Environmental Performance of Concrete: Definition and Assessment Methodology

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1. Introduction

Waste utilization: blast furnace slag, fly ash, silica fume, clopper slag, recycled agregates, waste incineration ash, ・・・
Admixture utilization: water reducer, AE agent, shrinkage reducing agent, viscosity modifiying agent, rust inhibitor, synthetic fibers, bacteria, ・・・
Low-carbon binders: blended cements, geopolymer or alkli-activated materials, ・・・
New construction method: self-compacting, 3D printing, ・・・

- High performance concerete
- Special concrete with new functions
- virgin resource-saving concrete
- ・・・

Need to

> **Confirm** they're really eco-friendly concretes.
> **Compare** the environmental friendliness of concretes with different technical performances (TPs).
> **Design** the concrete that meets TP requirements and maximizes environmental friendliness.

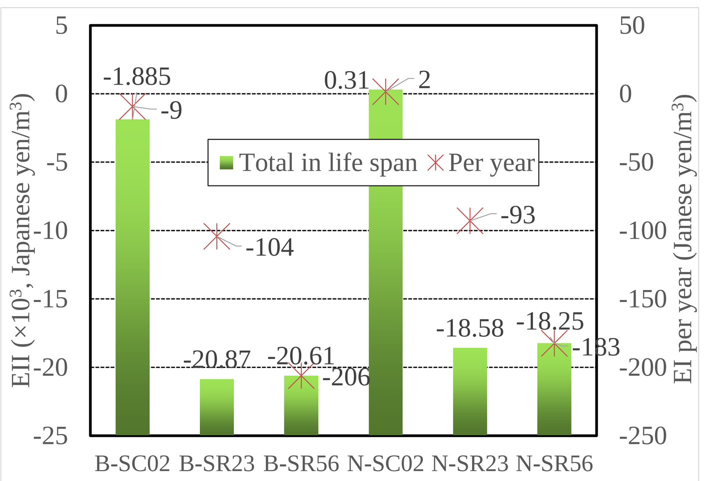
Environmental performance (EP) assessment is required

3. Assessment Examples of Concrete EP

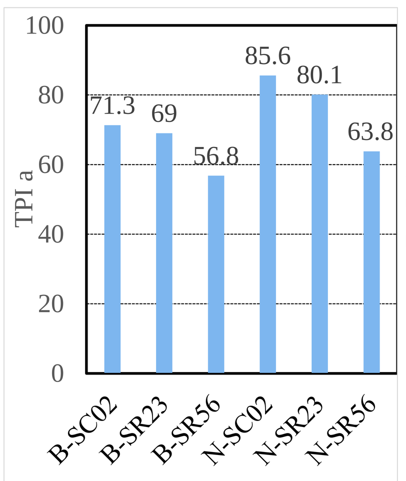
Raw materials, mix proportions and technical performances of concretes

Mix code	Type and amount of cement		Water	Blended sand	Coarse aggregate			AE water reducer	Technical performances					
					Type and Water absorption(%)		Amount		*Sl*	*A*	*Fc*		*DS*	*CR*
											28d	91d		
B-SC02	Slag cement (B type)	381	185	741	Limestone	0.22	1000	1.905	19.5	4.1	42.6	50.0	560	3.54
B-SR23				709	RCA (Grade H)	2.18			20.0	4.2	38.7	54.8	780	2.43
B-SR56				628	RCA (Grade L)	5.82			16.0	4.3	37.4	48.7	860	3.15
N-SC02	Portland cement	378		746	Limestone	0.22		1.890	19.5	4.5	40.4	47.2	570	1.43
N-SR23				711	RCA (Grade H)	2.18			19.5	4.7	41.2	47.6	830	0.95
N-SR56				606	RCA (Grade L)	5.82			15.5	5.7	35.2	40.8	960	1.98

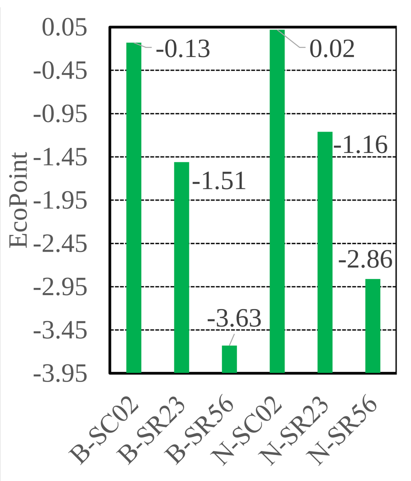
[Notes]
1) Data source: H. Takeuchi, et. al., Durability of recycled aggregate concrete for expanding its application, *Proc. of the Japan Concrete Institute*, 30(2), 373-378, 2008, but types of aggregates were supposed, and the carbonation rate factors were obtained by regression analysis from the relationship charts between the carbonation depth and the accelerated carbonation period.
2) Blended sand was a blend of recycled fine aggregate and mountain sand in a ratio of 3:7 by mass.
3) *Sl* is slump (cm), *A* is air content (%), *Fc* is compressive strength at 28 day or 91 days (MPa), *DS* is drying shrinkage at 6–month age (×10^{-6}), and *CR* is Carbonation rate factor (mm/√week)



Environmental impacts



Integrated TPs



EcoPoints

- Negative EI expresses that environmental protection benefits resulted from waste use.
- B-SR23 has the smallest EI, but B-SR56 has the best EcoPoin t (largest negative value).

