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# Carbon reduction of precast concrete under the marine environment

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## HIGHLIGHTS

- Low-carbon precast concrete panel for marine environment was developed.
- A life cycle assessment technique was used to estimate the carbon dioxide reduction.
- A significant carbon reduction was estimated.

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## ABSTRACT

In this study, precast concrete panel was developed by substituting blast-furnace slag for part of the unit weight of cement in the precast concrete mix. A life cycle assessment technique was used to estimate the carbon dioxide reduction. Carbon reduction in the materials as well as during the production phase was considered. Blast-furnace slag substitution ratios of 50, 60, and 70 wt.% were used to develop the precast concrete panel formulation. The steam curing time was taken as a variable with values of 8, 7, 6, 5, and 4 h. Results showed that the precast concrete panel formulation with 60% of the unit weight of cement replaced by blast-furnace slag satisfied the design compressive strength criterion when steam curing was applied for 6 h. The carbon dioxide emission was 33.8% lower than that of the control mix, which underwent no blast-furnace slag substitution and 8 h of steam curing.



## 1. Introduction

In case of structure under the marine environment, it is very important to choose the material and mix proportion due to directly deterioration and steel rebar corrosion by sea water and sea breeze. Concrete mixture which required durability should be secure the minimum compressive strength 28–35 MPa, the maximum water–cementitious ratio (W/C) 0.40–0.50 according to ACI 318-11. Especially, the maximum W/C of 0.40, the minimum compressive strength 35 MPa were required for concrete exposed to sea water directly or indirectly such as spray zone. In addition, it should be secure durability by increasing permeability resistance to substituted part of cement with pozzolanic material fly ash, silica fume or slag. These substitution material has direct effects on the permeability of the concrete and tend to enhance the resistance to chloride penetration through the pore structures of concrete. The effect of substitution material on porosity is attributed to the products of the pozzolan–lime reaction, which has higher molecular weight silicate chains than those of the C–S–H phase of hydrated cements [1]. The hydration reaction of blast-furnace slag proceeds with the collapse and decomposition of the glass structure by hydroxyl ions ($OH^-$) derived from released portlandite ($Ca(OH)_2$) during the hydration of cement. In case of concrete which substituted to 30–50% blast-furnace slag and cured enough, it could be increase strength by making the concrete internal structure densely. And also it could be improve durability through decreasing the permeability [2]. Through this, it could be made high-strength and durable concrete.

So, directly or indirectly exposed to the marine environment, high-strength concrete mixture should be used more than 35 MPa in order to secure durability for deterioration factor such as salt and sulphate. A high-strength concrete mixture is used to ensure sufficient durability, but this increases the unit weight of the cement required to manufacture the precast concrete.

The manufacture of 1 tonne of Portland cement emits ~870 kg of $CO_2$ [3]. Production of cement, the main component of concrete, consumes a great deal of resources and energy, and also emits significant amounts of greenhouse gases, such as $CO_2$, $SO_2$ and $NO_x$, that cause global warming. Furthermore, these resources may become depleted in the future. The cement industry alone is responsible for 4.4% of the $CO_2$ emission from all industries, and

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so is one of the main targets for greenhouse gas reduction [4,5]. The Kyoto Protocol was prepared by the United Nations Framework Convention on Climate Change (UNFCCC) to regulate and prevent global warming. Since 2013, in accordance with the Bali roadmap, each signatory country is obliged to reduce greenhouse gas emissions. The amount of reduction was specified as a 'deep cut', without a specific target [6].

The construction industry is evaluating alternative materials to replace Portland cement, whose manufacture is responsible for most $CO_2$ emissions. Blast-furnace slag, which is commonly used as a substitution, improves durability by enhancing water-tightness. It is also a more environmentally friendly material than Portland cement because its manufacture is less energy-intensive and no calcination process is required [5,7].

To concerned for the environment increases, precast construction method was used to not affecting harmful influence in surrounding ecosystem such as sea pollution, taint of sea water during construct the marine structure. Precast concrete can be used with confidence in very aggressive environments compared with cast-in place due to manufacture the factory under the tight quality control. It has excellent durability under the deterioration environment by secure the required strength as manufacturing through the quality control. Especially, precast concrete is not only resistance to salt or sulphate but also microbial attack experienced in some marine environments. Because precast concrete productions are cast in a plant and delivered to job site, disruption to the surrounding community is greatly reduces. This result in substantially quieter construction sites [8].

