material constants, and the average hot deformation activation energy Q = 274 kJ/mol was obtained. Moreover, the processing map was constructed based on the dynamic material model and Prasad's criteria, revealing an optimal hot working range of 480°C to 550°C at strain rates ranging from 0.1 s-1 to 0.001 s-1. The power dissipation map revealed that the safe domains predominantly consisted of a combination of dynamically recovered and dynamic recrystallized grains. The finite element simulation (FEM) results revealed a non-uniform distribution of stress and strain fields, with the highest effective values concentrated at the center of the specimens. Additionally, the FEM simulation indicated that regions with higher-power dissipation (such as 550°C at 0.001 s-1) led to lower plastic strain, demonstrating higher plasticity in these zones.

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EFFECT OF SC ADDITION AND THERMOMECHANICAL PROCESSING ON THE ELECTRICAL, MECHANICAL, AND THERMAL-RESISTANT PROPERTIES OF AL-ZR BASED CONDUCTOR ALLOYS

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The demand for electric power is rapidly increasing due to the swift development of economic activities. This trend has led to a growing necessity for aluminum alloy wires that exhibit a favorable combination of electrical, mechanical, and thermal-resistant properties. The effects of Sc addition and two thermomechanical processing routes on these properties were investigated using transmission electron microscopy, EBSD analysis, electrical conductivity measurements, micro-hardness measurements and tensile tests with and without thermal exposures. The microalloying with Sc (≤ 0.10 wt.%) resulted in a substantially high strength of 188-209 MPa, representing 73-88% improvement compared to the Sc-free base alloy, while maintaining excellent electrical conductivity of 57.4-59.9% IACS. Moreover, the maximum strength reduction was limited in the Sc-containing alloys to ≤ 6.0% after thermal exposures at 310 and 400 ^{0}C. Both processing routes yielded comparable mechanical and electrical properties, where the maximum differences in the strength and electrical conductivity between both routes were 12 MPa and 1.4% IACS, respectively. The excellent combinations of electrical, mechanical and thermal-resistant properties made the developed alloys promising candidate materials for four standard grades of thermal resistant aluminum conductors.

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INVESTIGATING THE IMPACT OF MN MODIFICATION ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF SELECTIVE LASER MELTED ALSI10MG ALLOY: AS-BUILT AND T6 CONDITIONS

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The impact of Mn modification on the microstructure and mechanical properties of AlSi10Mg alloy produced by selective laser melting (SLM) in both as built and T6 conditions were investigated. The microstructure was characterized by SEM and TEM. The results show that the Mn-containing alloy promoted nanosized Si precipitation in the as-built state and changed the eutectic microstructure. As a result, the yield strength (YS) increases from 254 MPa to 298 MPa with a slight reduction in elongation from 12% to 10.3% compared to the base AlSi10Mg alloy free of Mn. During T6 heat treatment, the Si network structure changes from continuous to particulate, affecting the mechanical properties of both modified and base AlSi10Mg alloys. In addition, Mn suppressed β-AlFeSi formation and formed the α-Al(Fe,Mn) Si particles, providing additional strengthening contribution. The YS in Mn modified alloy reached 321 MPa representing a 28% improvement relative to AlSi10Mg. Furthermore, the total elongation slightly improved (12% vs. 11%). These results afford a promising way to improve the performance of AlSi10Mg manufactured by SLM.

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THE EFFECT OF ANNEALING ON MICROSTRUCTURE, MECHANICAL PROPERTIES, AND ELECTRICAL CONDUCTIVITY OF HYPOEUTECTIC AL-SI CONDUCTOR CABLES

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Hypoeutectic Al-Si alloys, considered for novel aluminum conductor cables, face limited applications due to low electrical conductivity (EC). Our study investigates the effect of annealing on AA4043 rods from Properzi continuous casting. Rods underwent annealing at 250°C and 350°C for 4h and 24h. Microstructural analysis employed optical microscopy, SEM, EBSD, and TEM. Annealing significantly increased EC across all samples, shifting from 50 to 58% IACS, yet it led to decreased mechanical properties. The 4h, 250°C-annealed specimen exhibited optimal characteristics: an EC of 58.6% IACS, microhardness at 43 HV, and tensile strength of 141 MPa. EBSD identified partial recrystallization at 250 °C and full recrystallization at 350 °C, while TEM demonstrated nanosized Si precipitates. The enhancement in EC and changes in mechanical properties can be attributed to reduction of Si in solid solution and alterations in grain boundaries due to annealing. The findings offer insights into improving EC in novel Al-Si conductor alloys while understanding the trade-off with mechanical performance.

