METAL2022

SEPTEMBER 5–9, 2022
HELSINKI, FINLAND

PROCEEDINGS OF THE INTERIM MEETING OF THE ICOM-CC METALS WORKING GROUP

EDITED BY PAUL MARDIKIAN, LIISA NÄSÄNEN, AND AKI ARPONEN

ICOM-CC
ICOM international council of museums – committee for conservation

SUOMEN KANSALLISMUSEO
FINLANDS NATIONALMUSEUM
THE NATIONAL MUSEUM OF FINLAND

Metropolia
University of Applied Sciences

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Cover image: Viking Age swords found in Finland, now in the Archaeological Collections of the Finnish Heritage Agency. The hilts in Viking Age swords are true masterworks of metal technology. The mythical animals and palmettes in the hilt of KM10833:1 (front cover, left) were created with gilt silver and niello; in the pommel of KM9243:1 (back cover, right), copper and silver wires weave a herringbone motif. © Finnish Heritage Agency

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Foreword

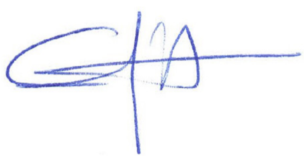
The National Museum of Finland and Metropolia University of Applied Sciences were proud to jointly host Metal 2022, the 10th Interim Meeting of the Metals Working Group, part of the International Council of Museums – Committee for Conservation. This 30-year milestone event took place for the very first time in Finland and the Northern European region.

After nearly three years of global uncertainty and isolation caused by the COVID-19 pandemic, and considering the Russian attack on Ukraine, we were very pleased that, despite all the challenges, Metal 2022 went full steam ahead as a hybrid meeting at the spectacular Suomenlinna Fortress, a UNESCO World Heritage Site in Helsinki's harbour. The decision to offer a hybrid conference format was another first that greatly expands professional inclusion and outreach of the Metals Working Group and strongly reflects upon and promotes the overarching theme of the conference: 'Sustainability in the Conservation of Cultural Heritage'. This is a vibrant topic reflecting the professional and personal priorities of today: eco-friendly treatment approaches, cross-disciplinary collaborations, social justice, conservation education, as well as data science, computational techniques and visualisation.

The Metals Working Group is concerned with all issues related to preserving and presenting cultural historical objects made of metals or metallic alloys. These constitute a vast percentage of almost any museum collection. This is also the case at the National Museum of Finland, which is why we were delighted to see professionals in metals conservation and related sciences gather in Helsinki to bring together the latest developments in this field. Another reason for pride is this publication, in which all the papers and poster abstracts presented at the conference are featured. The publication adds to the already vast body of scientific articles disseminated in the Metals Working Group's conference publications. These publications are of huge importance and a remaining point of reference to all those working in the field of metals conservation worldwide.

Conservation is at the core of preserving cultural heritage, transmitting its value, as well as documenting and enabling its interpretation in various ways. Without conservation, there would be no tangible heritage displayed in museums and its preservation, presentation and use for research, interpretation, learning or enjoyment would not be possible. Conservation is a key element in the cultural heritage sector and thanks to it, museums can better fulfil their function of serving society. Conservation is also an ever-growing and developing science in its own right. Because of our role, knowledge, interdisciplinary expertise and responsibility, the National Museum of Finland aims to be on the frontline in developing the field. We have ambitious goals for introducing new conservation methods and promoting research efforts and perspectives within the field, as well as embracing more sustainable practices.

All of this is very much in line with the papers presented in this publication, which is the result of a tremendous amount of work from contributors, authors and reviewers alike from all over the world, the Metals Working Group coordinating team and the conference organisers in Helsinki, to whom we are deeply thankful. It was indeed our great pleasure to welcome you to Helsinki!



Elina Anttila
Director General
The National Museum of Finland

Eero Ehanti
Keeper, Head of the Conservation Department
The National Museum of Finland

Preface

This publication contains the proceedings of Metal 2022, the Interim Meeting of the ICOM-CC Metals Working Group that was held in Helsinki, Finland, on September 5–9, 2022, hosted by The National Museum of Finland and Metropolia University of Applied Sciences.

