LIFE-CYCLE ASSESSMENT OF REPAIR AND MAINTENANCE SYSTEMS FOR CONCRETE STRUCTURES

Vemund Årskog,[1] Sverre Fossdal,[2] and Odd E. Gjørv[3]
[1]Ålesund College, Norway
[2]Norwegian Building Research Institute, Norway
[3]Norwegian University of Science and Technology, Norway

Abstract

In many countries, there is a growing amount of deteriorating concrete infrastructures that not only affect the productivity of the society, but also has a great impact on resources, environment and human safety. The poor and uncontrolled durability with repairs and maintenance of all these concrete structures are consuming much energy and resources and are producing a heavy environmental burden and large quantities of waste. Therefore, the increasing amount of repairs and maintenance of concrete structures is not only a question of technical performance and economy, but also a question of impact to the environment.

In the present paper, the framework and methodology for quantifying the environmental burden of various repair materials and systems for maintenance of concrete structures are briefly outlined. This includes materials and energy consumption, waste generation and emission to the environment.

1. Background

Over recent years, there has been an increasing concern on how human activities affect the loss of biodiversity, the thinning of stratospheric ozone, climate changes and the consumption of natural resources. The term "sustainable development" (SD) was introduced in the final report of the Brundtland Commission (World Commission on Environment and Development, WCED) of 1987, where SD is defined as follows:

> Development that meets the needs of the present without comprising the ability of future generations to meet their own needs.

On the basis of weight, volume and money, the construction industry is the largest consumer of materials in our society. Thus, approximately 40% of all materials used are related to the construction industry [1]. From a production point at view, several of the construction materials have a great impact on both the local and global environment. This is particularly true for concrete as one of the most dominating construction materials. Therefore, an increased environmental consciousness in the form of a better utilization of concrete as a construction material and the creation of a better harmony and balance with our natural environment represent an increasing challenge to the construction industry, as expressed by the Lofoten Declaration of 1998 [2].

In addition to the large consumption of natural resources for concrete production, the production of portland cement is based on a very energy consuming and polluting industrial process. Thus, the production of each ton portland cement releases almost one ton of carbon dioxide in addition to a number of other polluting constituents to the atmosphere. The production of portland cement worldwide constitutes approximately 5% of the total global emission of CO_2. Therefore, proper design for durability and long-term performance of concrete structures is very important [3].

During recent years, deterioration of reinforced concrete structures has emerged as one of the most demanding challenges facing the construction industry [4]. Public agencies are already spending a significant proportion of available construction budgets for repair and maintenance of their existing structures.

In the years to come, repair and maintenance of concrete structures will be the subject to strict requirements both with regard to environmental impacts and economical constraints. It is very important to take environmental effects into consideration both during design and construction as well as in the management system for concrete structures.

The objective of the present paper is to focus on the framework and methodology for quantifying the ecological effects and impacts from various methods and systems for repairs and maintenance of concrete structures. Life-cycle assessment (LCA) includes assessment of materials and energy consumption, waste generation, emission to the environment and health risk.

2. Framework for Life-Cycle Assessment

The Institute of Ecosystem Studies define ecology as follows:

> The scientific study of the processes influencing the distribution and abundance of organisms, the interaction among organisms, and the interactions between organisms and the transformation and flux of energy and matter.

A practical way of interpreting LCA is to determine the impact on the environment, caused by all human activities throughout the whole life cycle of a structure. This is, however, a very difficult process since the relationship between the external environment and the category endpoint can be very complex. Normally, the LCA will stop at the step before the category endpoint showing only the impact categories, which is fairly easy to do, and then interpret the results from the various category indicators. The concept of category endpoints [5] is shown in Fig. 1. The methodological framework for the assessment of environmental impacts is given in the ISO-standards 14040-14043 [5-8].