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THE OUT-OF-PHASE THERMOMECHANICAL FATIGUE BEHAVIOR OF AL-9SI-3.5CU ALLOYS

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Al-Si-Cu cast alloys have been widely used as combustion engine components such as cylinder heads. However, their application potential is significantly hampered by thermomechanical fatigue (TMF), one of the most detrimental failures of essential engine parts. In this study, the out-of-phase TMF (OP-TMF) behavior of Al-9Si-3.5Cu cast alloys was systemically investigated under various strain amplitudes ranging from 0.2% to 0.6% and temperature cycles spanning 60 ºC to 300 ºC. The results reveal an obvious decrement in TMF lifetime with increasing strain amplitudes. Under the TMF loading, cyclic stress softening occurred in all investigated strain amplitudes, resulting from the coarsening of θ′-Al2Cu precipitates. The fracture analyses reveal the initiation of cracks at multiple points. Notably, the primary crack initiation sites are near-surface cast defects such as porosity. Additionally, certain brittle phases (e.g., Si and intermetallics) act as additional crack initiation sites. Based on the experimental results, two methods to enhance the high-temperature TMF of aluminum alloys can be proposed: 1. optimization of the casting process to minimize cast defects; 2. enhancement of thermal resistance properties.

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ANODE REACTIVITY INVESTIGATION BY DEVELOPING THE SODIUM SULFATE TEST METHOD

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In aluminum production, carbon consumption due to anode reactivity, especially with gaseous species such as CO2 and O2, exceeds theoretical expectations. Accordingly, air and CO2 reactivities have been developed as standard test methods; however, there is a significant difference between the test and the electrolytic cell conditions that impacts the results. Currently, a proper test method is needed to provide logical and robust correlations between test results and net carbon consumption of anodes in electrolytic cells, with more similarity between tests and electrolytic cell conditions. This study focuses on the development of an experimental test revisiting an existing reactivity method based on a sodium sulfate bath to simulate an electrolysis bath to assess the reactivity of the anode, in particular the part of the anode immersed in the bath. Studying sodium sulfate reactivity has advantages, such as overcoming obstacles encountered when testing in a molten cryolite bath, for example, the need for an electric current.

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A SHORT REVIEW ON SUPERPLASTICITY OF ALUMINUM ALLOYS

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Superplastic aluminum (Al) alloys can be used in the forming processes to fabricate complex geometry components for a wide range of applications in the automobile industry, where lightweight and high stiffness are needed. Those alloys exhibit extreme tensile elongation of more than 300 % at high homologous temperature and appropriate low strain rate. Superplasticity occurs in Al alloys by the mechanisms of grain boundary sliding, solute drag creep and diffusion creep. Grain boundary sliding usually leads to extensive superplasticity. Activation of grain boundary sliding depends on grain size, strain rate sensitivity, deformation temperature and alloy chemical composition. A complete understanding of influencing factors on Al alloy superplasticity is the key to developing novel superplastic Al alloys. This review discusses the superplastic behavior of several Al alloys, especially focusing on Al-Mg 5xxx alloys. It highlights the mechanisms that govern superplasticity of Al alloys at low and high strain rate. The factors which influence superplasticity are analyzed. As practice industrial applications, high cycle time superplastic forming operations such as the quick plastic forming, and the high-speed blow forming are briefly discussed.

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FRICTION STIR WELDING PARAMETERS DEVELOPMENT OF AA6061-T6 EXTRUDED ALLOY USING A BOBBIN TOOL

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Friction stir welding with the bobbin tool (BT-FSW) is a solid-state welding process that uses two rotating shoulders opposed by a pin. In this process, the lower shoulder replaces the support plate used in conventional tool friction stir welding (CT-FSW) to promote the bonding of joints in the solid state. The welding parameters of the BT-FSW, such as tool pin profile, rotational speed, welding speed and axial force, have a considerable effect on the microstructure and mechanical properties of the resulting joint. In the present study, two 8 mm AA6061-T6 aluminum alloy extrusions were welded by the BT-FSW process with a threaded pion and eight different welding parameters (tool rotation speed and welding speed). The maximum tensile strength value was achieved using optimal welding conditions with a tool rotation speed of 850 rpm/mm and a welding speed of 650 mm/min. Furthermore, several points are studied including the efficiency of the welded joint, the defects of the weld zone and the fatigue life with the optimized parameters.