The conference program for Metal 2022 formed a dynamic ensemble of paper and poster presentations, as well as invited lectures by leading voices in our field. Authors from 26 countries, including Young Conservation Professionals, presented their work in Helsinki. In addition, two pre-conference workshops on *Cleaning Silver Objects* and *Oxygen Consumption* were offered, as well as two wonderful post-conference day trips.

We were thrilled to welcome Dr. Caitlin Southwick, who delivered a passionate keynote address on how to become better advocates for sustainability in our field. Caitlin also served as a moderator during an inspirational panel discussion on sustainability—the theme of the conference—exploring with our panelists and the audience the future of cultural heritage conservation.

For the first time in the history of our Working Group, virtual attendance was offered for those who were not able to travel to Helsinki. The live-streamed and recorded virtual component expanded the outreach and access of the Metals Working Group community worldwide. We hope that a hybrid conference model can remain an option for future Interim Meetings.

Metal 2022 also marked the 10th international meeting of the Metals Working Group and offered numerous opportunities to celebrate the resilience and many achievements of our members and friends. Gathering together in person after a worldwide pandemic felt like a remarkable achievement and clearly demonstrated the most important pandemic takeaway—our desire for community and face-to-face dialogue.

Congratulations to all the authors, who have put so much of themselves into this conference and worked tirelessly to have their contributions included in this volume. Their collective work not only reflects the constant dialogue between conservation practice and conservation research, but it also provides an important snapshot of the vitality and creativity of the metals conservation community worldwide.

Paul Mardikian
Terra Mare Conservation, LLC
Coordinator, ICOM-CC Metals Working Group

Liisa Näsänen, **Aki Arponen**, and **Eero Ehanti**
The National Museum of Finland

Heikki Häyhä
Metropolia University of Applied Sciences

Acknowledgments

The proceedings were edited by Paul Mardikian, Liisa Näsänen, and Aki Arponen.

The ICOM-CC Coordination Team for 2020–2023 comprised Coordinator Paul Mardikian and Assistant Coordinators Jerrad Alexander, Valentin Boissonnas, Nicola Emmerson, Elodie Guilminot, Vandana Singh, and Ellen van Bork.

Liisa Näsänen from the National Museum of Finland served as Program Chair.

The Steering Committee comprised Liisa Näsänen, Eero Ehanti, Heikki Häyhä, and Paul Mardikian.

The local organizing committee comprised Liisa Näsänen, Eero Ehanti, Heikki Häyhä, Elisa Ahverdov, Aki Arponen, Stina Björklund, Satu Haapakoski, Anna Hyppönen, Roni Iilomo, Pia Klaavu, Rachel Fay-Leino, Jenniina Laine, Kari Nordfors Ane Orue-Etxebarria, Päivi Paajanen-Salmi, Sanna Paakkanen, Viktor Sohlström, Toni Spännäri, Tuomas Aatola, and Jussi Linkola.

We thank the students and lecturers from the bachelor's degree program in Conservation at the Metropolia University of Applied Sciences, students of Information and Communication Technology at the Metropolia University of Applied Sciences, the Design and Implementation services Valovirta at the Helsinki XR Center, Avanio Oy, and the Collections and Conservation Centre of the Finnish Heritage Agency.

We thank the Program Committee for volunteering their time to peer review and discuss abstracts and papers:

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Thank you to invited speakers Laura Brambilla, Philippe de Viviés, Arie Pappot, and Lisa Young for accepting our invitation to be part of Metal 2022 and contribute to the diverse program; to Ahmad N. Abu-Baker, Jerrad Alexander, Aki Arponen, Emilio Cano Díaz, Nicola Emmerson, Elodie Guilminot, Ian D. MacLeod, Ellen van Bork, and Cátia Viegas Wesołowska for chairing the paper sessions; and to Anna Hyppönen and Ane Orue-Etxebarria for chairing the poster sessions.

