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Laboratory Concrete Specimens Waste, a Case Study on Life Cycle Assessment

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Abstract. Material laboratories generally receive extensive amounts of concrete specimens for testing purposes. The tested specimen rises an environmental issue from the point of view of material waste accumulation. A study at the material laboratory was conducted, resulting in a database of daily concrete waste deposited at the landside, and the predicted increase trends based on a one-decade period of data collection. Based on these data, the emission of CO₂ resulting from these test samples was evaluated, and a life cycle assessment plan was designed through impact assessment and interpretation of results. Practical solutions for a cradle-to-cradle and cradle-to-gate approach were explored, implemented and evaluated.

1. Introduction

Concrete is one of the primary chosen materials in most Asian countries including Indonesia. Indonesia a volcanic-based archipelago that counts numerous active volcanos producing sand and stones, known as fine and coarse aggregates. These are the basic materials for concrete. The land also has an abundance of silica-based materials suitable for cement making. Cement is the predominant bonding agent for concrete in this large country. The use of this building material is also supporting job opportunities in large numbers since the process provides work prospect “from cradle to grave” in the concrete industry. Other advantages of this material are its excellent resistance to humidity, in combination with almost no maintenance after hardening. The concrete also has a high resilience towards rust, and other weather-exposed factors.

The government mandated a strict evaluation of concrete products and focused primarily on its quality. The mechanical properties most important are the compression and tensile strength. The latter is compulsory when dealing with rigid paving. As of 2018, the Indonesia Concrete code adapted the ACI 318 entirely, putting an even higher standard of testing of concrete material. Additionally, the National Policies are heavily concentrated on the physical infrastructure development, thus putting the concrete consummation in an upward spiral.

It is common knowledge that the production of cement produces a significant amount of CO₂, released into the air. This gas is one of the most dominant factors in the greenhouse effect. The percentage of the CO₂ per weight of cement production is ranging between 60% ~ 77%. Further, the binding strength of cement is predominantly dependent upon its calcium silicate component (Ca₃SiO₅). This calcium silicate is mined from nature, and thus forms a threat to the land-conservation concept. The production of cement itself produces large amounts of dust that pollutes the air and groundwater.



Another negative environmental aspect is, that in contradiction to steel which is 100% reusable and wood which is 100% biologically degradable, the demolished concrete is virtually useless and creates yet another waste product. Figure 1 shows the adverse effects of cement on the environment.

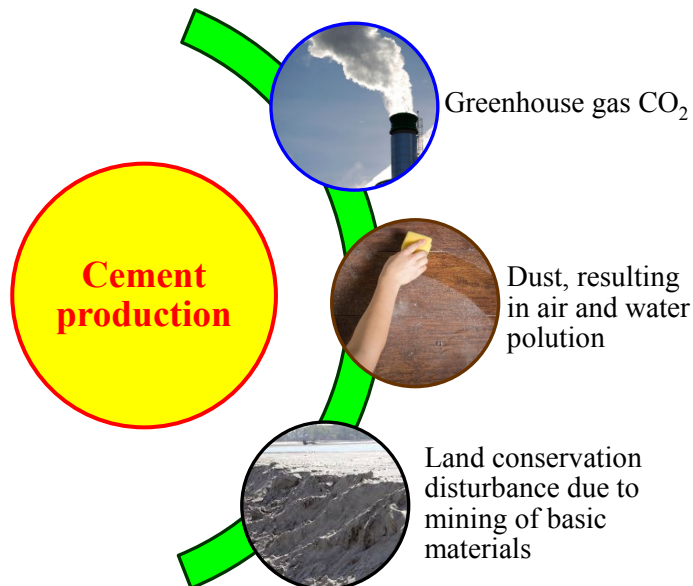


Figure 1. The negative impact of cement production

In the year 2018, use of 30 million tons of cement was recorded by the Indonesian Department of Trade, resulting in an increase of 3.6% compared to 2017. The number of specimens that are tested at laboratories increases linearly to the growth of cement demand. The firm regulations and commitments for better quality control results in an even higher rise in waste material, originating from tested specimens.