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THE EFFECT OF MOISTURE ON THERMALLY INDUCED POROSITY DURING T6 HEAT TREATMENT OF AL-SI10MG PROCESSED BY LASER POWDER BED FUSION

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The starting powder feedstock is a significant factor affecting the quality of parts produced by laser powder bed fusion (LPBF). The quantification of the powder quality is typically assessed by particle morphology, particle size distribution and powder flow behavior. Contamination of the powder particle surface by adsorbed moisture is starting to be recognized as an additional factor to be controlled to minimize defect formation. This presentation will show how various moisture content on AlSi10Mg powders may nucleate porosity during the T6 heat treatment.

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MATHEMATICAL MODELING OF THE DESULFURIZATION OF THE EFFLUENT GASES FROM ELECTROLYSIS CELLS

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Effluent gases from the electrolysis cells contain SO2. A SO2 scrubbing process would reduce the environmental impact. In this project, a model was developed for SO2 removal using an alkaline sorbent (hydrated lime, Ca(OH)2) through a semi-dry desulfurization process in a laboratory-scale reactor. The semi-dry process is more advantageous for sulfur capture compared to dry and wet processes due to the drawbacks associated with them, including the post-treatment expenses and/or the excessive sorbent usage. The model involves a turbulent multiphase flow with a rate expression representing the SO2-Ca(OH)2 reaction in the reactor. A parametric study was carried out to analyze the effects of the humidity and the sorbent content on the level of desulfurization. The model and some of the results are presented in this poster.

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MODELING THE RESISTIVITY OF GREEN ANODES

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The production of carbon anodes faces significant challenges due to the variability of raw materials and the absence of real-time information about the final quality attributes of the anodes. Hence, operators need to frequently adjust the anode paste formulation relying on their experience to guide their decisions. However, these adjustments can lead to improper pitch dosing and inferior anode quality. To address this issue, studies have demonstrated that green anode resistivity measurements obtained through a 4-point probe (4PP) could be used for the implementation of process control and optimization strategies. The project aims to use 4PP information in order to develop a dynamic model relating green anode resistivities to anode formulation, and pitch ratio in particular. This model will later be used to design an automatic control scheme that adjusts the pitch in the green anode formulation to achieve the optimal pitch demand (OPD) and to maintain it despite various disturbances.

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ONLINE MONITORING OF ALUMINUM REDUCTION CELL PERFORMANCE

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In aluminum smelting cell operating stability is a key element. To achieve it, the floor operators have to quickly react when a cell strays off course. Several reports are in place at the plant to highlight the critical cells which require manual intervention, based on univariate analysis. Due to the abundance of variables that affect process stability, an online multivariate analysis report was put in place to improve the critical cell determination while also giving insights into what causes the problem. It was shown that in 89% of the cases the problem was found within the cells deemed critical by the multivariate report.

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THERMODYNAMIC AND PHASE EQUILIBRIUM MODEL FOR INERT ANODE SPECIES DISSOLVED IN THE ELECTROLYTE FOR ALUMINUM PRODUCTION

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Currently, pure aluminum is predominantly produced using the Hall-Héroult process and as consumable carbon anodes are commonly used, resulting in a high rate of carbon dioxide emissions in the environment. Anodes based on a new carbon-free material are being developed in Québec by Elysis, which originated from a partnership between Alcoa and Rio Tinto. This would be very beneficial to the environment as pure oxygen is emitted as part of the main reaction instead of carbon dioxide. This change in anode material requires understanding the possible reactivity between it and the cryolite-rich fluorinated electrolyte. This project is intended to push forward the development of a thermodynamic model that takes into consideration the main constituents of inert anodes by obtaining sufficient experimental information for every relevant subsystem of the targeted chemical system, and calibrating a model compatible with the FactSage thermochemical software package, considering the fluorides and oxides of the key inert anode elements (iron, copper, and nickel) dissolved in the base electrolyte (NaF-AlF3-CaF2-Al2O3). The developed model will be used to assess the reactivity and solubility problems associated with constituents of the anode and their partial dissolution in the electrolyte.