We thank Miguel Mertens, Guy Silva, and the team from use.it, Portugal, for their hard work and unwavering support of Paper-flow, the paper management platform used for our conferences, and Joan Reifsnyder for assisting with collecting the copyright transfer agreements.

Last but not least, we are thankful for the work of Carla Nunes and Eduardo Pulido, Portugal, who were responsible for the layout and design of another beautiful Metals Working Group volume. Carla Nunes, Per Christopher Foster, and Wendy Ran also provided copy editing.

Introduction

For nearly three decades, the Interim Meeting of the Metals Working Group has served as a network to keep members of our growing community connected, forming one of the largest Working Groups within ICOM-CC and possibly the largest group of metal conservation experts in the world. This success has only been possible through the determination, hard work, and stamina of generations of colleagues and amazing hosting institutions.

I extend my heartfelt thanks to our conference hosts for taking on the task of organizing an in-person and virtual meeting, and staying the course, through such a difficult time. Bringing Metal 2022 to the Nordic Countries has been a wonderful experience. The National Museum of Finland and Metropolia University of Applied Sciences surmounted enormous challenges during an unprecedented world pandemic and economic downturn. Navigating through a world of unknowns prompted the organizing committee to offer a hybrid meeting with both safe in-person and virtual attendance options—a first in the history of the Metals Working Group. Organizing the conference on Suomenlinna, a UNESCO World Heritage Site located at the entrance to Helsinki's harbor, added a unique dimension to the whole experience. The exceptional social program and the post-conference day trips made the conference a truly memorable event. I would also like to thank our hosts for their determined fund-raising efforts, which resulted in 22 travel grants for presenting authors.

Like previous Metals Working Group conferences, Metal 2022 is the result of a vast amount of unseen work and preparation. I am particularly grateful for a great team of Assistant Coordinators and thank Jerrad Alexander, Valentin Boissonnas, Elodie Guilminot, Nicola Emmerson, and Vandana Singh for co-leadership and wisdom at much-needed times.

Finally, I would like to thank the former Coordinator of the Metals Working Group, Claudia Chemello, for her guidance during this Triennium. None of this work would have been possible without her unconditional support.

Paul Mardikian
Coordinator, ICOM-CC Metals Working Group

DiscoveryMat: A Freeware Electrochemical Tool for the In Situ Analysis of Aluminum Alloys in the Cooling Systems of Historical Vehicles

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Abstract

Corrosion of aluminum alloys is frequently observed in the cooling systems of functional vehicles dating from 1920 to 1940 in the Musée National de l'Automobile in Mulhouse, France. This paper shows how DiscoveryMat, a freeware analytical tool, has been successfully used for the in situ analysis of the materials concerned. The tool is based on the monitoring of the electrochemical behavior of metals in different test solutions and relies on a database to propose possible alloy compositions. The analysis of a corpus of detached parts representative of this problem has made it possible to enrich the database, thus enabling the precise identification of the problematic aluminum alloys in real conditions directly on the vehicles. The results of these analyses showed that the corroded parts are all made of Al-Cu(-Si) alloys, whereas the most recent and stable parts are made of Al-Si alloys.

Keywords

DiscoveryMat, freeware analytical tool, alloy identification, aluminum, car, cooling system

Introduction

The Musée National de l'Automobile de Mulhouse's (MNAM) collection numbers over 600 vehicles, most of which are technically functional cars. However, only a few (80) can actually be driven. They benefit from an annual maintenance service and at least one annual drive around the museum's circuit. A condition file attached to each vehicle is updated with information about the driving conditions and observations made during maintenance. This allows for a reassessment of the vehicle's functional status and, if deemed necessary, whether it should be immobilized.

During these inspections, the conservation team noticed a recurrent problem with the cooling system of some early-20th-century cars. Aluminum alloy parts were corroding rapidly, compromising the tightness of the system. This problem was occurring on vehicles dating from 1920 to 1940. The MNAM approached the Haute École Arc Conservation-restauration (HE-Arc CR), in Neuchâtel, Switzerland, and its research unit (UR-Arc CR) to collaborate on understanding the problem.

