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# Compressive Strength of OPS based Self-compacting Concrete Incorporated with Fly Ash under Elevated Temperature

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**Abstract.** The application of organic lightweight aggregates (LWA) such as rice husk, coconut shell and oil palm shell in concrete are gaining popularity. However, organic substances are generally flammable under elevated temperature. As such, it is important to understand the strength performance of concrete with organic LWA under elevated temperature. To this end, this paper presents the compressive strength and mass loss of lightweight self-compacting concrete (LWSCC) when exposed to elevated temperature. In the research, comparison was made between the LWSCC samples of the control mix and mix with 40% of fly ash replacement. The compressive strengths of these mixes at 28-day were 31.35 MPa and 22.77 MPa respectively while at 90-day age, they were 33.27 MPa and 25.04 MPa respectively. Compressive strength of LWSCC samples were studied experimentally under different temperature of 26°C (room temperature), 100°C, 200°C and 300°C respectively. The experimental results showed that there is significant reduction in concrete compressive strength within the temperature range of 100°C- 200°C. When temperature was increased to 300°C, the concrete experienced strength reduction of nearly 84% and 79% at 28-day and 90-day age respectively for control mix. When 40% fly ash is incorporated, the concrete experienced strength reduction of nearly 72% and 66% at 28-day and 90-day age respectively.

## 1. Introduction

Concrete is regarded as one of the common materials in construction industry. Ancient Romans were the earliest large-scale users of concrete (ACI-213, 2003). However, its use became rare after the Roman Empire had collapsed. It was only until the middle of the eighteenth century that concrete technology started to re-develop. Several innovations in concrete technology have been achieved since then. One of the notable one is the self-compacting concrete (SCC). In the late 1980s, self-compacting concrete (SCC) was developed in Japan.SCC possesses the ability to flow under its own weight, filling the formwork with complex geometry, and the region of congested reinforcement more compactly and thus it eliminates the necessity of external vibration (EGSCC, 2005; Okamura & Ouchi, 2003). The application of SCC in construction industry has been gaining popularity due to its versatility and advantages. According to Shi et al. (2015), the production cost of SCC is generally higher than normal concrete due to more cement paste was used compared to normal concrete in order to achieve self-compacting ability. Meanwhile, supplementary cementitious materials can be incorporated in concrete in order to reduce the material cost. Fly ash is one of the most common supplementary cementitious material used which can enhance the fresh and hardened state properties of concrete. In the past decades, SCC was further developed into lightweight self-compacting concrete (LWSCC) by researchers with the use of lightweight aggregates in order to reduce the self-weight of structures. Pumice, expanded clay, expanded shale etc. are example of lightweight aggregates used in concrete production. Oil palm shell (OPS) is one of the organic waste products generated after the extraction of oil from oil palm tree (Okafor, 1988; Okpala, 1990). OPS is traditionally disposed of either through incineration by conventional process or in landfill (Rahman Sobuz et al., 2014). These disposal methods are not only expensive but also have created many environmental issues. As such, many researchers have been studying the potential of using OPS as replacement material in construction industry. Extensive research has been carried out on using waste (OPS) as alternative aggregates for the production of lightweight concrete in South East Asia (Alengaram et al., 2013).

Under normal conditions, most concrete structures are subjected to a range of temperature no more severe than that imposed by ambient environmental conditions. However, there are important cases where these structures may be exposed to much higher temperatures. Exposure of concrete to elevated temperature affects its mechanical and physical properties. The degradation of concrete compressive strength when exposed to elevated temperature are crucial in special structural application. The data of concrete under elevated temperature could provide a basis for the design and evaluation of postulated accident conditions. Several research has been carried out to study the effect of elevated temperature on normally vibrated concrete, lightweight concrete (LWC), SCC and LWSCC. Sancak et al. (2008) investigated the effects of silica fume on compressive strength of LWC under elevated temperature up to 1000°C. The authors reported that the use of silica fume in concrete could result in higher strength loss when subjected to elevated temperature. From the result, all the concrete failed to sustain after 1000°C due to the deterioration of the bond between the aggregates and cement. The authors concluded that normal concrete experience higher strength loss at elevated temperature when compared to LWC. Pathak and Siddique (2012) studied self-compacting concrete with 30%, 40% and 50% of fly ash replacement under the temperature of 100°C, 200°C and 300°C. All mixes fulfilled the filling and passing ability requirement. The authors also studied the mass loss of concrete sample at the age of 28-day and 91-day of curing period. The authors reported the compressive strength of SCC decreased as the temperature increased up to 300°C. The authors also observed that the compressive strength of SCC experienced slight improvement in the temperature range of 200°C-300°C due to modification of the bonding properties of the cement paste hydrates.

