ECOPROT

ECO-FRIENDLY CORROSION PROTECTING COATING OF ALUMINIUM AND MAGNESIUM ALLOYS

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Deliverable 4.5

Monitoring of the environmental performance indicators

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1 REMINDER OF THE OBJECTIVES OF THIS DOCUMENT

1.1 Context of the study

In spite of their excellent corrosion protection behaviour, chromates are now declared environmentally hostile (carcinogenic, produce DNA damage, skin allergy, asthmatic reactions, and ulcerations). The European Community has forbidden the use of chromate coatings in all industrial sectors, except aeronautics, from July 2007. In aeronautics, chromate coatings should be forbidden by September 2017.

The replacing chromate-based coatings by environmentally friendly systems were studied in MULTIPROTECT project. The objective was to develop a protective system containing alternative corrosion inhibitors. At the end of the project, Cerium-based (CexOy) coatings showed a promising behaviour as alternatives to chromate-based systems (higher corrosion resistance). At present, the objective of the ECOPROT project is to industrialize the production of Cerium-based (CexOy) coatings.

1.2 General purpose of the LCA

In order to industrialize the procedure, the main objectives of the project are to:

- Evaluate by means of LCA, the environmental impacts of **pure glass-like CexOy coatings ("sol gel coating")**, over its entire life cycle

  → Cradle-to-grave LCA (from raw material extraction until the end of life)

- Compare its environmental performance with that of **conventional chromate-based coatings** for a similar performance in terms of corrosion resistance.
- Guide the development of CexOy coatings towards sustainable solutions

While ensuring the study conforms to the ISO 14040-14044 standards.

Note that this study is done on pilot scale coatings only, and not on industrial scale coatings.

1.3 Specific aim of deliverable 4.5

Deliverable 4.5 has been written within the framework of the LCA, in order to monitor environmental performance indicators along and after the project.

Its objective is to define and follow specific indicators, being themselves either taken directly from environmental indicators calculated in the LCA, or specific indicators created in parallel.

2 SCOPE OF THE STUDY

2.1 Functional unit and reference flows

Life cycle assessment relies on a "functional unit" as a reference for evaluating the components within a single system or among multiple systems on a common basis. It is therefore critical that this parameter is clearly defined and measurable. The functional unit for this study is:

Ensure the protection of aluminium // magnesium alloys on 1 m^2 during 1 year complying with the aeronautics requirements (corrosion, mechanical constraints)

The reference flow associated with this Functional Unit is the amount of coating / area (kg/m2) for each application, and for each coating, scaled to 1 year of use.

The different scenarios are based on the different products studied:

- Pure glass cerium-based (Ce_xO_y) coating ("sol gel coating")
- And its alternative studied for comparison : conventional chromate-based coating

Two distinct applications are considered:

- Protection of aluminium alloys
- Protection of magnesium alloys

2.2 System boundaries

The system boundaries identify life cycle stages, processes and flows considered in the analysis and include:

- All activities relevant to the study:
- All processes and flows that contribute significantly to the potential impacts;

As shown in Figure 1 below:

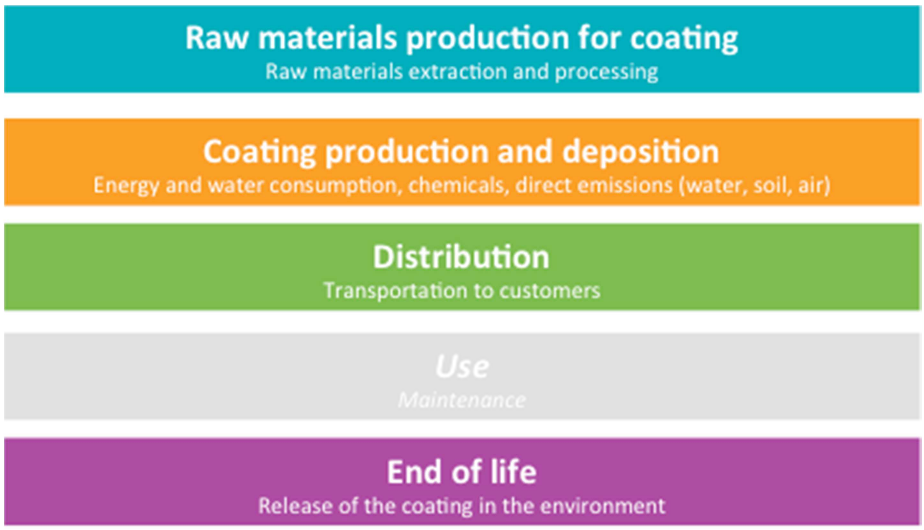

Figure 1: Description of the boundaries

3 ENVIRONMENTAL PERFORMANCE INDICATORS

3.1 Introduction

The conclusions that can be drawn on this comparison are the following:

- For the impact categories freshwater ecotoxicity and human toxicity, cancer, and the endpoint indicator human health, Ce-based sol-gel coating effectively proves to be a good substitute to Cr-based coatings, since Cr-based coatings impact 1,5 to 30 times more than the Ce equivalent ones, on a given alloy. The impact of chromate based coatings on toxicity / ecotoxicity related indicators is mostly due to emissions of Cr(VI) at the end of life stage. A contribution of about 50% of the total impacts is due the potential emissions in the environment of Cr(VI). However, it shall be reminded that potential impact of cerium emissions at end of life on human toxicity could not been taken into account because of lack of existing data. This result is very important in the context of REACH regulation and other European laws related to the prohibition of chromate coatings. Indeed, the use of chromate-based coatings will be forbidden in aeronautics by September 2017 because of their high toxicity and ecotoxicity effects.

- Yet, for almost all other impact categories (climate change, non-renewable energy, acidification, eutrophication, mineral extraction, water withdrawal), cerium based coatings have more impact than chromate based coatings, ranging itself from 50% to 80% less impacts. This conclusion is linked to the fact that Ce-based coating requires a much higher amount of raw materials, as compared to Cr-based coating.
- Even if the aim is not the comparison between aluminium and magnesium alloys applications, it can be seen that the results are slightly varying in the two cases; this difference is explained by the fact that the materials and processes for the two coatings are different between aluminium alloys and magnesium alloys. The cerium based sol-gel coating tends to perform slightly better when made for magnesium alloy application as compared to aluminium application.

3.2 Main information from the Table

- Most of the results used to fill the Table are taken from the LCA. This is particularly the case for the indicators linked with climate change/greenhouse gases emissions, resources, impacts on human health (release of chromium into environmental media, particulate matters, etc.) or on ecosystem quality (release of chromium into environmental media, acidification, eutrophication, etc.)
- For some indicators, the calculations are direct, since they directly arise from a change in the process, such as passing from chromium to cerium.
- The values provided in the Table below sometimes depend on the scenario considered. Indeed, the environmental performances can depend on the application done, being either on aluminium or on magnesium alloys, depending on how much substance is deposited on the surface.
- All the calculations can be found through the reading of Del 4.4, much more detailed.

3.3 Table of environmental performance indicators

Executive Agency for Competitiveness and Innovation CIP Eco-innovation first application and Market Replication Projects Call 2013 Call Identifier: CIP-EIP-Eco-Innovation 2013					
INDICATORS					**ECOPROT**
Objective	**Indicators**		**Absolute Impact**	**Relative Impact**	**Comment**
Improved Environmental Performance	Greenhouse gas emissions	CO2	6,06 e-2 kgCO2eq/FU for a magnesium alloy	3,5 times more impacts wrt baseline (Cr scenario for magnesium alloy)	Considering a Functional Unit being "Ensure the protection of aluminum // magnesium alloys on 1 m2 during 1 year complying with the aeronautics requirements (corrosion, mechanical constraints)". The impact of the cerium based coating is mainly due to the raw materials (60% of the total impacts) and the coating production stages, representing almost 100% of the impact of the whole life cycle stages for cerium alloys. In particular, this contribution arises from the impact of cerium concentrate production for the raw materials, and electricity & ethanol consumption during coating production. Levers of improvement for those life cycle stages are to reduce the amount of cerium needed during deposition, for a given Functional Unit. Results for Aluminum protection are different.
		Methane	-	not applicable	All the GHG emissions related to the project are consolidated into the "CO2" indicator, with the help of characterization factors, that express the impact of methane (and other gases contributing to climate change) relatively to CO2. The final unit (CO2eq) reflects these calculations.