Condition report on the studied cars

The purpose of the cooling system is to remove excess heat from the engine. A coolant flows around the heated parts through the jacketed walls of the engine block (cast steel) and the cylinder head (cast aluminum alloy). It flows out of the engine through a system of pipes (cast aluminum or copper alloy) and hoses (rubber) that connect it to the radiator, where the liquid is cooled down by ambient air and sometimes by a fan (Figure 1). Once cooled, it returns back to the engine, where the cycle starts again (Kennedy 1913). This coolant was originally water but has since been replaced by commercial coolants (Excell –35°C [Diframa] or MB 325.0 [Mercedes Benz]), a mix of water, antifreeze, and other additives such as corrosion inhibitors.

A condition report was carried out on a selection of French manufactured cars that are currently or were formerly functional, focusing on the aluminum parts of their cooling systems (Table 1).

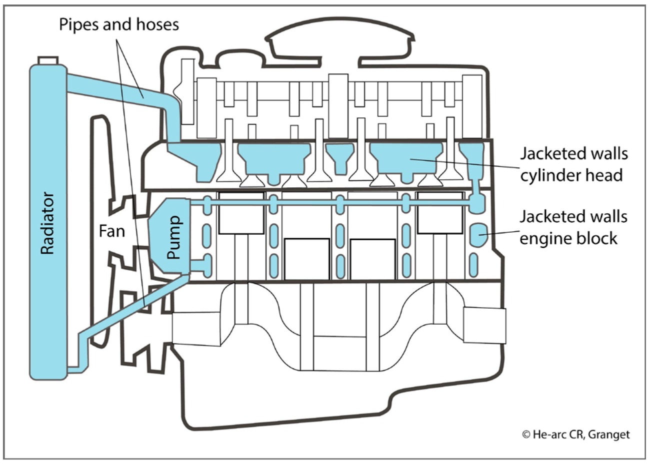

Figure 1. Simplified illustration of an engine, with the cooling system in blue

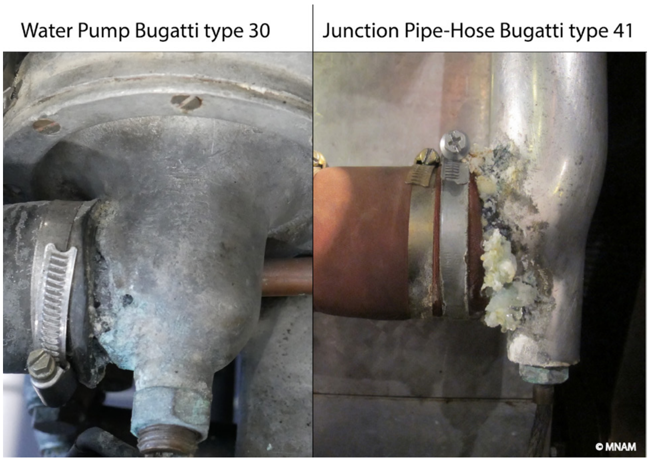

Figure 2. Corrosion issues on a water pump (Bugatti T30) and at the junction of a pipe and a hose (Bugatti T41)

Table 1. Different sets of French manufactured car parts dating from 1921 to 1939: (1) test set and (2) validation set for DiscoveryMat

BRAND	MODEL	YEAR	CODE	PARTS	SET
Bugatti	Type 37	1926	B37	pipe water pump gasket camshaft block	1. Test set Detached part
	Type 41	1928–1933	B41	pipes water pumps	
	Unknown	~1930	Bx	pipe	
Hispano-Suiza	Type H6B	1938	H6B	water pump	
Panhard & Levassor	Dynamic c. Junior	1936	PDJ	water pump piston	
Bugatti	Type 30	1922	B30	pipes water pump camshaft block	2. Validation set Attached parts
Simca Gordini	Type 5	1937	S5	pipe cylinder head	

Figure 3. Metal heavily corroded under the hose of a Bugatti T28

Corrosion was observed at the junction between aluminum alloy pipes and rubber hoses on most of these cars. As this assemblage is often imperfectly tight, it is possible that it creates a confined zone of moisture at the interface between the two materials. Local differences in oxygen and ion(s) concentration are generated, inducing an environment favorable to the start of corrosion. A gelatinous and bulky product forms, probably composed of aluminum hydroxide, and further compromises the tightness of the system (Figure 2). In severe cases, the rubber cracks and the hoses must be replaced if the vehicle is to remain functional. When disassembled, it can be seen that the same product has developed on both the outer and inner surfaces of the pipe and has sometimes consumed the metal significantly (Figure 3).

