Sustainable Concrete Repair & Protection Products – The Impact on Renovation Works

Michel Donadio[1,*], *Josefa* Nüsslein[2], *Katherine* Agapitos[2], *Wayne* Smithers[3] and *Johannes* Lohner[1]

[1]Sika Services AG, Tüffenwies 16, 8048 Zürich, Switzerland
[2] Sika Technology, Tüffenwies 16, 8048 Zürich, Switzerland
[3]Sika South Africa (Pty) Ltd, 9 Hocking Place, 3608 Pinetown, South Africa

Abstract. Repair and protection systems can have a positive impact on sustainability by prolonging the life of a structure and reducing the amount of new construction works. Over recent years, new products and technologies for use as concrete repair mortars and protective coatings, have been developed and launched on the market with lower environmental footprints than their traditional counterparts. To help visualise the environmental impact of these new technologies and products with improved environmental footprints, this paper will use a Life Cycle Analysis (LCA) of a repair project in Johannesburg, South Africa, which was completed in 2021. Two different scenarios will be compared and assessed – the first, is an existing product range for concrete repair and protection works that was used on the project, and the second is an alternative solution using the new and more sustainable technologies-based product range. This paper will provide an example of the positive environmental impact for such asset owners, by using more sustainable concrete repair and protection materials, by focusing on the Global Warming Potential (GWP) and Abiotic Depletion Potential fossil (ADP fossil) indicators.

1 Introduction

Concrete structures are subject to ageing processes due to the action of atmospheric CO_2, moisture and humidity, chlorides, and other aggressive influences, etc. These deleterious elements can attack and/or penetrate the concrete, and if they reach the reinforcing steel rebars, this can result in steel corrosion. This expansive steel corrosion will then lead to concrete spalling, and if no remedial measures are taken, structural failure of the impacted structures may eventually occur.

Environmental impact can be considerable if the structure has to be demolished and completely replaced / rebuilt because of the deterioration and failure. To avoid this situation, appropriate remedial, repair and protection works can have a positive impact on the environment, because this can effectively limit damage and deterioration, preventing or delaying any demolition, through reinstating the structural capacity, uses, service-life and aesthetics of the existing structure.

Generally, concrete repair works are carried out using cement-based materials, and protective concrete coatings typically use materials made with organic polymers derived from fossil raw materials. This paper seeks to compare these traditional concrete repair and protection materials with new alternative products that use of biomass balanced and/or high-quality recycled materials.

2 Objectives

Recently, a new generation of concrete repair mortars and protective coatings with lower carbon footprints, have been introduced to the market.

By using the example of a specific recent renovation project where typical concrete repair mortars and protective coating were used, we will compare the environmental impact of this renovation using these products, versus using the newly developed materials that have not only a lower carbon footprint, but also an increased technical performances.

3 Method

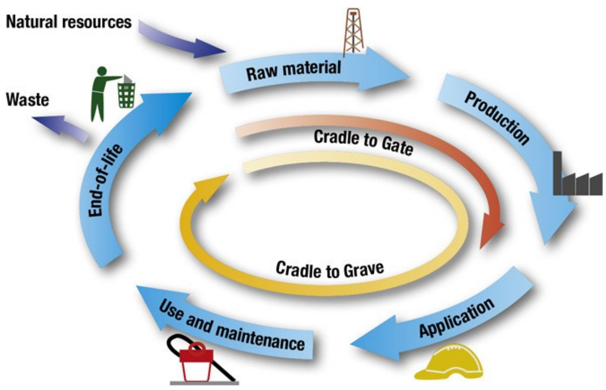
Life Cycle Assessment (LCA) provides a method to quantify and evaluate potential environmental impacts throughout a product's life cycle (Fig. 1). It starts with raw material extraction and transportation, through to its manufacturing and application at the customer's site. The life cycle assessment concludes at the use and end-of-life phases, where the product is finally treated as either waste or recycled. To evaluate a product's impact at the factory gate, a cradle-to-gate analysis is carried out, which includes exclusively[1] the respective raw materials impact, transportation, production, and packaging.