4. Summary

- To compare the EPs of different concretes, the function unit of LCA should include TP and service life.
- To assess the EP of concrete using recycling materials, EBs from landfill of waste (CO_2, land use change, etc.) should be deducted.
- EPI proposed in this study essentially indicates the eco-efficiency of concrete. When doing mix design, select the mixture that satisfies the TPs, but has a smaller EcoScore.

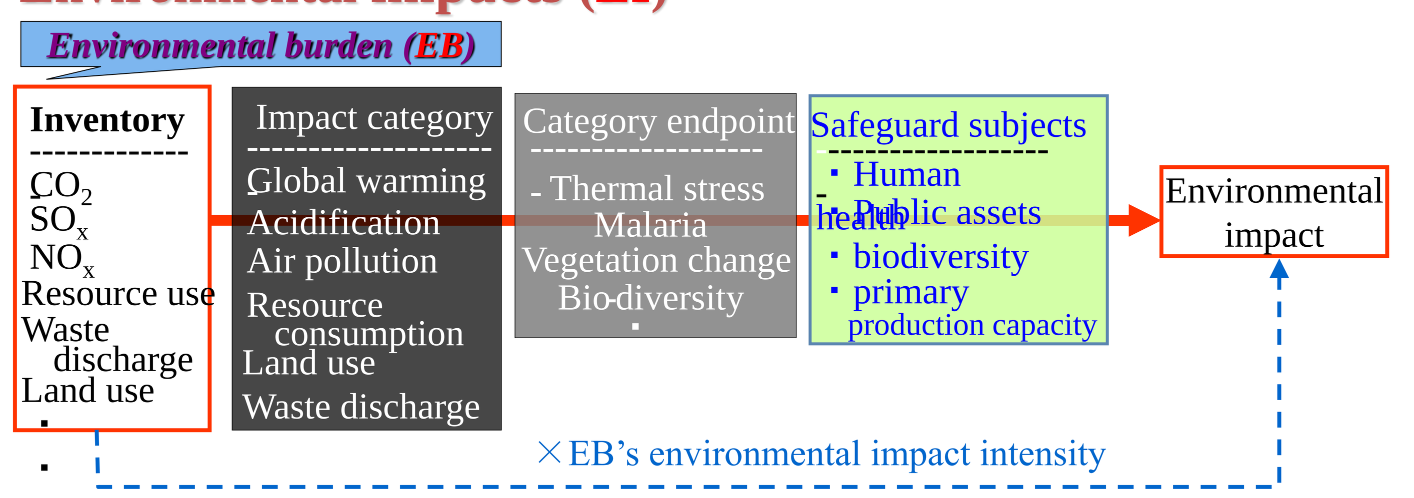
2. Definition & Calculation of Environmental Performance

Concrete amount → *For representing environmental adaptability of concrete*

- **Function unit: m^3×TP×*Life span***

TP → Integrated TPs for a comparison of different concretes

・Environmental impacts (EI)



Benefits of waste use: not disposing waste in final landfill:
- Decrease of natural source consumption, energy use and emissions
- Decrease of Lang use change
- Increase of CO_2 uptake of forest or ocean

- **EP definition: Environmental Impact (EI) per year of the life cycle of concrete with unit volume (m³) and required TPs.**

EP indicator: $EPI = \frac{EI\ indicator/(m^3 \cdot year)}{TP\ indicator}$

- **EI Indicator**: $EII = \sum_m [(M_m \times I_{pm}) + (\frac{M_m}{1000} \times D_m) \times I_t] + I_{po}$

where
M_m : Amount of raw material m in concrete of 1m³ (kg),
I_{pm} : EI intensity of producing raw material *m* (1/kg),
D_m : Transportation distance of raw material or concrete, or waste (km),
I_t : EI intensity of transportation (1/ t・km),
I_{po} : EI intensity of processes (mixing, pumping, casting, curing, demolishing, etc., 1/m³)

$I_{pm} = \sum_i [(E_{vi} - E_{wi}) \times F_i]$

Reduction in the EBs due to waste recycling ($-E_{wi}$)

where i : EB item,
E_{vi} : Amount of EB item i (e.g. CO_2) caused by the acquisition or production of raw material *m*
E_{wi} : Amount of EB item *i*, caused by the disposal of the wastes used for producing raw material *m*
F_i : Integrating factor of EB item *i*

- **EI of service phase**:

Number of repairing × EI in other phases (production, construction, and demolition/disposal) × **3%**

Class of life span	Life span (years)	Period without major repairing (years) based on JASS5:1997	Number of repairing
Short term	30	30	0
Standard	65	30	1
Long term	100	65	1
Super-long term	200	100	1

[Note] JASS 5: Japanese Architectural Standard Specification- Reinforced Concrete Works

Integrating factor F_i of EB items (Source: LIME 2)

EB category		Atmospheric emissions								Waterborne releases			Energy resource consumption			Habitat Loss	Solid wastes
EB item		CO_2 (kg)	SO_x (g) (Spot)	NO_x (g)		CH_4(g)	N_2O(g)	PM 2.5(g)		COD(g)	T-N (g)	T- P (g)	Oil (kg)	Coal (kg)	Natural gas(kg)	Land use change (m²)	Landfill disposal(kg)
				Spot	Linear			Spot	Linear								
Impact intensity (¥/kg, g)	Mean value	2.77	4.07[1]	0.60	1.93	7.33 E-02	0.87	8.20	90.5	6.40 E-04	8.25 E-02	0.97	3.18	22.9	1.45	6.94 E+4[1]	20.1[2], 16.9[3], 14.1[4], 13.6[5], 20.1[6], 30.5[7]
	Standard deviation	1.64	7.46[1]	2.02	14.68	4.36 E-02	0.52	28.20	298.0	-	-	-	1.81	118.0	1.26	6.94 E+5	12.2[2], 9.7[3], 8.3[4], 9.5[5], 14.3[6], 27.0[7]

[Notes] 1) in case of quarrying soil or rock, 2) Incineration ash, 3) Cement solid, 4) Molten slag, 5) Slag, 6) Dust, 7) Unclear

- **Estimation of life span**: JASS5(2015) regulations

(1) Concretes affected by other than salt attack

91-day Compressive strength (N/mm²)	General environment	Ligh-weight concrete		Intense freeze-thaw environment	Concrete with Eco-cement	Recycled aggregate (RA) concrete				Concrete without rebars
						RA: gade H		RA: grade M		
		Type 1	Type 2			Type 1	Type 2	Type 1	Type 2	
18	Short term (30 years)	Short	Short		Short	Short	Short	-	-	Short
21	-	-	-	Short	-	-	-	Short	Short	-
24	Standard (65years)	Standard	Standard	-	Standard	Standard	Standard	-	-	-
27	-	-	-	Standard	-	-	-	Standard[2]	Standard[2]	-
30	Long term (100 years)	Long term		-	-	Long term	Long term	-	-	-
36	Super-long term (200 years)[1]	-	-	-	-	-	-	-	-	-

[Notes] 1) limited to Portland cement, 2) apply in locations where drying shrinkage is not required.

(2) Concretes subjected to salt attack

91-day Compressive strength(N/mm²)		Environment	Min. cover thickness(mm)	Life span
Portland cement	Slag cement (type B)			
36	33	Salt damage	50	Short term (30 years)
33	30		60	
30	24	Quasi-salt damage	40	
24	21		50	
36	33		40	Standard (65years)
33	30		50	
30	24		60	
36	33		50	Long term (100 years)
33	30		60	

- **TP indicator: Integration of technical performances**

(1) Absolute integration - Common performance items, criteria values and weight factors → TPIa

(2) Relative Integration - Rater selects performance items, sets target values and weight factors for the selected performances → TPIr

Performance	Index of performance		TPI a				
			Test result			Score	Scoring method
Workability (W)	Sl	Sl, if Sl<21cm or Sf<40cm Sf. in other cases.					= (Sl./26)×100
	Sf						= (Sf./600)×100
	Segregation resistance (visual judgement)		NS	SS	S		No segregation NS: -0; Slight segregation SS: -30; Segregation S: -50
Strength (S)	28-day compressive strength (MPa)						= (Input/60)×100
Carbonation resistance (C)	Carbonation rate factor (mm/√week)						= (1+(3.0-input)/3.0)×100 Score is 0 if calculated value is negative
Drying shrinkage resistance (D)	6-month drying shrinkage (×10^{-6})						= ((1+(400-input)/400)×100 Score is 0 if calculated value is negative
TPIa	—		—				=(W×1.0 + S×1.0 + C×0.5 + D×0.5)/3

- **EcoPoint and EcoScore**

$$EcoPoint = \frac{EII_a/(m^3 \cdot year)}{TPI_a}$$

EIIa assessment considers the specified EB items: CO_2 emission, oil/coal/natural gas consumption, land use change, and waste disposal.

EcoPoint is used for comparing the environmental performances of different structural concretes.

$$EcoScore = \frac{EII_r/(m^3 \cdot year)}{TPI_r}$$

EIIr assessment considers the EB items selected by rater.

EcoScore is used for concrete mix design to achieve the required TPs and the lowest annual EI over the life cycle.