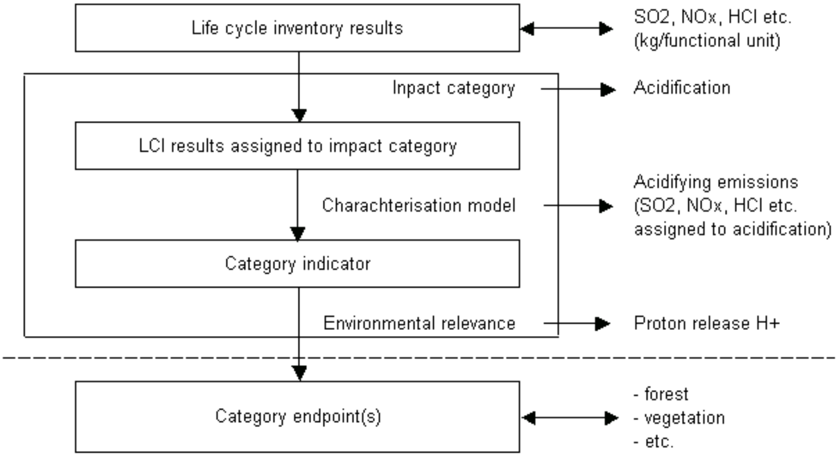

Fig. 1: Concept of category indicators

In order to apply the concept of category indicators on repairs and maintenance of concrete structures, all steps in the process have to be thoroughly evaluated. From the condition surveying of the concrete structure, the method and type of repair or maintenance action are first selected. These selections depend on the condition of the structure and the conditions of external environment as well as type of equipment and materials to be used in the process. The next step is to determine the functional unit, which is the reference unit used in the life-cycle study [7]. All emission, energy and flow of materials occurring during the process are related to this unit. The functional unit shall be measurable and depends on the goal and scope of the analysis. The goal of the life-cycle assessment shall unambiguously state the intended application and indicate to whom the results will be addressed. Thus, the functional unit for a protective coating may be defined as the unit surface (m^2) protected for a specified period of time.

The life-cycle inventory (LCI) phase will then consist of the following:

1. Quantifying the amount of all raw materials, chemicals and equipment that are necessary to fulfil the repair or maintenance function. This quantification gives the reference flow [8], for which all inputs and outputs are referred to and are closely connected to the functional unit.

2. Environmental data of consumed raw materials, chemicals and equipment from the suppliers (specific data) or from databases (generic data) or from a LCI carried out at supplier level. All materials used should have an environmental declaration with a "Cradle to port" type of scope. The environmental declaration shall include use of resources such as energy (renewable or non renewable), materials (renewable or non renewable), water and waste as well as emissions to air and water.

3. Quantifying and classifying the waste from the process such as recycling or disposal (hazardous or not hazardous).

The calculations to impact categories should be carried out according to Fig. 1. The impact categories will be: Global warming, ozone depletion, acidification, photo-oxidant creation and eutrophication. All calculated effects should be potential effects.

The classification is assignment of LCI results to impact categories. Classification and characterization should be carried out according to ISO 14042, using effect factors from IPCC * in the Montreal protocol [9]. Emission of a specific gas may be assigned to more than one category. An example is emission of $NO_{x,}$, which will be assigned to the categories of both eutrophication and acidification.

The final result may be displayed as impact categories or weighted to an environmental index, where the weighting is the process of converting indicator results of different impact categories by using numerical factors based on value-choice. This is an optional element in ISO 14042. Thus, factors from value-choices may be based on political targets according to the Kyoto-protocol or other similar preferences. Interpretation of the results based on ISO 14043 shall identify, qualify, evaluate and present the findings of significant issues.

3. Case Studies

3.1. General

In order to demonstrate how the above methodological framework for assessment of environmental impacts can be applied to various types of repair and maintenance systems for concrete structures, two examples of commonly used systems have been the subject for analysis [10], the results of which are briefly outlined in the following. The one system was a patch repair with shotcreting, where the damage was caused by a chloride-induced corrosion of embedded steel. The other system was a hydrophobic surface protection, which is commonly used as a preventive measure for protection of concrete against chloride penetration and moisture.

For both cases, some common assumptions for the calculation of the ecological impacts were made:

- Same transport distance forth and back (60 km)
- Materials and equipment were transported by truck.
- Fuel consumption (diesel) for the truck was 0.2 kg per ton-km
- Same functional unit (1 m^2 of repaired or protected concrete surface for a period of 10 years)

3.2. Patch repair

The analysis was based on the following assumptions:

- Surface area repaired: 30 m^2
- Rebound of shotcrete: 25%
- Power supply on construction site based on diesel engines

The various steps of the process considered:

- Removal of concrete cover to an average depth of 50 mm by high pressure hydro jetting (1000 bar)
- Cleaning of the reinforcing bars by sand blasting
- Protective coating of the reinforcement
- Application of the shotcrete layer
- Curing measures for the applied shotcrete

The consumption of energy and the ecological impacts of the patch repair are summarized in Table 1.

Table 1: Energy consumption and ecological impacts of the patch repair.