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ENHANCED ELEVATED-TEMPERATURE MECHANICAL PROPERTIES OF HOT-ROLLED AL-CU ALLOYS - EFFECT OF ZIRCONIUM ADDITION AND HOMOGENIZATION

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Al-Cu alloys are promising candidates for elevated-temperature applications. However, the studies on Al-Cu alloys with severe deformation at elevated temperatures are limited. In this work, the microstructural evolution and mechanical properties of hot-rolled Al-Cu 2022 alloys were systematically investigated to explore the effects of Zr addition and different homogenization procedures. Two-step low-temperature homogenization promoted a denser and finer distribution of Al3Zr particles in the Zr-containing alloy, which provided heterogeneous nucleation sites for θ"/θ' precipitates during the T7 treatment, increasing their number density. The Zr-containing T7-treated alloy exhibited a higher tensile strength than the base alloy. The Zr-containing alloy thermally exposed at 300 °C for 100 h still exhibited a higher tensile strength than the base alloy at both room and elevated temperatures. The Zr-containing alloy with two-step homogenization showed the highest yield strength of 157 and 114 MPa at 20 and 300 °C, respectively, which was 26% and 20% higher than that of the base alloy with conventional one-step homogenization. The strengthening mechanisms of the T7/T7A-treated alloys were quantitatively analyzed based on their microstructural characteristics. The predicted yield strengths agreed well with the experimentally measured values.

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DESIGN AND OPTIMIZATION OF ALUMINIUM MEMBER'S SECTIONS FOR BUILDING EFFICIENT 120-160 KV POWER TRANSMISSION TOWERS

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The use of aluminium in civil engineering applications has increased significantly over the past decades. Aluminium is a durable, lightweight, and recyclable material that can provide alternative structural solutions for building power transmission towers. In order to achieve this objective, it is necessary to develop structural members that take advantage of specific properties of the material.This paper presents a section optimization study of an existing medium-voltage steel 120-160 kV lattice tower owned by Hydro-Québec, considering the use of various extruded aluminium sections. The proposed optimized aluminium sections are compared with the steel sections of the existing tower. A SAP2000 structural finite element stick model of the tower coupled to a Matlab optimization routine is used to optimize the aluminium sections. ASCE10-15 and CSA-S157-17R22 standards are used to impose the design constraints for selecting the optimized aluminium square and octagonal hollow sections, with and without stiffeners. This study proposes optimized section shapes suitable for constructing aluminium lattice transmission towers. The study reveals that the proposed aluminium tower prototype is twice as light as its steel counterpart and similar in cost.

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IMPACT OF THE MORPHOLOGICAL CHARACTERISTICS OF HYDRATED LIME PARTICLES ON THE SEMI-DRY DESULFURIZATION PROCESS AT LOW TEMPERATURES

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To minimize the release of sulfur-containing compounds (such as SO2 and SOx) during aluminum production, a semi-dry desulfurization process was implemented. In this process, hydrated lime (Ca(OH)2) was utilized as a sorbent to capture SO2 at low concentrations from the effluent gases. This study aimed to explore the impact of surface properties, morphology, and particle size on the reaction between hydrated lime and SO2 in the presence of humidity. The findings showed that the semi-dry desulfurization process led to a strong reaction between Ca(OH)2 and SO2, resulting in the formation of products CaSO3/CaSO4. The size of the particles was found to be a crucial factor influencing the extent of conversion. To further investigate these effects, X-ray photoelectron spectroscopy analysis was conducted, providing insight into the changes in the chemical composition of the final products and complementing the investigation on the influence of the particle size and surface area of hydrated lime on the reaction.