2. Concrete life cycle assessment (LCA)

Life cycle assessment is an evaluation method of input, output and potential environmental impacts data for a product, during its entire life cycle [1], [2]. The life cycle for concrete starts from the extraction of natural resources for the production of concrete, i.e., the excavation of aggregates and the extraction of cement components; lime (CaO) from chalk formations, limestones, sea-shells or calcareous rocks; silica (SiO₂) from clay or sand formations and argillaceous stones; alumina (Al₂O₃) from clay or bauxite formations; and iron (Fe₂O₃). The material then goes into its production stage, involving stone crushing and cement production. From here on the material goes into production, and the concrete is mixed and placed, entering stage 3 of the process. For laboratory specimens, this stage is the preparation of concrete specimens, in accordance with the code and function of the concrete as a structural element or component.

Upon completion of the structure, the concrete will enter its service life and is categorized in stage four. The length of this stage is dependent on the design criteria and returning period of loading (earthquake, flood), the quality and strength of concrete, the behavior of users and external factors such as humidity, salinity exposure, and cyclic loading. For the laboratory specimens, this life span is much shorter, acknowledging that specimens are customary tested at the age of 28 days, or even earlier.

Passing this stage, the structure needs to be replaced, demolished or removed. For the specimens, this stage is entered almost immediately after testing, but the result is the same: rubbles of cracked or deteriorated concrete. When a sustainable, green concrete is hoped to be achieved, the material needs to be either recycled or reused.

The life cycle of both concrete materials can be seen in figure 2a and figure 2b. To achieve a sustainable cycle, a link between stage six and stage one should be designed. Life cycle assessment of concrete thus involves an evaluation of all five stages, while identifying the potential environmental aspects of each stage.

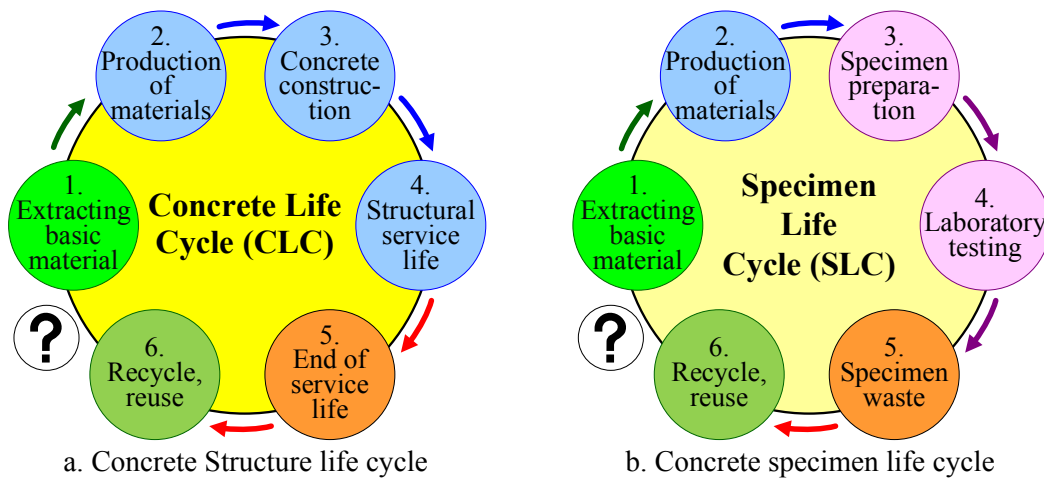


Figure 2. Life cycle of concrete

The utilization of LCA can be used to identify the prospect of environmental improvements, in each stage of the life cycle [3], [4]. This paper looked into the life cycle assessment that can be conducted for laboratories to reduce the negative effect of concrete waste. The research and study are focused in particular to filling the link between the last stage and the first stage.