An LCA for a construction product manufacturer can therefore provide a quantitative environmental profile

* Corresponding author: donadio.michel@fr.sika.com

within this given framework. This can help improve or differentiate between products and solutions in terms of the potential environmental benefits. This LCA of refurbishment products was performed by the Sika Global Product Sustainability Department according to the ISO 14040 series[1] and EN 15804 standards[2] Recently, a new generation of concrete repair mortars and protective coatings with lower carbon footprints, have been introduced to the market.

Fig. 1. Schematic of the entire life cycle for construction products



3.1 Scope of the analysis

The Functional Unit taken for the LCA is the refurbishment of a concrete structure completed during the year 2021 in Johannesburg, South Africa. The exact quantity of materials applied on the structure was considered in the assessment. To perform the LCA, an inventory analysis step was also necessary, i.e., for the data collection, as well as calculation procedures to quantify the relevant inputs and outputs of the products / system.

Product data collection was carried out by the manufacturer and corresponds to the measured or qualified data, including formulations of the products, transportation, packaging, and production in South Africa. The systems were then modelled in the product sustainability software GaBi 10.0, based on collected data and on datasets from commercial databases (the most recent Sphera and ecoinvent databases were used). In addition, supplier specific data was collected for the biomass balance dispersion included in the protective coating scenarios. Transport to job site, installation, and end-of-life treatment were excluded from the scope of this analysis.

The impact assessment phase associates inventory data with environmental impact categories (calculated with the CML 2001 method). Two impact categories were considered relevant for this example, as these depict sustainability drivers in refurbishment: carbon footprint and resource efficiency.

<u>Global Warming Potential (GWP 100 years)</u>

The global warming potential measures the potential contribution to climate change from the impact of human emissions on the radiative force of the atmosphere. Most of these emissions enhance it, causing the temperature at the earth's surface to rise (the so-called "greenhouse effect")[3]. It is measured in kgs (or tonnes) of carbon dioxide (CO_2) equivalents for a 100-year time horizon.

<u>Abiotic Depletion Potential of Fossilised raw Materials (ADP fossil)</u>

The abiotic depletion potential reflects the use of non-renewable resources, such as crude oil for example, which are associated with the declared unit. This is measured in kg Sb eq and has a global scale that is based on concentration reserves and rate of de-accumulation[3].

4 Description of the two repair & protection scenarios

As the two scenarios are based on the same product type, and the same application process for both systems, the application is not taken into consideration in the LCA.

4.1 Existing materials

The repair and protection works on this structure were made using the following product types:

Table 1. Existing materials for the renovation works.

Usage	Product type	Quantity used
Reinforcing steel bars corrosion protection	1-Component cementitious based corrosion protection slurry – named herein as **Slurry-A**	500 kg
Concrete repair	1-Component cementitious repair mortar – named herein as **Repair-A**	~21 tonnes.
Concrete protection	1-Component acrylic concrete protective coating – named herein as **Coating-A**	2 900 L

Notes: other materials such as corrosion inhibitors, chemical anchoring, or cement grout were also used in the overall remedial works on this project but are not part of this comparative study.

4.2 Alternative solutions

Recent R&D works in Europe and South Africa have allowed the production of new range of concrete repair mortars and protective coatings having a lower carbon footprint, plus a better overall technical performance.

Table 2. Alternative solution with more sustainable materials for the renovation works.

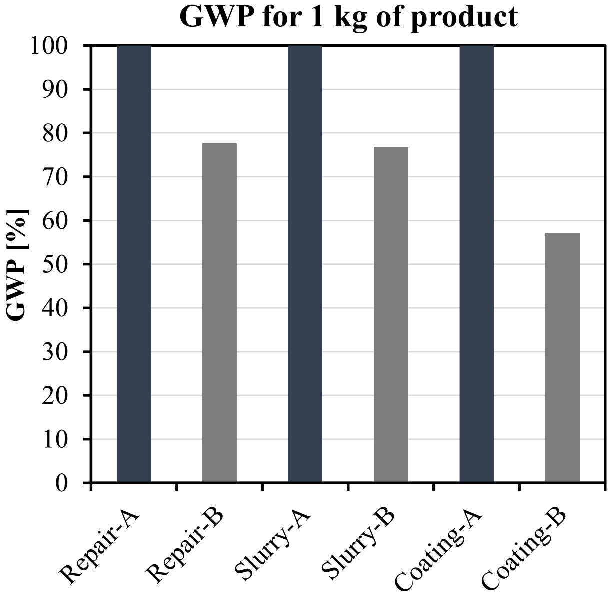
Usage	Product type	Quantity used
Reinforcing steel bars corrosion protection	1-Component cementitious based corrosion protection slurry – named herein as **Slurry-B**	500 kg
Concrete repair	1-Component cementitious repair mortar – named herein as **Repair-B**	~21 tonnes.