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CHARACTERISATION OF THE THERMO-MECHANICAL BEHAVIOR OF THE CATHODE ASSEMBLY

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Omolbanin Saeidi[1,2], Daniel Marceau[1,2], Simon-Olivier Tremblay[1,2], Mohamed Rachik[3], Antoine Godefroy[4], Sébastien Charest[4]

The electrical resistance of the cathode assembly represents 8% of the operating voltage (4.2V) of a 400kA electrolysis cell and this, mainly associated with the electrical contact resistance (ECR) at the cast iron/carbon interface (CCI). Depending on the temperature and the contact pressure at the interface, the ECR depends indirectly on the initial air gap at CCI and its evolution caused by the different deformation mechanisms present in the cathode assembly. In addition to the evolution of the instantaneous deformations appearing as the temperature of the cathode assembly increases during the commissioning, creep deformations appear in the collector bar steel and the sealing cast iron throughout the cell life. These delayed deformations will have the effect of reducing the contact pressures at the CCI and thus increasing the ECR. In this study, we propose to characterize the air gap at the CCI characterized by 3D scan as well as the mechanical behavior at high temperature (including creep) of the collector bar steel and the sealing cast iron. Finally, all of this information will be used in a ¼ cell model to study its behavior in the preheating phase and operation.

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EFFECT OF COOLING METHOD ON GREEN ANODE PROPERTIES

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Carbon anodes play a crucial role in the electrolytic production of aluminum, which affects the cost and greenhouse gas emissions. All steps of the production process, including the cooling of green anodes, influence anode quality. Cooling could be done by immersion in water, spraying water, forced or free air, or their combination. However, high-temperature gradients in anodes during cooling could lead to thermal stresses, causing cracks that expand during baking. The pitch continues to penetrate coke pores until it solidifies after compaction. Cooling significantly affects this process. Numerous green anodes were produced under the same conditions and from the same raw materials in the UQAC Carbon Laboratory and were cooled using different methods. Thermocouples were placed in the center and on the surface of the anodes to monitor the temperature variation with time. Simulations were carried out with ANSYS for the same cases. The thermal model was validated by comparing the experimental data with the model predictions.

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STUDY OF FRICTION STIR BELDING WITH BOBBIN TOOL OF ALUMINUM

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Bobbin-tool Friction Stir Welding (BT-FSW) is a variant process of Friction Stir Welding with particular tool configuration, composed of an additional shoulder taking support on the lower surface of base metal. It enables additional heat input, more homogeneous heat flow in the thickness direction and complete penetration of the pin. It is also more convenient for some assembly configurations. However, the process involves numerous parameters and BT-FSW welds have particular microstructure and the optimization is consequently difficult. BT-FSW tests were realized with different tools and parameters especially rotation and advance speeds on aluminum sheets. Then the samples were analyzed to determine the impact of welding parameters on physical and mechanical properties of the weld and to optimize this one and get closer to the properties of base metal. From these analyses, predictive models of weld properties with welding parameters will be established in order to define suitable parameters depending on wished results and to upgrade BT-FSW.

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OPTIMIZATION OF THE RESISTIVE-BED FOR THE PREHEATING OF ELECTROLYSIS CELLS

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The preheating of the electrolysis cells can be carried out by different techniques. However, for economic reasons, the aluminum industry generally prefers to opt for an electrical approach using a resistive bed composed of coke and/or graphite. During this stage, the electrolysis cell undergoes significant electrical, thermal, chemical and mechanical changes. It must therefore be carried out meticulously in order to minimize the impact of these changes on the start-up as well as on the life of the electrolysis cell. The primary objective of this work is to determine the best parameters likely to lead to quality preheating. First, the thermal and electrical properties of the coke/graphite mixture will be determined as a function of the temperature and the level of confinement, for different composition ratios. The properties obtained will then be used in a ¼ cell model developed using the ANSYS™ WB software. The impact of different resistive bed configurations will then be studied, and the quality of preheating determined through the use of previously determined performance indicators. The results thus obtained will provide crucial information for obtaining an optimal preheating.

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THERMODYNAMIC AND PHASE EQUILIBRIUM MODEL FOR SALT FLUXES USED FOR METAL PROCESSING AND ALUMINUM ALLOY RECYCLING

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The objective of this research is to develop, initially, a thermodynamic model for a manganese fluoride-based salt flux used in the processing of manganese-containing aluminum metal alloys. Aluminum alloys containing multiple alloying elements and various impurities are typically treated with chloro-fluoride salt fluxes. This project aims to gain a deeper understanding of the potential chemical transfer of manganese between the liquid metal phase and the salt flux. Depending on the treatment goal, manganese needs to either be removed and transferred into the salt flux or recycled and retained as an alloying element after the removal of other undesirable impurities. Therefore, the thermodynamic modeling will be contingent on the other constituents of the salt flux. The findings from this study could have significant implications for the aluminum industry, enabling improved optimization of processing procedures for manganese-containing aluminum alloys.