	Air quality	Particulate matters	4,45 e-5 kgPM2,5eq/FU	2,3 times more impacts wrt baseline (Cr scenario for magnesium alloy)	Considering the same Functional Unit as expressed above, the major impacts relate to raw material, especially cerium concentrate production.
		Avoided chromium emissions to air (carcinogenic/toxic substance)	7,04 to 7,93 to mg/FU depending on the application	-100% wrt baseline	Considering the same Functional Unit as expressed above, this category include the suppression of any form of Cr (Cr6, Cr3) in process, whatever the media of emission (air/water). Depending on the scenarios and their end-of-life, emissions can occur either in air (Cell D12) or water (Cell D19). Air emissions are however only considered for the full LCA inside a sensitivity analysis. Results for this category "Avoided chromium emissions to air" apply only in the case of the sensitivity analysis. The emissions considered include both the emissions during end-of-life (7 to 7,9 mg/FU), as well as during coating production (0,03 to 0,04 mg/FU) Moreover, it also depends on the type of application (Mg or Al alloys), on which the quantity used of Cr differs, which explains the range of variation of the quantity deposited.
	Reduction / substitution of dangerous substances	Irritant / Corrosive	-	not applicable	This category is not evaluated within the LCA framework
		Mutagenic / Carcinogenic	-	not applicable	Already included in the avoided emissions to air/water
		Toxic	-	not applicable	Already included in the avoided emissions to air/water
		Persistent / Bioaccumulative	-	not applicable	This category is not evaluated within the LCA framework

		Avoided chromium emissions to (waste)water (carcinogenic/toxic substance), in mg/year	13 to 13,9 to mg/FU depending on the application	-100% wrt baseline	Considering the same Functional Unit as expressed above, this category include the suppression of any form of Cr (Cr6, Cr3) in process, whatever the media of emission (air/water). Depending on the scenarios and their end-of-life, emissions can occur either in air (Cell D12) or water (Cell D19). The emissions considered include both the emissions during end-of-life (7 to 7,9 mg/FU), as well as during coating production (6 mg/FU) Moreover, it also depends on the type of application (Mg or Al alloys), on which the quantity used of Cr differs, which explains the range of variation of the quantity deposited.
	Waste management	Prevention	-	-	This project is not aimed at reducing any type of waste. Deposition of substances against corrosion has been considered not to have any influence on the end-of-life of the materials. As a consequence, waste prevention is not an issue here.
		Waste minimization	-	-	Same answer as above.
		Reuse of waste / Substance recovery	-	-	No recovery has been considered within this project. Materials on which the substances have been deposited are supposed to last the maximum lifetime, and that the substance has no influence on it.
		Material recycling	-	-	No recycling is foreseen for any material or waste.
		Waste diverted from landfills	-	-	End-of-life is not modelled as a landfill but rather as a place where planes end their life in huge deserts, where land use is not an issue