Aim of the project

The aim of this research project was to identify the different aluminum alloys in the cooling systems of the set of samples. This characterization could easily be done in situ with a portable X-ray fluorescence (XRF) system. However, this type of device is expensive and not easily accessible for most museums. Within the scope of this study, we wanted to test DiscoveryMat (Haute École Arc 2021), an analytical tool and free software developed by UR-Arc CR that provides qualitative analyses of heritage metals developing thin corrosion layers. The fact that it is also portable, low-cost, and easy to use provides institutions that acquire it and are trained in its use with new expertise (Degrigny et al. 2018).

Method

DiscoveryMat is designed to monitor the corrosion potential (E_{corr}) of a metal over time performed in three different solutions (Evian mineral water, pH = 7.2; potassium nitrate 1 wt%, pH = 5.9; sodium sesquicarbonate 1 wt%, pH = 9.5). It then compares the plots obtained with those already entered into the database of known composition determined by XRF. An algorithm computes the distance of similarity (*d*) between the plots of the material studied and those of all the entries in the database. It takes into consideration the difference in the slope and curvature of the plots for the first 10 minutes (the initiation phase) and in the values of the potential at the end of the measurement (the development phase) (Degrigny et al. 2010). The smaller the *d*, the more relevant the match. For this study, a satisfactory match was established for $d < 2000$ (Granget 2020). The results are presented in the form of a table of database entries classified in increasing values of *d*, as well as superimpositions of the plots of the material studied and those of each database entry. This makes it possible to appreciate the greater or lesser similarity of the shape of the plots and to discard irrelevant proposals.

Previous work has refined the measurement protocol (Degrigny et al. 2010) in order to obtain reproducible and interpretable plots on heritage objects of various copper (Degrigny et al. 2018), silver (Fontaine 2012), or aluminum alloys (Despland 2018).

As the database of aluminum alloys is not very extensive (only 42 entries, mostly wrought alloys), leading to probably poor results, it was essential to enrich it with alloys from the automotive industry from between 1920 and 1940 in order to improve the relevance of the analysis. This was carried out in two steps: first, electrochemical measurements were performed on a first set of detached car parts, which are easy to handle and enable the tool's applicability to be tested. They were completed with quantitative XRF values (three-point measurement with a Niton XL3t XRF handheld analyzer, 50 kV, Ag anode, Thermo Fisher Scientific) to form new entries in the database. Measurements were then carried out on a second set of parts still attached to two cars, an approach more in line with the in situ analyses envisaged by the MNAM, to validate the relevance of the enriched database.

Results

The preliminary results on the detached parts show that, even though *d* almost always exceeds the 2000 threshold, it is often possible to identify the main elements in the alloy. The parts seem to be made of either aluminum-silicon alloys (Al-Si) or aluminum alloys containing silicon (Si), copper (Cu), and sometimes zinc (Zn). According to XRF analyses, most alloys are indeed from the Al-Si or Al-Cu(-Si) alloy families (Table 2).