3. Concrete waste and its trends

The Construction and Material Laboratory in Central Java has collected seven years' worth of data starting in 2011. The majority of cementitious material was categorized as cylinders, mostly 150 by 300 mm, 150x150x150 mm cubes, 150x105x600 mm tensile specimens, paving blocks and mortar (figure 3a). The data evaluation shows that the cylinders are the most used specimens. While a fluctuation is recorded, a rising trend in volume is noticed, supporting the former statement that the government puts its attention on the infrastructure and physical development of the country. It also implies that concrete is the most used material for structures. Coming second are the cubes and tensile specimens. The cubes show an unmistakable downwards pattern, only in the last year a surge was recorded, originating from the fact that middle- and lower-class contractors are now taking part in the building mechanism. These contractors usually rely on their older cube casts. Both the tensile specimens and paving blocks also show an increasing tendency, suggesting that the transportation sector contributes to the use of concrete for their paving. The data in figure 3b represents the spreading of concrete volume based on the type of specimens for the year 2017.

The cement content was further estimated as a function of compression strength based on the ACI method. From the recorded strength data, an average of 35 MPa was set as margin for determining the cement content. It was calculated that for every 1 m³ of concrete, 0.204 m² cement was consumed. Based on the research of [5], [6], [7] the CO₂ emission was calculated as follows:

$$\text{CO}_2\text{emission} = V_{\text{cement}} \times C_{\text{clinker}} \times \text{EF}_{\text{clinker}} \quad (1)$$

Where: V_{cement} stands for the volume of cement produced, in m³; C_{clinker} is the clinker fraction within the cement and $\text{EF}_{\text{clinker}}$ is the clinker emission factor. A clinker is a nodule, sized 3 to 25 millimeters as a product of sintering between the limestone and alumina-silicate. Per default, this factor is set to 0.5 tons of CO₂ for every ton of clinker. The Intergovernmental Panel on Climate Change (IPCC) suggested a correction to accommodate the influence of cement kiln dust (CKD) by 2%. The guidelines also recommended a value of 0.95 for the clinker factor [8].

The total yearly concrete waste in the laboratory, its cement content and the CO₂ emission released into the air during the production is shown in figure 4. This data accounts for one laboratory only; it could therefore, be imagined that the number of concrete wastes, and its corresponding CO₂, has a significant impact on the environment.