Wu et al. (2013) studied the compressive strength of polypropylene fibre based LWSCC under elevated temperature up to 600°C. The authors observed that LWSCC without polypropylene fibre experienced strength loss as temperature increased up to 600°C. For polypropylene fibre based LWSCC, strength recovery was observed in the temperature range of 200°C-400°C. The author explained that the strength recovery was due to the general stiffening of cement gel or the increase in surface forces between gel particles owing to the removal of absorbed moisture. The author concluded that LWSCC maintains higher residual compressive strength when compared to normally vibrated concrete. Muthusamy and Kolandasamy (2015) studied organic based lightweight aggregates (coconut shell) in LWSCC with different content of silica fume under temperature up to 800°C. LWSCC experienced significant strength loss in the temperature range of 400°C-800°C when compared to previous temperature range. The authors concluded that the changes of compressive strength of concrete subjected to high temperatures depend on the type of materials present in concrete, as well as on environmental factors such as the temperature, moisture content, heating rate, dehydration of C-S-H gel, thermal incompatibility between aggregates, and cement paste.

Several research was carried out for normally vibrated OPS concrete. Jumaat et al. (2015) studied the compressive strength of oil palm shell (OPS) with different level of replacement and palm oil clinker (POC) in LWC under elevated temperature up to 500°C. The author stated that concrete with high OPS content experienced higher rate of strength loss due to OPS being an agricultural waste which shrinks due to elevated temperature. For concrete with POC aggregates, no sign of strength deterioration was observed because POC aggregate is an inorganic material produced at a high temperature of about 850°C. The author concluded that OPS aggregates possesses poor elevated temperature resistance when compared to POC aggregates. Arel and Shaikh (2018) studied the effect of silica fume in steel fiber reinforced OPS concrete under elevated temperature up to 450°C. The author stated that the increase in silica fume fineness could reduce the strength loss of concrete when subjected to elevated temperature. Also, the increase of steel fiber length could slightly improve the strength loss in OPS concrete under elevated temperature. However, there is limited research on the compressive strength of OPS based LWSCC under elevated temperature. The effect of elevated temperature on OPS based LWSCC is still unknown as it has more cement content. The aim of this research was to determine the performance of light weight self-compacting concrete incorporating Oil Palm Shell (OPS) and fly ash under elevated temperature. The effect of temperature ranging from 100 to 300 on compressive strength and mass loss of LWSCC at 28-day and 90-day ages were studied.

## 2. Experimental Programme

### *2.1. Materials*

### *2.1.1. Ordinary Portland Cement (OPC)*

Ordinary Portland Cement (OPC) grade 45, conforming to ASTM: C150/C150M-12 was used. The Blaine fineness of cement is 3510cm$^3$/g. The specific gravity and particle density are 3.14 and 2950kg/m$^3$ respectively.

### *2.1.2. Fly Ash*

The fly ash used was supplied from a coal-fired power station in Sejingkat, Kuching and classified as Class F low calcium fly ash as per ASTM C618. The chemical composition is shown in Table 1.

**Table 1.** Chemical properties of cement and fly ash

| Chemicals | Cement (%) | Fly Ash (%) |
|---|---|---|
| Silicon dioxide $(SiO_2)$ | 20.0 | 57.8 |
| Aluminium oxide $(Al_2O_3)$ | 5.2 | 20.0 |
| Ferric oxide $(Fe_2O_3)$ | 3.3 | 11.7 |
| Calcium oxide $(CaO)$ | 63.2 | 3.28 |
| Magnesium oxide $(MgO)$ | 0.8 | 1.95 |
| Sulfur trioxide $(SiO_3)$ | 2.4 | 0.08 |
| $K_2O$ | - | 3.88 |
| $TiO_2$ | - | 2.02 |
| $Na_2O$ | - | 0.30 |
| Loss on ignition | 2.5 | 0.32 |

### *2.1.3. Coarse Aggregates*

Oil palm shell (OPS) was used as coarse aggregates in this research. OPS was obtained from palm oil mill in Lambir, Miri-Bintulu, Sarawak, Malaysia. They were washed and sieved. All the OPS were soaked in water for 24 hours. OPS were then allowed to air dry so that saturated surface dry (SSD) condition can be achieved before being used in concrete mixing.

### *2.1.4. Fine Aggregates*

Natural river sand and crushed OPS were used as fine aggregates. Crushed OPS in the size range of 600μm to 5mm and river sand with nominal size of 600μm were used.

### *2.1.5. Superplasticizer*

Type F superplasticizer (SP) complying the requirement of ASTM C494 and BS En 934-2 European Standard was used in this study. As a high range water reducing admixture, it is capable of reducing the water demand of concrete by at least 12%.

