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Impact of concrete quality on sustainability

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Abstract

With the increased focus on sustainable construction, building products are being required to document the environmental impact associated with their manufacture and show continuous improvement. This article focuses on the concrete mixture and demonstrates how improved concrete quality can play an important role in developing concrete products with reduced environmental impact and contribute to sustainable development. Improved concrete quality practices and lower standart deviations of compressive strength result required average strength for a specified strength. The carbon footprint for the producer with S = 8.6 MPa, was calculated to be about 41% higher than that for the producer with S = 2.4 MPa. Improved job-site cylinder curing practices can contribute to sustainability. Concrete mixtures can be optimized to contain low cementitious content with a target w/cm the lowest amount of mixing water content for a 12.5 mm slump be used and higher workability levels can be attained with admixtures dosages. Proper maintenance of plant and mixers ensures reduced energy and waste, tracking concrete and ambient temperatures at the plant can help reduce the energy for heating and cooling the concrete. Monitoring batching accuracy ensures conservation of materials while reducing the variability of the concrete produced. This helps sustainability through reduced energy use in handling rejected concrete, supplying new concrete as a replacement, lowering the amount of coring, and lowering the amount of repair material. At this time, standard deviation in Indonesian concrete industry still high, therefore, opportunities for improvement of the quality and sustainability of concrete in Indonesia are very big.

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Keywords: *concrete quality ; concrete sustainability ; concrete admixtures; standart deviation ; cementitious material*

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1. Introduction

The annual growth rate of cement production is 4% due to rapidly increasing construction in developing countries (World Business Council for Sustainable Development 2015). In more recent times, the story of concrete is closely related to the development of Portland cement. As concern for the future of our planet has grown, so too has our understanding of the importance of sustainable development and construction. Buildings are one of the heaviest consumers of natural resources, and account for a significant proportion of energy consumption and greenhouse gas emissions. In fact, the building sector is responsible for around 40% of global energy consumption and over 30% of global greenhouse emissions.

Concrete has been used in the construction of durable bridges, roads, water-supply structures, medical facilities, housing and commercial buildings to give people a social foundation, a thriving economy and serviceable facilities for many years. Such a ubiquitous form of construction has a significant impact on sustainability, a concept that needs to be clearly understood. Environmental responsibility is certainly part of it, but any form of construction must also be socially beneficial and economically viable. A building material, to be truly sustainable, must address all three of these criteria.

To strive for an even higher level of sustainability, the supply sector has been working for many years on a range of measures aimed at reducing the environmental impact of concrete production. This briefing provides designers, builders and owners with information on the sustainable performance of concrete materials, demonstrating that concrete is truly the responsible choice for sustainable development.

2. What is the sustainability?

A sustainable concrete structure is one that is constructed such that the total societal impact during its entire life cycle is minimal. Designing with sustainability in mind includes accounting for the short-time and long-time consequences of the structure. An integrated sustainable design process can reduce the projects costs and operating costs of the development. Achieving sustainable development requires methods and tools to help quantity and compare the environmental impacts of creating and providing the goods and services used by our society.

Fig. 1. How to make sustainability concrete

2.1. Social Impact

Without durable infrastructure such as roads, highways, rail networks, wharf and port facilities, the word's economies would grind to a halt. Concrete enables these facilities to be built economically, which has an inherent social equity dimension as well. Concrete buildings are safe, easy to maintain and commonly have a design life of 50 years or more.

2.2. Environmental Impact

The only true method of assessing a building system's environmental impact is via a life-cycle assessment. A life-cycle assessment of a range of concrete buildings commissioned by CCAA showing that concrete buildings perform very strongly across all environmental indicators, including energy use and CO_2 emissions.

At the material production level, the three major industries that provide concrete-cement, premixed concrete and extractive, are all continuing to make further reductions in their environmental impacts, through plant efficiencies, technology uptake and embracing an environmental awareness culture. Currently, in Indonesia, not many project apply the life-cycle assessment.

2.3. Economic Impact

The construction industry has impacted on economies for thousands of years. Concrete plays a pivotal role in overall economic growth, both locally and globally.

3. Target a low standard deviation

Variability in compressive strength, as measured by standard deviation (S), is an excellent indicator of a company's quality.

Table 1. Target Average Strengths for *f'c* = 27.6 MPa

QC Standards (ACI 214R)	Excellent	Very Good	Good	Fair		Poor	
S, (MPa)	2.4	3.1	3.8	4.5	5.2	6.6	8.6
f'cr (MPa)	30.8	31.8	32.9	34.5	36.2	39.4	44.2
Cementitious content (kg/m^3)	265	273	284	298	311	339	380
CO_2 footprint (kg/m^3)	275	283	293	307	321	348	390

Table 1 shows the calculated required average strength for a specified strength of 27.6 MPa based on the ACI 318 and 301 requirements for different levels (ACI 214R) of concrete quality as measured S. Based on the assumption that 1 kg of cementitious material equates to a compressive strength of 0.15 MPa . Table 1 estimates that the cementitious content for the producer with the S = 8.6 MPa is 43% higher than that for the producer with S = 2.4 MPa, also includes the environmental impact of one factor-the carbon footprint.