DiscoveryMat measurements were made in a second phase on parts still attached to two vehicles: a Simca Gordini 5 and a Bugatti Type 30. The plots were compared to those of the database, completed or not by the new entries from the detached parts. It is clear in Table 3 that the updated database allowed better identification of the

Table 2. Identification of detached parts of H6B, PDJ, B37, and Bx using DiscoveryMat and comparison with XRF analyses; *d* highlighted in gray if > 2000

	DiscoveryMat		XRF
	Composition	***d***	
H6B a	Al, Si, Cu, Zn	1319	Al 90.6, Cu 6.5, Sn 1.7, Fe 0.7, Si 0.5
H6B b	Al, Si	2008	Al 88.3, Si 10.1, Cu 0.8, Fe 0.6, Zn 0.1, Pb 0.1
PDJ a	Ø	7178	Al 86.9, Cu 8.9, Ni 2, Fe 1.4, Si 0.5, Pb 0.3
PDJ b	Ø	5579	Al 89.2, Cu 7.6, Ni 1.8, Si 0.7, Fe 0.7
PDJ c	Ø	6851	Al 76.9, Si 12.6, Cu 10, Fe 0.5
B37 a	Al, Si, Cu, Zn	4136	Al 85.3, Cu 11, Si 1.3, Zn 1.1, Fe 1.1, Pb 0.2
B37 b	Al, Si, Cu, Zn	2085	Al 90, Cu 7.4, Fe 1, Zn 0.8, Si 0.7, Pb 0.1
B37 d	Al, Si, Cu, Zn	3897	Al 89.6, Cu 6.7, Si 1.8, Fe 1, Zn 0.8, Pb 0.1
B37 e	Al, Si	2504	Al 82.7, Si 13.4, Cu 2, Ni 0.8, Fe 0.8, Mn 0.2, Zn 0.1
Bx	Al, Si, Cu, Zn	1146	Al 83.2, Cu 9.9, Zn 3.2, Si 2.1, Fe 1.3, Pb 0.3

Table 3. Identification of attached parts of S5 and B30 using DiscoveryMat, with the database enriched, or not, with the entries from detached parts and XRF analyses; *d* highlighted in gray if > 2000

	Database without detached parts		Database with detached parts		
	Composition	***d***	**Composition**	***d***	**XRF**
S5 a	Al, Zn, Cu, Si	2935	Al, Zn, Cu, Si	2935	Al 73.8, Si 21.3, Cu 2.8, Fe 1.3, Zn 0.3, Mn 0.3, Pb 0.2, Sn 0.1
S5 b	Al, Si, Zn, Cu	4217	Al, Si, Cu, Zn	1390	Al 71.6, Si 12.9, Cu 9, Zn 4, Fe 1.3, Ni 0.5, Mn 0.3, Pb 0.2, Sn 0.2
B30 a	Al, Cu, Si, (Zn or Mg)	4796	Al, Cu 8.4, Si 2.4, Fe 1.3, Zn 0.6, Pb 0.1, Ni 0.1	2651	Al 84, Cu 11.2, Si 2.3, Fe 1.2, Zn 1, Sn 0.2, Pb 0.1
B30 b	Al, Zn, Cu, Si, Pb	4228	Al, Cu 10, Si 1–2, Fe 0.5, Zn	1187	Al 75.5, Cu 17.6, Zn 2.4,Si 2, Fe 1.5, Pb 0.4, Sn 0.6
B30 c	Al, Si, Cu, Zn	6543	Al, Cu 11, Si 1.3, Zn 1.1, Fe 1.1, Pb 0.2	2436	Al 82.9, Cu 11.9, Si 2.3, Fe 1.4, Zn 1, Sn 0.3, Pb 0.2
B30 d	Al, Cu	3284	Al, Cu 7–12, Si 1–2, Zn 0.5, Fe	1073	Al 77.5, Cu 16.5, Si 2.4, Zn 1.5, Fe 1.1, Sn 0.5, Pb 0.5
B30 e	Al, Cu, Mg	2383	Al, Cu 7–12, Si 1–2, Zn 0.5, Fe	1438	Al 85.9, Cu 9.4, Si 1.7, Fe 1.8, Zn 0.9, Sn 0.2, Pb 0.1
B30 f	Al, Si, Cu, Zn, Fe	6160	Al, Cu 11, Si 1.3, Zn 1.1, Fe 1.1, Pb 0.2	1870	Al 86.4, Cu10.2, Si1.5, Fe1, Zn0.7, Sn0.1, Pb0.1

alloys in most cases. Al-Cu(-Si) alloy families were accurately found and a more relevant idea of the proportions for the main elements was given. The better performance of DiscoveryMat for these alloys is due to the 11 new entries of similar composition added to the database from the first set of detached parts. However, there was no improvement for the part “S5a,” a hypereutectic Al-Si alloy that is still not represented in the database.