This study evaluated replacement of a portion of Portland cement with blast-furnace slag for the manufacture of precast concrete panel for marine environment. The optimum mix proportion for a low-carbon concrete that emitted less $CO_2$ during manufacture was identified. Additionally, the precast concrete was produced in a factory and underwent steam curing, unlike typical concrete. Steam curing was performed as follows: 3 h of pre-set curing in dry air at room temperature after concrete pouring, followed by 8 h of isothermal curing in an acceleration chamber. So, the steam curing time required to create an acceptable precast product was shortened, which also reduces the level of $CO_2$ emitted during the production phase.

## 2. Materials and mix proportions

This study identified the optimum mix proportion using blast-furnace slag to reduce $CO_2$ emissions from precast concrete panel used for marina building.

### 2.1. Cement and aggregates

The cement used was Type I Portland cement, which has a specific gravity of 3.15. Crushed stone of 2.63 specific gravity and 25 mm maximum size was used for coarse aggregate, and river sand with a specific gravity of 2.65 and a fineness modulus of 2.49 was used for fine aggregate.

### 2.2. Ground granulated blast-furnace slag

Blast-furnace slag is an industrial by-product of the manufacture of pig iron. It can improve the long-term strength and durability of concrete and reduce $CO_2$ emissions by ~288 kg/tonne when used instead of cement in Portland cement manufacture [5]. Blast-furnace slag generates hydration products similar to those generated by cement, albeit by a different hydration mechanism. The hydration reaction of blast-furnace slag proceeds with the collapse and decomposition of the glass structure by hydroxyl ions ($OH^-$) derived from released portlandite ($Ca(OH)_2$) during the hydration of cement. In case of concrete which substituted to 30–50% blast-furnace slag and cured enough, it could be increase strength by making the concrete internal structure densely. And also it could be improve durability through decreasing the permeability [2]. Blast-furnace slag with this potential hydraulicity undergoes a similar hydration as cement, and can be considered an environmentally friendly replacement material for cement in terms of recycling an industrial by-product and reducing $CO_2$ emissions.

In this study, blast-furnace slag was substituted for cement at the ratios of 50, 60, and 70 wt.% with respect to cement weight. The optimal mixing ratio of the precast concrete panel for marine environment was identified. Table 1 shows the physical and chemical properties of the blast-furnace slag used in this study.

### 2.3. Mix proportions

In this study, high-strength concrete with a design compressive strength of 50 MPa, target slump of 150 ± 20 mm, and air content of 4.0 ± 1.5% was produced as a plain mixture. To derive the optimal mixing ratio for precast concrete panel for marine environment, the blast-furnace slag substitution ratio was adopted as the experimental variable; values of 50, 60, and 70 wt.% with respect to the cement weight were used. The precast concrete mixture should have sufficient demolding strength after steam curing. However, replacement by blast-furnace slag may degrade the early strength. For that reason, an accelerating agent was used at 3 or 4 wt.% of the cement weight. Table 2 lists the mix proportions.

## 3. Experimental

### 3.1. Steam curing

The precast concrete panel was produced in a factory and underwent steam curing, unlike typical concrete. Steam curing was performed as follows: 3 h of pre-set curing in dry air at room temperature after concrete pouring, followed by 8 h of isothermal curing in an acceleration chamber whose temperature was raised at a rate of less than 20 °C/h to 60 °C. In this study, it was evaluate the effect of isothermal curing time to use cylindrical test specimens 100 mm in diameter and 200 mm in length. After the isother-

**Table 1**
Chemical components of ground granulated blast furnace slag.

| Specific gravity | Loss on ignition (%) | Fineness ($cm^2/g$) | $SiO_2$ (%) | $Al_2O_3$ (%) | $Fe_2O_3$ (%) | CaO (%) | MgO (%) | $K_2O$ (%) | $Na_2O$ (%) |
|---|---|---|---|---|---|---|---|---|---|
| 2.90 | 0.48 | 4530 | 34.4 | 12.7 | 0.50 | 41.3 | 5.93 | 0.50 | 0.40 |

**Table 2**
Mix proportions.

| | W/B (%) | S/a (%) | Slump (mm) | Air (%) | Unit weight ($kg/m^3$) | | | | | Admixtures (C × wt.%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | W | C | BF[a] | S | G | AA[b] | AD[c] |
| Plain | 36.3 | 39.8 | 148 | 4.4 | 165 | 455 | 0 | 686 | 1038 | – | 0.6 |
| S50 | | | 140 | 4.0 | 165 | 227.5 | 227.5 | 686 | 1038 | 3 or 4 | 0.7 |
| S60 | | | 135 | 3.5 | 165 | 182 | 273 | 686 | 1038 | | 0.8 |
| S70 | | | 135 | 3.5 | 165 | 136.5 | 318.5 | 686 | 1038 | | 0.8 |

[a] Blast furnace slag.
[b] Cement-based accelerating admixture.
[c] PC-based AE water-reducing agent.