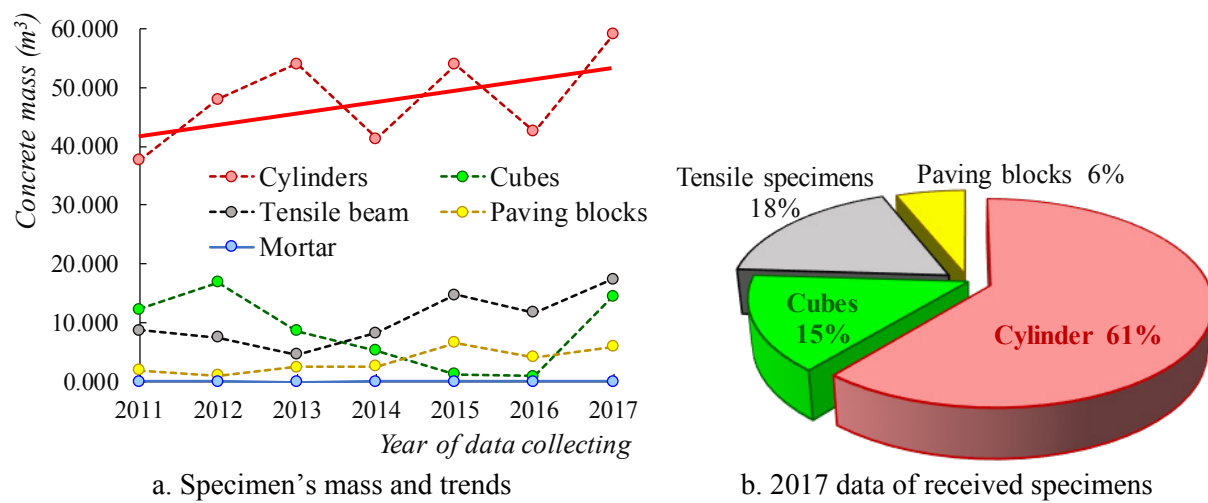


Figure 3. Specimen laboratory data 2011–2017

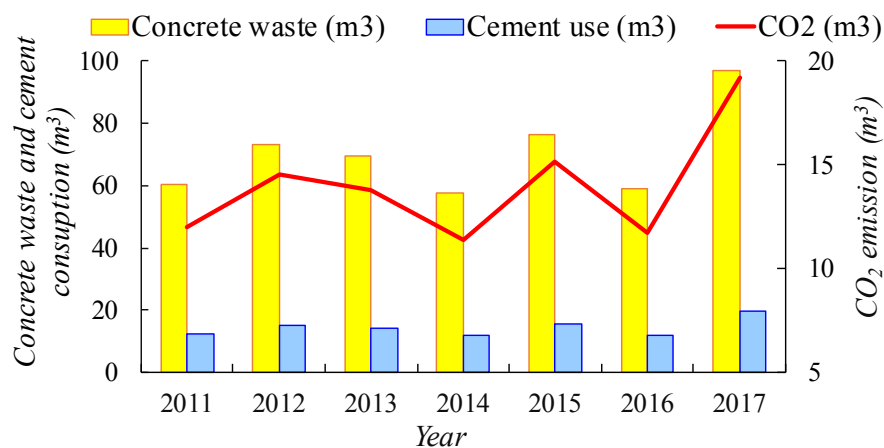


Figure 4. Estimated concrete waste and corresponding CO₂

The figures 5a and 5b illustrate the waste problems that arise from specimen testing.



a. Specimen waste



b. Tested cylinders

Figure 5. Specimen waste at the laboratory yard

4. LCA on laboratory concrete waste

To better elucidate the goals of LCA at the laboratory, the analysing steps for determining the action plane are laid out (figure 6a), while figure 6b explains the possible action steps within the life cycle. The LCA that can be implemented at the laboratory are the two last stages, the *grave-to-cradle* assessment, and the *cradle-to-cradle* appraisal.