In general, it can be shown that every 0.69 MPa reduction in S will result in material cost savings of \$ 1.74/m^3 when S > 3.5 MPa, and cost savings of \$ 0.88/m^3 for lower S. Having a lower "S" also substantially reduces the changes of low-strength problems. Therefore, in order to reduce the standard deviation then we must know deviations in material, batching and testing.

4. Better Job-Site Curing and Overall Testing Quality

The factors that can increase the component of variability associated with testing include practices for making specimens; standard curing and subsequent testing-specimen care during initial curing at the job-site; transportation to the lab; curing at the lab; and procedures used to test the specimens for compressive strength.

An important effect is temperature and moisture afforded to the test specimens for the initial 24-to 48 hour period after they are cast. No standardized initial job site curing practices has been shown to lead to more than 7 MPa reduction in the measured compressive strength test results for a typical 28 MPa concrete mixture.

5. Mixture Optimization

Concrete mixture optimization involves the adaption of available resources to meet varying engineering criteria, construction operation and economic needs. Economic considerations include materials, delivery, placement, and progress time related costs. Optimization is often informally taken into consideration before and during construction on a non-quantitative basis by adding half a bag of cement, cutting the rock 100 pounds and replacing it with sand, or adding a high-range water reducer.

By optimizing the packing of the combined aggregate gradations, concrete admixtures and cementitious material, the cement paste content needed to make concrete can be reduced, improving sustainability, cost, performance, durability and workability.

5.1. Supplementary Cementitious Materials

From the production of concrete, cement is the most expensive material and can account for up to 60% of the total materials costs. The paste fraction of a concrete mix is usually 25% to 40 % of the total volume. A portion of cement can be substituted by supplementary cementing materials (SCMs), but there is greater potential to reduce the cement content needed for concrete mixes by optimizing the combined aggregate gradation of mixes.

Blast furnace slag (GGBFS) is a waste product that can be used as recycled aggregate or ground to a similar fineness as cement to participate in hydration reactions. GGBFS is by-product of iron manufacture and is added to improve plastic and hardened properties in concrete GGBFS (Slag) has a higher activation energy required to initiate hydration. Slag blends produce concrete with lower early strengths.

- 1 tonne of GP cement requires **7500** MJ of energy
- 1 tonne of Slag requires **700 – 1000** MJ of energy
- 1 tonne of Fly ash requires **150 – 400** MJ of energy

Table 2, Mixture proportion for 40% slag cement concrete at same w/cm

w/cm	CM (kg/m^3)	Water (kg/m^3)	Paste (%)	Aggregate voids	CA/FA (kg/m^3)
0.47	275	129	24	0.94	1283/828
	301	141	26	1.02	1249/806
	313	147	27	1.06	1231/796
	338	159	29	1.14	1198/774
	389	183	33	1.30	1131/730

Table 2 derived from on going NRMCA research project provides possible cementitious and water contents for 40% slag cement concrete mixture at a w/cm of 0.47

It is clear that for a given w/cm the combination of lower mixing-water content and associated cementitious materials content leads to a lower paste volume. At lower paste volumes, the paste does not completely fill the combined aggregate void content. As the paste volume increases from 24% to 33%, the amount of coarse and fine aggregate decreases by more than 237 kg/m^3. It was found that as the paste volume increased at the same w/cm the compressive strength was the same, while shrinkage and rapid indication of chloride ion penetrability (ASTM C1202) values increased.

A minimum amount of mixing-water content (142-148 kg/m^3) was required to attain a 15 mm slump without admixtures. However, once the mixing water content exceeded the minimum value, higher cement content mixtures tended to further increase the water demand. So it is suggested that for a target w/cm, the lowest amount of mixing-water content for a 15 mm slump be used, thereby requiring the lowest amount of cementitious content. Higher workability levels can be attained using water-reducing admixtures.