Discussion

According to the XRF analyses, the parts are composed of three main types of alloys from this period: hypereutectic Al-Si alloys, eutectic Al-Si alloys with or without Cu, and Al-Cu alloys ranging from 4 to 12% Cu and containing Si, Zn, Ni, or Sn. Moreover, all corroded parts are made of Al-Cu alloys or contain large proportions of Cu (Figure 4).

These results are corroborated with what can be found in historical and technical literature. Indeed, in the 1910s, Al-Cu alloys such as Duralumin became widely used (L’Aluminium français 1924) for the production of both wrought and cast car parts, because they were lighter than steel and also because the presence of copper improved the mechanical strength of the metal. However, it quickly became apparent that these alloys had poor corrosion resistance. When used in casting, they produced porous parts with a high chance of breaking when released from the mold (Guillemot 1933). This may explain why, during the 1910s and 1920s, in parallel with the search for a better aluminum alloy composition for casting, efforts were made to further lighten steel for engine castings (Bodet 1931). Therefore, it is not surprising to find that the Al-Cu parts from the cars were heavily corroded. These problematic alloys can now correctly be identified by DiscoveryMat.

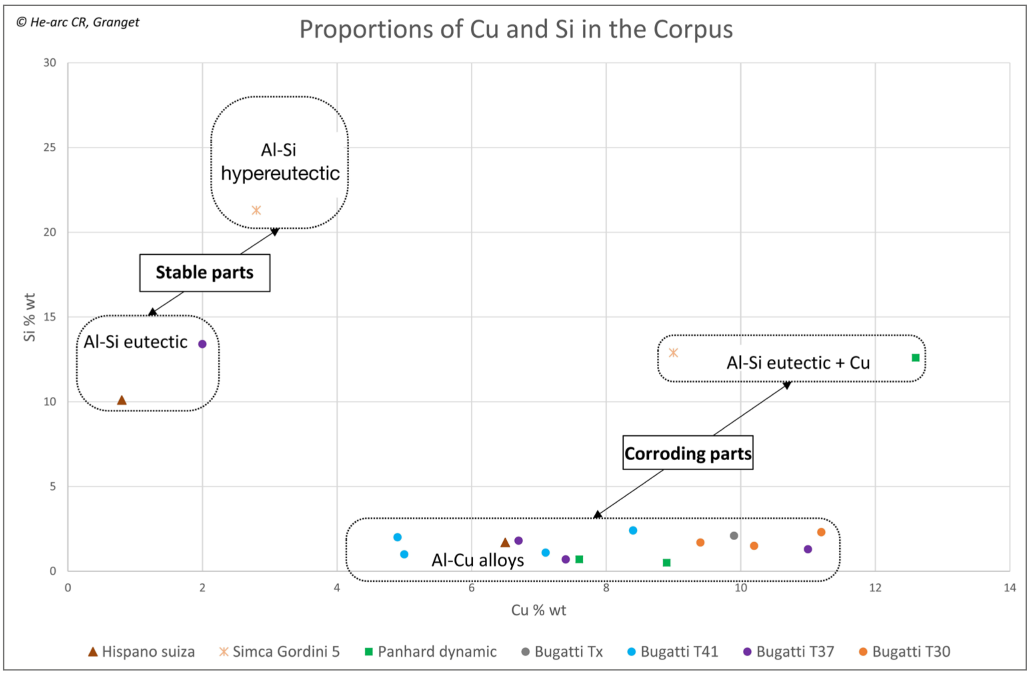

Figure 4. Proportions of Cu and Si in the alloys of the studied parts

In the 1920s, the family of Al-Si alloys, namely Alpax, eutectic Si = 13 wt% (L'Aluminium français 1926), and hypereutectic, Si > 13 wt% (L'Aluminium français 1924), was created. Silicon conferred aluminum mechanical properties similar to those provided by copper but better corrosion resistance and casting properties. From the second half of the 1920s, they slowly found their place in the automotive industry, more specifically in the casting of more complex engine parts subject to friction or thermal stresses, such as pistons, cylinder heads, and cooling systems' parts (Guillemot 1933). This information validates the results from the XRF analyses, showing that all the latest and more stable parts from the selected cars were made of eutectic and hypersilicated Al-Si alloys. For example, the Hispano-Suiza water pump had two parts (H6B a & b), one of which (HB6B b) was surprisingly not corroded. The analyses showed that this part was made of Al-Si alloy (Talbe 2); according to the conservator, it was probably replaced a few years ago. A precise identification of these two alloy families is not yet possible with DiscoveryMat but could be achieved by adding more entries to the database.

Conclusion

This study demonstrates the suitability of DiscoveryMat as an in situ analytical tool for the qualitative identification of aluminum alloys. With the new entries added to DiscoveryMat's database, it was possible to accurately identify the Al-Cu alloy family as well as some secondary elements of materials of similar composition.