### *2.2. Mix Designs*

The main objective of this research is to study the compressive strength of LWSCC under elevated temperature. Two mix designs were designed i.e. control mix and the mix with 40% fly ash replacement. The maximum coarse aggregate is limited to 5mm in order to prevent the blockage in sample casting. The mix proportions are presented in Table 2.

**Table 2.** Mix proportion and fresh properties.

| Mix | M0 | M40 |
|---|---|---|
| **Cement (kg/m$^3$)** | 525 | 315 |
| **Fly Ash (kg/m$^3$)** | 0 | 210 |
| **Fine aggregate (kg/m$^3$)** | 720 | 720 |
| **Coarse aggregate (kg/m$^3$)** | 460 | 460 |
| **W/b** | 0.34 | 0.31 |
| **Sp (%)** | 1.65 | 1 |
| **Slump Flow (mm)** | 660 | 700 |

### *2.3. Sample Mixing and Casting*

Hobart A200 mixer was used for sample casting. An optimum mixing procedure was selected among several different mixing procedures. The mixing procedure started with filling the pan with all the aggregates and running the mixer for 1 minute. Then, cement was added and the mixing continued for another 2 minutes until all the materials were well mixed. Subsequently, the mixture was added slowly with water and mixing was continued for 1 minute. The SP was then gradually added and mixing continued for 1.5 minutes. Slump flow test was carried out immediately after mixing. Concrete cube specimens with size of 50x50x50mm were casted for compressive strength test.

### *2.4. Testing*

### *2.4.1. Fresh Properties*

The self-compacting ability of LWSCC was evaluated by performing slump flow test. Slump flow test was carried out by filling the slump cone and the maximum uninterrupted flow diameters in two orthogonal directions were measured. The tests were carried out in accordance to the standard procedure EFNARC (2002). As specified by EFNARC guideline, the workability can be classified as SF 1 to SF 3 based on resulting slump flow value. A slump flow value of less than 550mm is regarded as inability to flow while a value of greater than 850mm indicate the concrete might experience segregation or bleeding.

### *2.4.2. Compressive Strength Subjected to Elevated Temperature*

Concrete cube specimens were tested for compressive strength at the age of 28-day and 90-day. Similar heating method of Pathak and Siddique (2012) was adopted for this research. All the specimens were heated at a rate of 1°C/min up to specified temperature (100,200 and 300°C). After the oven reached the specified temperature, the heating of specimens was continued for 1 hour in order to ensure uniform heating. All the specimens were allowed to cool at room temperature after 1-hour heating. The specimens were tested at room temperature. The compressive strength tests were carried out in accordance to ASTM C39 procedures.

### *2.4.3. Mass Loss*

The mass loss test is aimed to study the dehydration process of cement paste. The mass of each specimen was measured before and after heating. Prior to taking mass measurement, the specimens must achieve saturated surface dry condition, in which all the pores were saturated and there was no film of water on surface.

## 3. Results and Discussion

### *3.1. Fresh Properties*

The Define Slump flow test is essential basic test which gives the indicator of flow ability of SCC. The slump flow results of both mixes are summarized in Table 2. The slump flows of these two mixes were within the range of 550-850mm which complied with the requirement of European guidelines (EGSCC, 2005). Both mixes were classified as class SF 2 as their slump flow values fall within the range of 660-750mm. Typical slump flow was shown in Figure 1.

**Figure 1.** Slump flow.

### *3.2. Compressive Strength at Elevated Temperature*

Table 3 shows the compressive strength of control mix (M0) and 40% fly ash mix (M40) under different temperature of heating at 28-day and 90-day of curing age. The relationship between compressive strength and temperature are illustrated in Figure 2. The relative strength ratio is defined as the ratio of given temperature to room temperature and it is presented in Table 4. Under room temperature, control mix and 40% fly ash mix achieved 31.35MPa and 22.77MPa respectively at 28-day age while at 90-day age, they were 33.27 MPa and 25.04 MPa respectively. With the 40% of fly ash replacement, it was observed that M2 attained 38% lower strength when compared to M1.

From Figure 2, it is noticed that both mixes experience strength reduction when temperature increased from room temperature up to 300°C at both 28-day and 90-day age. For 28-day age, strength reductions of about 24% and 12% were observed in the temperature range of 24°C-100°C for M0 and M40 respectively. About 14% and 10% strength reductions were observed at the 90-day age.

