Flowability of self-compacting concrete containing marine materials and steel fiber

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Abstract. In order to eliminate the main problems of clean water shortage and fine aggregate in the low land areas and the distant islands, it is purpose to utilize the sea water, marine sand, Portland composite cement and steel fiber to produce the high performance Self Compacting Concrete (SCC). The evaluation result on the mix design and flowability (slump flow, segregation) were discussed. The test results show that SCC made from sea water, marine sand and steel fibers was non-segregating concrete with a highly flowable type of concrete that spreads into the form without the need for mechanical vibration.

1. Introduction

As the world's largest archipelagic state, Indonesia has around 7.9 million square kilometers of sea water and is composed of more than 18,000 islands. To overcome the lack of infrastructure and environmental problems, the study presented is one part of the research work to accelerate the development of sustainable infrastructure on distant and remote islands.

In many concrete standards, the use of sea water as a concrete mixing water is still avoided because of the effect of salt on corrosion. One problem faced is the lack of fresh water to be used as concrete mixing water on a remote island. For this reason, research is needed that can explain the possibility of using sea water and sea sand as concrete material. Utilization of sea water and sea sand reduces the consumption of fresh water and river sand, thereby reducing the price of concrete works in coastal land areas and remote islands that lack fresh water sources and river sand. In recent years a number of successful attempts have been made on a trial scale regarding the use of seawater as concrete mixing water [1-3].

Most power plants in Indonesia use coal as fuel. Fly ash is a waste produced from burning coal in power plants. As electricity demand increases, the amount of fly ash produced by the power plant will increase. To create a cleaner environment and to achieve material savings through recycling waste materials such as fly ash, many cement plants produce blended cement containing fly ash [4,5]. Portland composite cement is a type of blended cement produced in Indonesia..

Chloride bonding in sea water with cement hydrates is called Friedelt salt [6]. Cement hydrate and SO4 content in seawater produce ettringite. As shown by Tjaronge in a research using blended cement called Portland composite cement, decreased formation of Ca(OH)2, increased formation of ettringite and Friedel salts from 1 day to 28 days did not have a negative effect on the process of developing C-S-H (tobermorite). In concrete containing sea water, sea sand and PCC cement, the hydration process, compressive strength and elastic modulus evolve well with increasing curing age, which reflects the process of developing C-S-H from the hydration reaction over time.[7]
In the remote islands, there is still a shortage of skilled and experienced workers in concrete casting work. Meanwhile, adequate compaction by skilled workers is needed to make concrete that has good durability. One effective solution to overcome the shortage of skilled workers is the application of Self Compacting Concrete (SCC). SCC is a fresh concrete that can flow at its own weight by maintaining its homogeneity to fully fill the mold without vibration or compaction energy [8].

Concrete is a mixture with a constituent consisting of cementitious material, coarse aggregate, fine aggregate, water, with or without additives. Quality concrete is one that has good mechanical properties and durability. The most important mechanical property of concrete is compressive strength. Unreinforced concrete (plain) is a brittle material, with a low tensile strength and a low strain capacity, so that cracks caused by shrinkage and creep are easy to occur and grow over time. The tensile strength value of normal concrete can be estimated around only about 9-15% of the compressive strength. To increase the tensile strength of concrete, it is necessary to use additional materials. One of the additional ingredients to improve the quality of concrete is steel fiber. The contribution of the steel fibers is to create the transformation from a brittle to a ductile type of material that would increase substantially the tensile stress-strain properties of the steel fiber concrete [9].

This paper reports for a part of ongoing investigation that focus to achieve an optimum correlation between sea water, marine sand, coarse aggregate, Portland composite cement and steel fiber to produce the high-performance SCC. The testing result on the mix design and flow ability (slump flow, segregation) of SCC were discussed.

2. Materials and experimental methods

2.1. Portland composite cement.

Portland composite cement with containing of fly ash and produced by Indonesia cement manufacture was used. Some component oxides and physical properties of cement used in this research are shown in table 1 and table 2, respectively. The component oxides and physical properties meet the requirement of SNI 15-7064-2004 (Indonesia Standard for Portland Composite Cement) [10].