Concrete protection	1-Component acrylic concrete protective coating – named herein as **Coating-B**	2 900 L

5 LCA Results

The results of the LCA study are presented in percentages, where the existing repair materials system is considered as 100%. The new alternative materials system products are then shown as percentage of their respective benchmark product. The absolute values of the products Repair-A, Slurry-A and Coating-A vary, but were normalised for comparability.

Fig. 2. GWP in relation to the benchmark products.

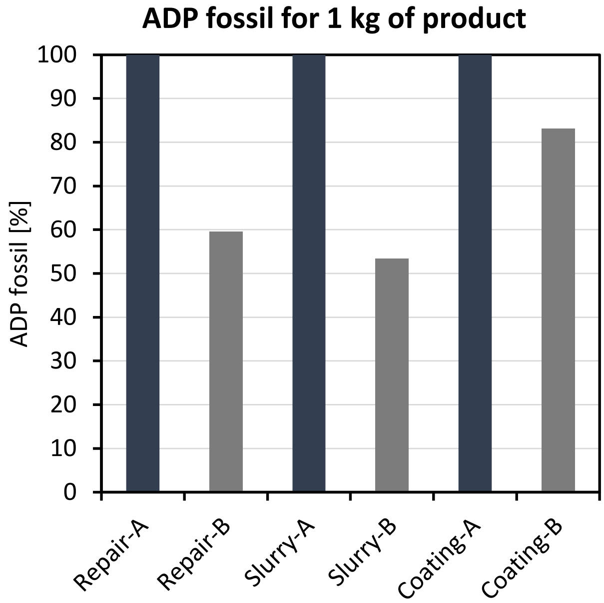


The results in figure 2 show that the more sustainable cementitious products, Repair-B and Slurry-B, show a 22% and 23 % reduction respectively, in comparison to their equivalent benchmarks, Repair A and Slurry-A for the **G**lobal **W**arming **P**otential; the new coating B having a reduction of 43% compared to its benchmark Coating A.

For ADP fossil (refer to figure 3), there is a 40% reduction for Repair B and 47% in Slurry B compared to their benchmark products. The ADP fossil of Coating B is reduced by 17% compared to its benchmark Coating-A.

When replacing the benchmark products with the newly developed more sustainable products on the repair project assessed in this paper, the embedded GWP overall could be reduced by 5,340 kg CO2 eq (Taking the average 52,7 g of CO2 per tonne-kilometres[4] emitted by a loaded truck, this is equivalent to ~5,000 km run by a 20 tons truck – approximatively the distance from Cape Town in South Africa to the port of Mombasa in Kenya), and the overall embedded ADP fossil could be reduced by 49,400 MJ (equivalent to ~1,120 kg Heavy Fuel Oil).

Fig.3. ADP in relation to the benchmark products.



Within the cradle-to-gate results, raw materials used in the manufacturing of the products have the highest contribution to the environmental impact. Production and packaging, as well as the transportation are comparatively low contributors to the GWP and ADP fossil indicators, highlighting the importance of raw material selection in the manufacturing of repair and protection products.

6 Added technical performances

6.1 For the corrosion protection slurry

The new corrosion protection Slurry-B has improved adhesion properties, which can allow application under dynamic load[5], e.g., as often required on a bridge for example.

6.2 For the repair mortar

The new repair mortar Repair-B is also characterised by improved bonding properties for application under dynamic load[5], plus it has increased resistance to aggressive environments[6]. Another improvement for contractors, is its ability to be applied in higher thicknesses, hence reducing the risks associated with multiple layer applications wherever high thickness is required.