5.2. Admixture Technology

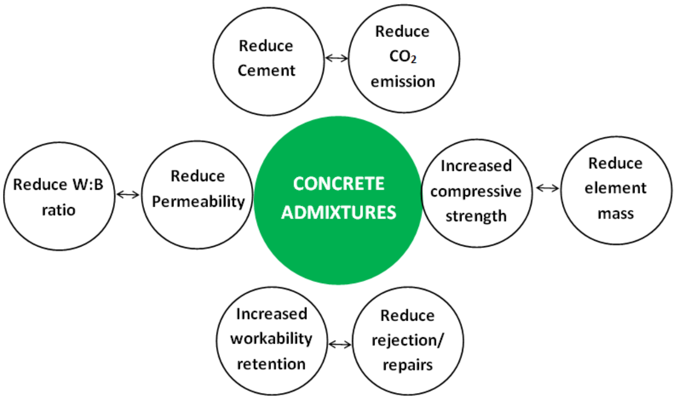

Fig. 2. Role of concrete admixture

Concrete admixture are a relevant part to achieve a significant energy reduction of the concreting process. Source wise admixture play and have an important task in prospect of sustainability.

PCE admixtures had smaller material intensity since lower amount of material and packaging goods are required. PCE admixtures contain lower amount of embodied energy to produce a product with the same effect as compared to other technologies. Environmental impacts of PCE are lower than other technologies.

5.3. The cement consumption in Indonesia and impact on sustainability

The use of cement in Indonesia is still too much, it can be seen in the ready mix companies in Java and outside Java and we can see its LCA parameters. Life cycle assessment (LCA) provides a method to quantify and evaluate potential environmental impacts throughout a product's life cycle from raw material purchase through production, use, end-of-life treatment, recycling to final disposal, commonly called cradle to grave (ISO, 2006). For LCA parameter three impact categories and resource indicators below are considered to be the most relevant:

• Cumulative energy demand	MJ
• Global warning potential	Kg CO_2- eq
• Eco indicator	Points

Optimizing the quality of concrete by using optimum aggregates gradation is done through a computer program so can obtained three charts : coarseness factor chart, individual retained chart and 0.45 power chart. Which has several benefits including increased workability, reduced segregation, reduced cracking and finally reduce cement content that impact on sustainability

Table 3, The use of cement in concrete (Concrete quality 20 MPa), compare between use in Java and outside Java

	Java		Outside Java	
Cement (kg)	215	245	270	336
Fly ash (kg)	90	-	40	-
Cumulative energy demand (MJ)	976.384	1079.917	1145.858	1345.690
Global warning potential (kg C0 eq)	173.394	195.480	215.572	259.358
Eco indicator (points)	22.376	23.497	23.16	23.829

From the table 3, we can compare with the use of cement in Australia with the same quality of concrete

Table 4, Concrete quality 20 MPa (source Gary Boon Australia)

Cement (kg)	186	92
Fly ash (kg)	-	46
Slag (kg)	46	92
Cumulative energy demand (MJ)	899.468	777.081
Global warning potential (kg CO_2 eq)	153.539	97.840
Eco indicator (points)	22.795	22.046

6. Fewer Returned Concrete and Hardened Concrete Issues

It is estimated that on average about 5% of concrete is returned to the plant, about 1%-2% is estimated for noncompliance with the project specifications such as slump, air content, and so forth (Obla 2010). By paying attention to concrete quality, the amount of rejected concrete, and fresh and hardened concrete issues due to quality reasons can be reduced. This helps sustainability through reduced energy use in handling rejected concrete, supplying new concrete as a replacement, lowering the amount of coring, and lowering the amount of repair materials.

7. Plant and Truck Mixer Maintenance

ASTM C94 requires that the uniformity requirements of concrete mixed in a truck mixer be met with 70 to 100 revolutions. An important aspect of maintaining concrete quality is to maintain concrete plants and trucks in good operating condition and capable of supplying concrete. Excessive buildup of hardened concrete in the range 5000 lbs can cause more than a 10% increase in energy consumption for mixing and transporting the concrete. This again does impact sustainable production of concrete.

8. Temperature Measurements

Tracking concrete and ambient temperature at the plan regularly can help reduce the energy for heating and cooling the concrete.

9. Batching Accuracy and Yield Measurements

Ensuring accurate batching facilitates proper inventory control of ingredients materials, reduced waste, and significant cost savings. In addition, regular measurements of concrete yield can help identify if material batching errors are occurring.

10. Mixture Adjustments

By making mixture adjustments based on trends of 3, 7 days strength test results, the producer can avoid potential low strengths problems (by day 28) and the same can also reduce their required average strengths.

11. Conclusions

Improve the quality of the concrete is important in relation to the environment impact and sustainability. Where the goal is to reduce the use of cement in the concrete mix. As we know in the manufacturing process, cement needs a lot of energy and produces a lot of carbon. Optimization of aggregate gradation, using cementitious materials and the selection of appropriate concrete admixtures also with a low standard deviation, proper maintenance of plant and mixers, concrete and ambient temperatures tracking, and monitoring of batching accuracy can help reduce energy and waste associated with the production, is the main concept of the sustainability.

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