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TWO-DIMENSIONAL STUDY OF THE BATH-METAL INTERFACE AGITATION CAUSED BY CARBON DIOXIDE IN AN ALUMINUM ELECTROLYSIS CELL WITH ANSYS FLUENTTM

Samuel Théberge[1,2], Lukas Dion[1,2], László Kiss[1,2], Thomas Roger[1,2], Simon-Olivier Tremblay[1,2], Sébastien Guérard[3], Jean-François Bilodeau[3]

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A thorough understanding of the spatiotemporal deformation of the bath-metal interface (BMI) is essential to reduce instability in electrolytic cells. For this reason, two-dimensional simulations of carbon dioxide bubble flow in an aluminum electrolysis cell were carried out using ANSYS FLUENT software. The model calculates the amount of current circulating locally under each anode in order to determine the amount of CO2 produced. This two-dimensional CFD model gives the opportunity to better understand the flow of bubbles in the electrolysis cell, and more specifically its effect on the bath-metal interface (BMI). This model is a first iteration that will later evolve into a three-dimensional model with the aim of providing more precise knowledge of the effect of each factor on the BMI deformation. The present work examines the influence of disturbances caused by a decrease in the anode-cathode distance (ACD). The reduction of the ACD demonstrates a nonlinear behavior that significantly increases the instability of the interfacial boundary movement (IBM) as the space is reduced. The results also indicate that the ACD has a negligible effect on the bath mixing areas which could have been beneficial to better distribute the alumina.

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TRIDIMENSIONAL REPRESENTATION OF THERMAL GRADIENTS SURROUNDING AN OBJECT OBTAINED BY COMBINING TOMOGRAPHY AND SCHLIEREN IMAGERY.

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The use of an intrusive sensor, such as a thermocouple or a pH probe to measure fluid properties, can be a source of perturbations of the flow. Schlieren imaging is a non-intrusive method using refractive index gradients from a transparent media to determine temperature or composition. Generally, Schlieren imaging is used for qualitative flow visualization and boundary layer observation. To obtain quantitative results, rainbow filter schlieren imaging can be used to precisely measure deflection angles of light rays going through the media. By taking deflection angles measurements from multiple points of view, a 3D reconstruction of the refractive index can be achieved by tomography. Once the reconstruction is completed illustrating specific refraction indexes from the observed media, known state equations of the media allow determination of temperature or composition gradients. A setup was developed, and an experimental validation of the concept was achieved. The data obtained allowed the 3D reconstruction of the studied phenomenon. This work will subsequently allow the study with a better precision of thermal and chemical exchanges of analogous models allowing the further understanding of the primary aluminum production process.

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SIDE LEDGE INVESTIGATION USING ANALYSIS OF INDUSTRIAL DATA

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In an aluminum electrolytic cell, the thermal balance is an important factor to lean towards optimum operation. The ledge thickness protecting the sidewalls is a key element of that equilibrium and the occurrence of divergence in its behavior may strongly influence the cell life, its energy performance, and the efficiency of the control, and optimization of the process. Despite the existence of numerous studies, the behavior of the ledge is still not fully understood, due to its difficult accessibility and complex composition. This work presents a novel approach for the transient study of the side ledge. Based on an extensive industrial data set, a numerical model will be coupled to a predictive model designed to detect the position of the isotherm constituting the ledge boundary. It will also facilitate understanding of the transient phenomena occurring in the cell by having a more precise width of the side ledge in real time. In addition, this coupling will enable the quantification of localized effects on bath temperature, ledge profile and heat distribution caused by discrete events. In the context of industry 4.0, this concept represents a viable tool for real-time energy control and optimization of the electrolysis process.