		Hazardous waste	1m2 of Al or Mg alloys/FU	-100% wrt baseline	Prevention of Cr-containing hazardous waste, due to Cr suppression (in any form: Cr6, Cr3) in process; based on 1 m2 of coated surfaces per Functional Unit
Better use of natural resources	Reduced resource consumption (excluding energy)	Reduced chromium consumption	20 mg/FU	-100% wrt baseline	Considering the same Functional Unit as expressed above, it includes any Cr-containing substances that are needed during the process: Sodium dichromate, and Cr-VI oxides (depending on the application).
	Water	Reduced water consumption	0,4 L/FU	2 times less impact wrt baseline (Cr scenario for magnesium alloy)	Both the 2 scenarios require water and waste, and the comparison has no particular significance. However, the results of the LCA show a slight difference in the water consumption, occurring during the production process. Some differences arise for Aluminum alloy, where 0,2 L/FU are avoided when switching from Cr to Ce.
	Energy	Energy from RES			No significant reduction of the RES consumption. The only potential reduction foreseen would be the one related to a global decrease in energy consumption. This aspect may have an influence on the renewable energy consumption, though not possible to evaluate
		Reduced energy consumption	0,12 kWh/FU	4 times less impact wrt baseline (Cr scenario for magnesium alloy)	Considering the same Functional Unit as expressed above, some energy reduction is possible, especially when the change in the substance is done for magnesium alloys. This improvement is linked with the production process, particularly during heating phases.

Others	Aquatic acidification	kgSO2eq/FU	4,45 e-4	2,3 times more impacts wrt baseline (Cr scenario for magnesium alloy)	Considering a Functional Unit being "Ensure the protection of aluminum // magnesium alloys on 1 m2 during 1 year complying with the aeronautics requirements (corrosion, mechanical constraints)". The explanation done for Climate Change also apply here: The impact of the cerium based coating is mainly due to the raw materials and the coating production stages, representing almost 100% of the impact of the whole life cycle stages for cerium alloys. In particular, this contribution arises from the impact of cerium concentrate production for the raw materials, and electricity & ethanol consumption during coating production.
	Aquatic eutrophication	kgPO43-/FU	2,07 e-5	3,2 times more impacts wrt baseline (Cr scenario for magnesium alloy)	Considering a Functional Unit being "Ensure the protection of aluminum // magnesium alloys on 1 m2 during 1 year complying with the aeronautics requirements (corrosion, mechanical constraints)". The explanation done for Climate Change also apply here: The impact of the cerium based coating is mainly due to the raw materials and the coating production stages, representing almost 100% of the impact of the whole life cycle stages for cerium alloys. In particular, this contribution arises from the impact of cerium concentrate production for the raw materials, and electricity & ethanol consumption during coating production.

	Non-renewable energy	MJ/FU	0,13	-6% wrt baseline (Cr scenario for magnesium alloy)	Considering a Functional Unit being "Ensure the protection of aluminum // magnesium alloys on 1 m2 during 1 year complying with the aeronautics requirements (corrosion, mechanical constraints)". The explanation done for Climate Change also apply here: The impact of the cerium based coating is mainly due to the raw materials and the coating production stages, representing almost 100% of the impact of the whole life cycle stages for cerium alloys. In particular, this contribution arises from the impact of cerium concentrate production for the raw materials, and electricity & ethanol consumption during coating production.
	Human health	DALY/FU	1,9 e-6	18 times less impacts wrt baseline (Cr scenario for magnesium alloy)	Considering a Functional Unit being "Ensure the protection of aluminum // magnesium alloys on 1 m2 during 1 year complying with the aeronautics requirements (corrosion, mechanical constraints)". The impact of the chromium based coating on the toxicity / ecotoxicity indicators are mostly due to chromium emissions at the end-of-life stage. Impacts associated with those emissions represent up to 55% of the impacts of the chromate alloy. Other impacts are obtained during coating production and deposition. This impact is linked with Cr losses during the process, as well as with energy consumption. One should remind that no impact has been affected to cerium release in the environment at end of life (by lack of relevant studies); this is an important limitation of this study, since it may not be a relevant hypothesis.

	Ecosystem quality	PDF.m2.y/FU	1,07 e-3	-30% wrt baseline (Cr scenario for magnesium alloy)	Considering a Functional Unit being "Ensure the protection of aluminum // magnesium alloys on 1 m2 during 1 year complying with the aeronautics requirements (corrosion, mechanical constraints)". The impact of the chromium based coating on the toxicity / ecotoxicity indicators are mostly due to coating production (90%). End-of-life is the second contributor to this category.