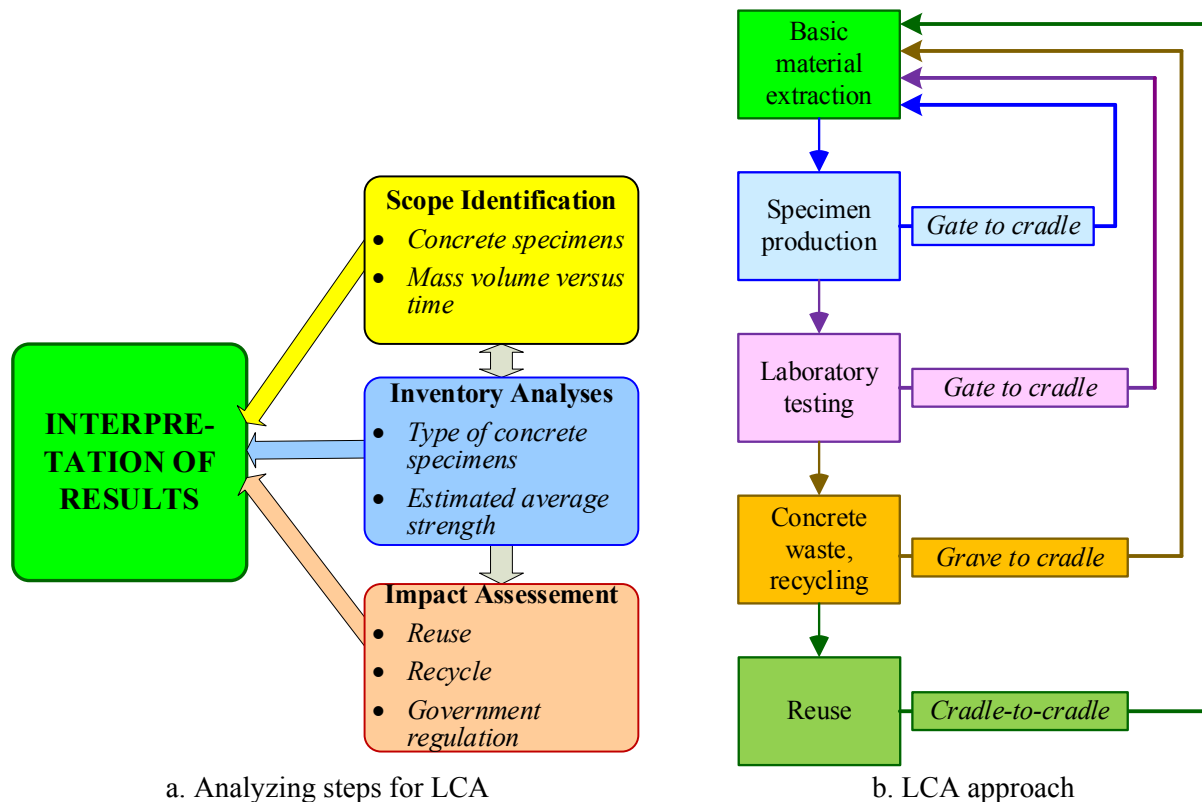


Figure 6. LCA laboratory specimen approach

For the *grave-to-cradle* two methods were directed: the first was the recycling of aggregates, and the second the crushing of concrete specimens. The recycling of aggregates involved the separation of coarse aggregates from the mortar matrix [9], [10]. The process was handled manually using a hammer and chisel. This method may sound ineffective, time-consuming and outdated, but for developing countries, this will provide work opportunities and generates an environmentally friendly method to regenerate the aggregates. The recycled aggregates can further be re-used as a concrete product; the mortar residue was used as landfill material. One of the major concerns during this process was the inconsistency in the end product since the system is highly dependent on human resources. The human factor is influenced by a range of disparities in the background, health, age and working ethics of workers. Another uncertain factor is the reality that the aggregates all have diversity in material properties. Therefore these recycled aggregates can only be used for low to medium strength concretes. The second approach was the crushing of concrete specimens. The process was conducted in two ways, manually, and using a professional stone crusher. The latter was unmistakable more expensive, and less environmentally friendly since the use of this equipment produces noise and consumes fuel. The resulting material was used as landfill or as sub-base for foundations and road paving. The manual production of recycled aggregates, however, exposes the workers to the potentially hazardous substances in the waste such as arsenic, polycyclic aromatic hydrocarbons, and hydrocarbons C10–C40 [11], [12], [13]. These impacts should be studied and long-term effect evaluated since the outcome will influence the schematics of recycling tactics.

The *cradle-to-cradle* approach was conducted by re-using the specimens in its original state. The assessment for this purpose depended highly on the geometries of the specimens. The cubes and tensile specimens were much more easily accommodated for, due to its square and therefore stable form. An advertisement was placed in the local newspaper that specimens could be taken for free, and these square-formed specimens were vastly being taken. The survey concluded that the concrete was used for foundations or fences, retaining walls, garage floors, and driveways. The 15x150x600 mm tensile specimens were extremely popular, especially when their separated parts were available (figure 7a). Contradictory to its high demand, it is seen in figure 3, that the cubes and blocks only accounted for 33% of the whole concrete waste batch. The team attempted to create a use for the cylinders and came up with a plan to promote the use of these specimens as building material for fences and minor retaining walls. The cylinders were sorted based on their geometrical properties; only the cylinders that remain in its original form were used. The cylinders were placed on their sides and constructed using a 1:3 cement-mortar-to-sand ratio as can be seen in figure 7b. This again generates work opportunity while rejuvenating the waste to a useful product. The cylinders were also used as a decorative foundation for garden furniture (figure 7c). The study on the reuse of specimens is undergoing, and it is hoped that in the future this concrete waste will be seen as a building material source.