The cars in the set of samples studied have aluminum alloys in their cooling systems that are representative of the transition period between 1920 and 1940: Al-Cu(-Si) was used in older vehicles, whereas Al-Si was slowly introduced during the 1930s. All the heavily altered parts were made of Al-Cu(-Si) alloys, which have lower corrosion resistance.

In addition to alloy identification, further study of the corrosion process that occurs at the interface between rubber and metal is necessary to better understand and prevent this phenomenon.

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References

L'Aluminium français. 1924. L'Aluminium dans la carrosserie automobile. *La revue de l'Aluminium* 3: 47–50.

L'Aluminium français. 1924. L'Aluminium dans le châssis automobile. *La revue de l'Aluminium* 3: 35–46.

L'Aluminium français. 1926. L'Alpax. *La revue de l'Aluminium* 15: 240–47.

Bodet, J. 1931. L'emploi des métaux légers rend plus économiques les moyens de transports. *La Science et la vie* 39(166): 333.

Degrigny, C., G. Guibert, S. Ramseyer, and G. Rapp, and A. Tarchini. 2010. Use of E_{corr} vs time plots for the qualitative analysis of metallic elements from scientific and technical objects: The SPAMT Test Project. *Journal of Solid State Electrochemistry* 14(3): 425–35.

Degrigny, C., E. Menart, and G. Erny. 2018. Easy-to-use, low-cost electrochemical open-source hardware to analyze heritage metals: Possibilities and limits. *Current Topics in Electrochemistry* 20: 15–23.

Despland, C. 2018. Identification des alliages d'aluminium d'objets ethnographiques et caractérisation de leurs produits de corrosion : analyse par voie électrochimique et par fluorescence X. Bachelor's thesis, He-Arc Conservation-restauration, Switzerland.

Fontaine, C. 2012. Analyse qualitative par voie électrochimique des alliages à base d'argent : application de l'outil CLAMTEC à ce type de matériau. Bachelor's thesis, HE-Arc Conservation-restauration, Switzerland.

Granget, E. 2020. Corrosion des alliages d'aluminium des circuits de refroidissement à eau de véhicules en contexte patrimonial. Master's thesis, HE-Arc Conservation-restauration, Switzerland.

Guillemot, L. 1933. Congrès mondial de Fonderie (Paris, 13–18 septembre 1932). *Bulletin de la société d'encouragement pour l'industrie nationale*, 310–20. Paris: BSPI.

Haute École Arc. 2021. *DiscoveryMat* [online]. Available at http://discoverymat.he-arc.ch:8080/ (accessed 28 October 2021).

Kennedy, R. 1913. *The book of the motor car: A comprehensive and authoritative guide on the care, management, maintenance, and construction of the motor car and motor cycle*, vol. 2, 1st ed. London: Caxton Publishing Company.

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