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THERMAL BALANCE OF OPERATIONAL EVENTS AFFECTING LOCAL ALUMINA DISSOLUTION IN ELECTROLYSIS CELLS

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A major challenge of aluminium electrolysis is to incorporate a large amount of alumina into the electrolyte. The research presented will highlight the localized phenomena which affect the energy balance of the cell, particularly in the region close to the alumina feeders. The related equations with the boundary conditions and initial values are also presented due to the upmost importance of these hypotheses on the final results. The study presented will investigate the effect of alumina injections by comparing their evolution during specific overfeeding and underfeeding strategies. The consequences and potential impact of these different operations strategies are presented with emphasis on the thermal imbalance that is generated over time. This will provide critical information to pinpoint the frequency and duration of events where the cell's ability to dissolve alumina is irregular. During these occurrences, the cell will be even more sensitive to external thermal variations, such as anode change or metal tapping. The outcome of this study will pave the way towards recommendations to the industry to improve the thermal stability of the cell. In the end, novel solutions such as digital twins may be proposed to maintain optimal working conditions and improve the competitiveness of newer cell designs.

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THE EFFECTIVE THERMAL CONDUCTIVITY OF AN ALUMINA RAFT DURING ITS INFILTRATION

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Primary aluminium production is performed with the electrolysis of dissolved alumina in cryolite. To sustain the continuous reaction of electrolysis, a constant amount of alumina needs to dissolve at the rate it is consumed. The Hall-Héroult process generally relies on the injection of about 1000 g of alumina powder for every ten few seconds, distributed at three to five points in the cell. Following the injection, the alumina rapidly agglomerates to form floating rafts that limit the exchange surface between the alumina and the electrolyte, thus limiting the dissolution rate. Rafts are formed by a complex interaction of the liquid infiltration, the gas release as well as, alumina dissolution, sintering, and phase change. All these phenomena have in common that they depend on the local temperature of the different phases in contact. Therefore, an accurate formulation of the heat transfer in the raft created with cold alumina is needed to understand the raft formation mechanisms. As part of a larger work on alumina dissolution, the work presented here sets out the basis of such a formulation and proposes a simple model to obtain the thermal conductivity of these rafts under specifically defined conditions.

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EFFECT OF VARIOUS DRAFT CONDITIONS ON THE GAS CONCENTRATION OF CARBON DIOXIDE IN A HALL-HÉROULT CELL

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The emission of carbon dioxide, a greenhouse gas, is an inherent by-product of the widely employed Hall-Héroult process utilized to produce aluminum. As the bubbles formed during the electrolysis process escape from the electrolysis cells, they initiate the generation of a gas flow underneath the anode. These discrete events create a fluctuating pattern in the gas volume fraction and gas coverage of the anode bottom. The movement and coalescence of bubbles in the bubble layer have a significant impact on the overall dynamics of gas escape. This gas flow is primarily a consequence of the continuous production of gases and the pressure differential created by the suction exerted from the electrolysis cell. The latter can have a significant impact on the resulting gas concentration level in different areas of the cell. The primary goal of this investigation is to comprehensively investigate the behavior and characteristics of gas concentration under a diverse range of draft conditions. To achieve this task, a numerical model performed using ANSYS/Fluent is presented along with the main validation process considered. The research aimed to understand how gas concentration within the cell is influenced by factors like gas exhaust pressure, incoming air, current efficiency, and cell amperage.

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EFFECT OF BIOCOKE PRODUCTION TEMPERATURE ON ANODE QUALITY

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The carbon anodes are made of petroleum coke, coal tar pitch, recycled anodes, and butts. In order to reduce greenhouse gas emissions, researchers tried to manufacture anodes using biocoke. However, the majority of these efforts did not give any result due to a deterioration of anode quality with this replacement. Recently, researchers of the Research Chair on Industrial Materials (CHIMI) of UQAC successfully replaced a portion of the petroleum coke with biocoke modified using an additive. Biocoke is produced through the pyrolysis of wood chips at a temperature similar to that used for anode baking in industry (~ 1100 °C). This study examines the impact of the final biocoke production temperature on anode quality. Biocoke was produced at four different temperatures (600 °C, 750 °C, 950 °C, and 1100 °C). Anodes were manufactured without biocoke (standard) and with modified and unmodified biocokes. Then, the anodes were characterized by measuring their density, electrical resistivity, air and CO2 reactivity, and bending strength.