a. Tensile specimens as retaining walls



b. Cylinders for fences



c. Garden furniture foundation

Figure 7. Reuse of tested specimens

5. Conclusion and suggestions

The data spanning a seven-year period suggested that the concrete at laboratories could not be ignored as a source of waste. The pattern suggested that this amount is rising and that a solution needs to be sought to apply the LCA for these tested specimens. Furthermore, the study at the material laboratory demonstrated that LCA can be implemented, although only the two last stages of the LCA could be accessed.

A method to return the material to its so-called 'cradle' was to recycle the specimens. The manual approach was chosen for, since developing countries have a great amount of manpower, and the

recycling and re-using process could generate work opportunities while conserving the use of fuel required by machinery. The use of specimens in its original form was also carried out, the usefulness of the specimens is highly a function of its geometric form. It was also found that collapse specimens were less constructive. The testing of specimens would best be stopped when the strength is reached, and not to be continued beyond this point to conserve the specimen's geometry. The tensile specimen's parts are best kept together, to increase its effectiveness.

References

- [1] Aitcin P and Mindess S 2017 *Sustainability of concrete* (CRC Press)
- [2] Sakai K and Noguchi T 2017 *The sustainable use of concrete* (CRC Press)
- [3] Biswas W K, Alhorr Y, Lawania K, Sarker P K and Esarrag E 2017 Life cycle assessment for environmental product declaration of concrete in the Gulf States *Sustain. Cities Soc.* **35** 36
- [4] Vieira D R, Calmon J L and Coelho F Z 2016 Life cycle assessment (LCA) applied to the manufacturing of common and ecological concrete: A review *Constr. Build. Mater.* **124** 656
- [5] Hanle L J, Jayaraman K R and Smith J S 2004 CO₂ Emissions Profile of the U.S. Cement Industry *Proc. 13th International Emission Inventory Conf. Working for Clean Air in Clearwater*
- [6] Ke J, McNeil M, Price L, Khanna N.Z and Zhou N 2013 Estimation of CO₂ emissions from China's cement production: Methodologies and uncertainties *Energy Policy* **57** 172
- [7] Zhang C, Han R, Yu B, Wei Y-M 2018 Accounting process-related CO₂ emissions from global cement production under Shared Socioeconomic Pathways *J. Clean. Prod.* **184** 20 451
- [8] IPCC 2006 *Guidelines National Greenhouse Gas Inventory*
- [9] Mah C M, Fujiwara T and Ho C S 2018 Life cycle assessment and life cycle costing toward eco-efficiency concrete waste management in Malaysia *J. Clean. Prod.* **172** 3415
- [10] Colangelo F, Petrillo A, Cioffi R, Borrelli C and Forcina A 2018 Life cycle assessment of recycled concretes: A case study in southern Italy *Sci. Total Environ.* **615** 1506
- [11] Vytlačilova V 2014 Content of Hazardous Substances in Recycled Aggregates *Recent Advances in Environmental Science and Biomedicine WSEAS Trans.*
- [12] Margarida B M, De Brito J, Martins I M and Silvestre J D 2018 Toxicity of Recycled Concrete Aggregates: Review on Leaching Tests *The Open Construction & Building Technology Journal* **12** 187
- [13] Głuchowski A, Sas W, Dziecioł J, Soból E and Szymański A 2018 Permeability and Leaching Properties of Recycled Concrete Aggregate as an Emerging Material in Civil Engineering *Appl. Sci.* **9** 81