| Table 1. Some component oxides of PCC. |
|----------------------------------------|
| No | Oxide                  | SNI 15-7064-2004 | Portland Composite cement (PCC) |
|----|------------------------|----------------------|---------------------------------|
| 1  | MgO (%)                | 6.0 max              | 0.97                            |
| 2  | SO₃ (%)                | 4.0 max              | 2.16                            |
| 3  | Loss of Ignition (%)   | 5.0 max              | 1.98                            |

| Table 2. Physical properties of PCC. |
|--------------------------------------|
| No | Physical properties | SNI 15-7064-2004 | Cement used (PCC) |
|----|---------------------|-------------------|--------------------|
| 1  | Air content of mortar (%) | 12 max             | 11.5               |
| 2  | Finess/ Blaine meter (m²/kg) | 280 min            | 382                |
| 3  | Expansion, % (max)    | 0.8 max            | -                  |
| 4  | Compressive strength  |                    |                    |
|    | a. 3 days (kg /cm²)   | 125 min            | 185                |
|    | b. 7 days (kg /cm²)   | 200 min            | 263                |
|    | c. 28 days (kg /cm²)  | 250 min            | 410                |
| 5  | Time of setting (Vicat test) : |                    |                    |
|    | a. Initial set, minutes | 45 min             | 132.5              |
|    | b. Final set, minutes  | 375 max            | 198                |
| 6  | False setting time (minutes) | 50 min             | -                  |
| 7  | Heat of hydration 7 days, cal/g |             | 65                 |
| 8  | Normal consistency (%) |                    | 24.15              |
| 9  | Specific gravity      |                    | 3.13               |
2.2. **Concrete mixture.**

Table 3 and table 4 show the concrete mixture and some physical properties of aggregates, respectively. Crushed stone (river stone) was used as coarse aggregate. The design slump flow was 650 mm.

| Table 3. Concrete mixture (in 1000 liters). |
|---------------------------------------------|
| Sea water (w), Cement (©), Marine Sand, Crushed stone, Superplasticizer, Steel fiber with hook |
| kg | kg | kg | kg | kg |
| 170 | 559 | 811 | 837 | 8.39 | 1% |

| Table 4. Some physical properties of aggregates. |
|-----------------------------------------------|
| Property | Crushed stone (diameter of 10-20 mm) | Marine sand |
| Specific gravity | Oven dry | 2.89 | 2.43 |
| | Saturated surface dry | 2.91 | 2.47 |
| Water absorption (%) | 0.62 | 1.75 |

| Table 5. Chemical composition of seawater. |
|-------------------------------------------|
| pH | Chemical Composition (mg/L) |
| 8.5 | Na | Ca | Mg | Cl | SO$_4$ | CO$_3$ |
| | 2085.2 | 348.4 | 1973.5 | 5303.7 | 134 | 576.6 |

| Table 6. Chemical composition of marine sand. |
|---------------------------------------------|
| Mg | Fe | Ca | Al | Cl | SiO$_2$ | MgO |
| 1.1 | 3.6 | 1.8 | 12 | 0.04 | 51190 | 1.95 |

This study used fiber with hook. Table 7 shows the physical properties of the fiber used in this study.

| Table 7. Physical properties of the steel fiber. |
|-----------------------------------------------|
| Property | Steel fiber with hook |
| Length (l) | 60 mm |
| Diameter (d) | 0.90 mm |
| Aspect ratio (l/d) | 65 |
| Tensile strength | 1.160 N/mm$^2$ |
| Young’s Modulus | ± 210.000 N/mm$^2$ |

2.3. **Testing methods for slump flow and T-500**

Slump flow test with T-500 test have been proposed for testing flow ability. Slump flow test was done according to EFNARC 2002 [11].

3. **Results and discussion**

The fresh state of SCC had a good free deformability and segregation resistance as shown in fig.1. The observations on slump flow showed that the fresh state of SCC flowed homogenously in all direction, therefore the flow spread was circular and the crushed coarse stones and steel fiber did not remain at the center of the flow spread after removal of Abrams’ cone. The time for SCC diameter to reach 500 mm (T500) was 2.6 seconds. The slump flow or the final diameter of when SCC has stopped flowing...
after lifting Abrams cone was 660 mm. Based on SCC standard by EFNARC, 2002 the SCC slump flow requirements are 650 - 680 mm and T50 is 2 - 5 seconds. Thus the SCC that designed in this study met the EFNARC, 2005 requirements for the value of slump flow and T50 produced. The visual observation on the cylindrical specimens showed that the surface of hardened concrete was smooth without any honeycomb, steel fiber balling and large air voids. This result showed that SCC flowed under its own weight and completely filled the mould, whilst maintaining homogeneity, without segregation, will lead to a good achievement of the compressive strength and durability.

![Slumpflow of SCC](image)

**Figure 1.** Slumpflow of SCC.

4. **Concluding remarks**

The interim result showed that marine sand and sea water can be used as fine aggregate and mixing water in the production of SCC while coarse aggregate and steel fiber with hook can adequately spread along with mortar to provide a good flow ability.

5. **Acknowledgments**

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