Process	Impact category				
	Use of energy (MJ/m^2)	Global warming (kg CO_2 eq/m^2)	Acidification (g SO_2 eq/m^2)	Eutrophication (g PO_4 eq/m^2)	Photo-oxidant formation (g Ethene eq/m^2)
Hydro jetting	677	84	75	1330	266
Cleaning of reinforcement	296	22	4	350	70
Protective coating on reinforcement	35	1,4	19	2,4	3
Application of shotcrete	59	4,4	19	70	14
Transportation	127	10	8	150	30
Sum	1194	122	125	1902	383

3.3. Hydrophobic surface protection

The analysis was based on the following assumptions:

- Hydrophobic agent: Iso-octyltriethoxy type of silane in combination with a mineral thickener.
- Surface area treated: 150 m^2

The various steps of the process considered:

- Preparation of the concrete surface by high pressure sand blasting (160 bar)
- Application of the hydrophobic agent by use of a high-pressure sprayer to a thickness of 0.25 mm. It was assumed that only 45% of the hydrophobic agent was applied to the concrete surface, which is equivalent to approximately 500 g/m^2, while the rest of the agent (approximately 600 g/m$^{2)}$ was emission to the air. The iso-octyltriethoxy type of silane is volatile and ethanol is released to the atmosphere.

The consumption of energy and the ecological impacts of the hydrophobic surface protection are summarized in Table 2.

Table 2: Energy consumption and ecological impacts of the hydrophobic surface protection

Process	Impact category				
	Use of energy (MJ/m^2)	Global warming (g CO_2 eq/m^2)	Acidification (g SO_2 eq/m^2)	Eutrophication (g PO_4 eq/m^2)	Photo-oxidant formation (g Ethene eq/m^2)
Production of hydrophobic agent	47	295	0.5	6	2
Surface preparation	17	13	0.4	7	1
Transportation and surface treatment	12	80	0.1	2	66
Long-term degradation		2171			1
Sum	76	2559	1	15	70

3.4. Comparison of the two cases

By comparing the two cases selected for analysis, it can be seen from Table 3 that the ecological impacts from the patch repair strongly exceeds that of the hydrophobic surface protection. The results demonstrate that the hydrophobic surface treatment can be repeated more than five times before the ecological impact in the form of photo-oxidant formation approaches that of the patch repair by shotcreting.

Table 3: Comparison between patch repair and hydrofobic treatment

Method	Impact category				
	Use of energy (MJ/m^2)	Global warming (kg CO_2 eq/m^2)	Acidification (g SO_2 eq/m^2)	Eutrophication (g SO_2 eq/m^2)	Photo-oxidant formation (g Ethene eq/m^2)
Hydrofobic treatment	76	2.6	1	15	70
Parch repair	1642	122	125	1902	383

4. Concluding Remarks

Assessment of impact on the environment caused by human activities throughout the life cycle of a structure may be very complex and difficult. Over recent years, however, a methodological framework for life-cycle assessments (has been established through a number of international standards and guidelines.

In order to carry out the present LCA, a number of assumptions had to be made. The results clearly demonstrate, however, that from an ecological point of view, it appears to be a very good strategy to carry out preventive maintenance of a concrete structure before a stage is reached where patch repairs may be necessary.

References

1. Ho, D.W.S., Mak, S.L. and Sagoe-Crentsil, K.K, “Clean Concrete Construction: An Australian Perspective”, Proceedings, Concrete Technology for a Sustainable Development in the 21st Century, ed. by O. E. Gjørv and K. Sakai (E & FN Spon, London and New York, 2000) 236-245.
2. Concrete Technology for a Sustainable Development in the 21st Century”, Proceedings of an international workshop in Lofoten, Norway, June, 1998, ed. by O. E. Gjørv and K. Sakai (E & FN Spon, London and New York, 2000) 386.
3. Gjørv, O.E., “Durability Design and Construction Quality.” Submitted to Proceedings of the International Conference on Advances in Concrete and Structures 2003, Xuzhou, Jiangsu, China (2003).
4. Horrigmoe, G., “Future Needs in Concrete Repair Technology”, Proceedings, Concrete Technology for a Sustainable Development in the 21st Century, ed. by O. E. Gjørv and K. Sakai (E & FN Spon London and New York, 2000) 332-340.
5. ISO 14042 Environmental management, Life cycle assessment, Life cycle impact assessment (2000).
6. ISO 14040 Environmental management, Life cycle assessment, Principles and framework (1998).
7. ISO 14041 Environmental management, Life cycle assessment, Goal and scope definition and inventory analysis (1999).
8. ISO 14043 Environmental management, Life cycle assessment, Life cycle interpretation (2000).
9. Centrum voor Milieukunde, Leiden, Holland, Environmental life cycle assessment of products (1999).
10. “Life Cycle Management of Concrete Infrastructures for Improved Sustainability, LIFECON”, The European Union – Competitive and Sustainable Growth Programme, Project No. G1RD-CT-2000-00378, Document D5.2 (2003).