6.3 For the protective coating

The new protective coating is characterised by higher crack-bridging resistance and capabilities[7], against both dynamic and static cracking. This will provide increased durability for the surface and the structure as deleterious elements including water, chlorides, and CO2 for example, will not be able to penetrate the surface, as the coating material will maintain its protective function for longer.

Additionally, the new coating is formulated to reduce green growths on the surface[8] [9], which may not have a direct impact on the durability of the structure, it will provide improved aesthetics and allow a reduction in future maintenance requirements.

7 Discussion

7.1 Environmental impact

The improvement in environmental indicators was achieved by optimizing the formulations of the refurbishment products, by shifting from non-renewable raw materials derived from fossil resources to renewable and resource efficient raw materials, as well as by using recycled materials.

In both cementitious products, Slurry B and Repair B, cement replacement was achieved by including supplementary cementitious materials (SCM) in the product formulation. SCMs tend to have lower GWP and APD fossil values compared to Ordinary Portland Cement, through using less energy and less fossil resources in their initial production phase than conventional cements. As these materials constitute a high proportion by weight of the products, the substitution results in a significant improvement in these two environmental indicators.

In Coating B, a biomass-balance based dispersion was used as the binder. In biomass-balanced raw materials, the biomass feedstock is introduced into the production at an early stage. In the results, the substitution of fossil-based dispersion with biomass-balanced dispersion gives reduced GWP, including lower biogenic emissions and uptake, as well as less ADP fossil.

For complete results, a further study including all life cycle stages, and also considering the higher durability and therefore longer repair cycles, needs to be considered. Further investigation of other environmental indicators e.g., GWP excluding biogenic emissions and uptake, will lead to a broader picture of the environmental impact from the products in both scenarios.

7.2 Improved performances

Overall, the new more sustainable concrete repair & protection system, would also have a beneficial impact on the durability of the structure, and with reduced maintenance works being required due to their improved technical performance and aesthetics as outlined in section 6 above.

8 Conclusion

By using a new generation of more sustainable concrete repair and protection system, the impact on the environment can be substantially reduced. Concrete repair and protection products can have a positive environmental impact, not only by extending the service life of structures and preventing or postponing demolition, but also by increased resource efficiency.

Additionally, due to the better performance of these products in term of their increased durability, the time to next maintenance can be significantly extended, thereby further reducing impact to the environment, not to mention the positive influence of improved aesthetics and reduced maintenance costs for the structure overall.

References

[1] International Organization for Standardization (ISO). Environmental management – Life cycle assessment – Requirements and guidelines, ISO 14044:2006; ISO: Geneva, (2009)

[2] CEN/TC 350, Sustainability of construction works - Environmental product declarations - core rules for the product category of construction products, EN 15804:2012, (2012)

[3] Guinée, J.B.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; Koning, A. de; Oers, L. van; WegenerSleeswijk, A.; Suh, S.; Udo de Haes, H.A.; Bruijn, H. de; Duin, R. van; Huijbregts, M.A.J. Handbook on life cycle assessment. Operational guide to the ISO standards. Kluwer Academic Publishers, ISBN 1-4020-0228-9, Dordrecht, (2002)

[4] 202108_truck_CO2_report - clean copy (transportenvironment.org)

[5] Kiwa report, P 11864-E, Tensile bond strength after vibrational stress according to the "Guideline for the Protection and Restoration of Concrete Building Components) by the German Committee for Reinforced Concrete (DAfStb)", Oct. 2001, (05.02.2019)

[6] LPM Report A-49'492-6.1E, tests according to the "Guideline for the Protection and Restoration of Concrete Building Components) by the German Committee for Reinforced Concrete (DAfStb)", Oct. 2001, (09.10.2020)

[7] Applus Report 21/32306914, Cracks bridging properties (Static & Dynamic), (7.03.2022)

[8] Tecnalia Report, 099267-a-a (M2), Resistance to fungus growth of a protective coating according to EN 15457:2014, (09.05.2022)

[9] Tecnalia Report, 099267-a-2 (M2), Resistance to algae growth of a protective coating according to EN 15458:2014, (09.05.2022)