Significant strength reduction was observed at the temperature range of 100°C-200°C for both mixes. Strength reductions of 43% and 50% were observed in these range for M0 and M40 at 28-day age respectively. Further minor strength reductions were observed in the temperature range of 200°C-300°C at 28-day age. The reduction of compressive strength is mainly due to expulsion of free water from internal pore and the dehydration of concrete at high temperature (Muthusamy & Kolandasamy, 2015). In the temperature range of 100°C-200°C, the heat energy is sufficient to cause phase transformation of cement paste which could cause shrinkage of cement paste and induce cracks in concrete and result in significant strength loss (Wu et al., 2013). From Table 4, it is noticed that the rate of strength reduction were improved when the age of concrete increased. It is also noticed that the incorporation of fly ash is able to improve the rate of strength reduction. At 300°C, the relative residual strength ratio of M0 was 0.16 and 0.21 for 28-day and 90-day respectively while M40 was 0.28 and 0.34 respectively.

**Table 3.** Compressive strength of concrete specimen at elevated temperature.

| **Temperature (°C)** | **Mix Compressive strength (MPa)** | | | |
|---|---|---|---|---|
| | **M0** | | **M40** | |
| | **28-day** | **90-day** | **28-day** | **90-day** |
| Room Temperature | 31.35 | 33.27 | 22.77 | 25.04 |
| 100 | 23.7 | 28.7 | 20.14 | 22.46 |
| 200 | 10.5 | 11.31 | 8.71 | 9.75 |
| 300 | 5.13 | 7.12 | 6.28 | 8.45 |

**Table 4.** Relative strength ratio at elevated temperature.

| **Temperature (°C)** | **Relative Strength Ratio** | | | |
|---|---|---|---|---|
| | **M0** | | **M40** | |
| | **28-day** | **90-day** | **28-day** | **90-day** |
| Room Temperature | 1 | 1 | 1 | 1 |
| 100 | 0.76 | 0.86 | 0.88 | 0.90 |
| 200 | 0.33 | 0.34 | 0.38 | 0.39 |
| 300 | 0.16 | 0.21 | 0.28 | 0.34 |

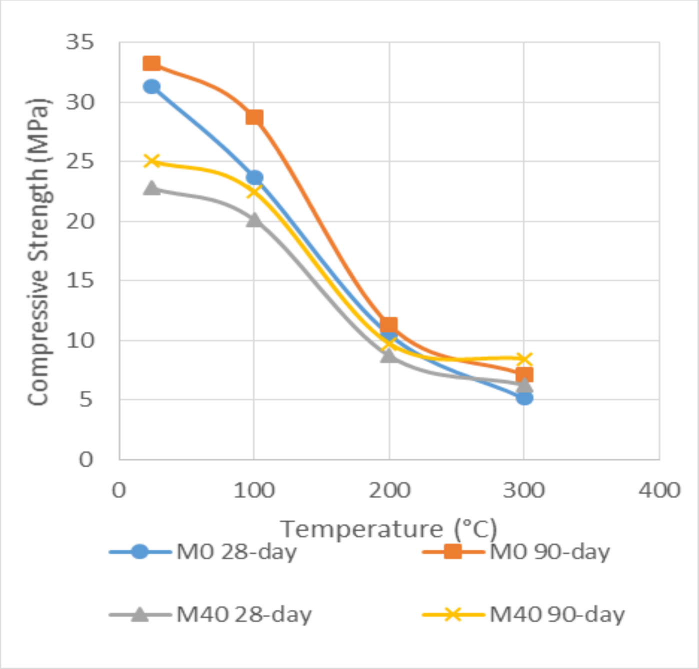

**Figure 2.** Compressive strength versus temperature.

### *3.3. Mass Loss*

The mass loss of concrete sample after heating is reported in Table 5 and illustrated in Figure 3. It is observed that the mass losses of concrete samples increased with increasing temperature. The increased in temperature resulted in increased rate of evaporation of moisture in concrete. It is also noted that the mass loss of 28-day and 90-day samples were almost similar. OPS is an aggregate with porous cellular structure which can trap water inside pore. It was noticed that the rate of water loss was increased in the temperature range of 200°C -300°C. These water contents correspond to the chemically bound water from decomposition of the C-S-H, carboaluminate hydrates and the dehydration of calcium silicate hydroxide. These observations agree with the findings of Pathak and Siddique (2012).

**Table 5.** Mass loss for LWSCC.

| **Concrete Mix** | **Temperature, °C** | **Mass Loss, %** | |
|---|---|---|---|
| | | **28days** | **91days** |
| M0 | 25 | 0.84 | 0.88 |
| | 100 | 3.69 | 3.12 |
| | 200 | 14.17 | 14.41 |
| | 300 | 23.45 | 22.24 |
| M40 | 25 | 1.52 | 0.69 |
| | 100 | 3.28 | 2.85 |
| | 200 | 13.76 | 12.72 |
| | 300 | 22.24 | 21.17 |

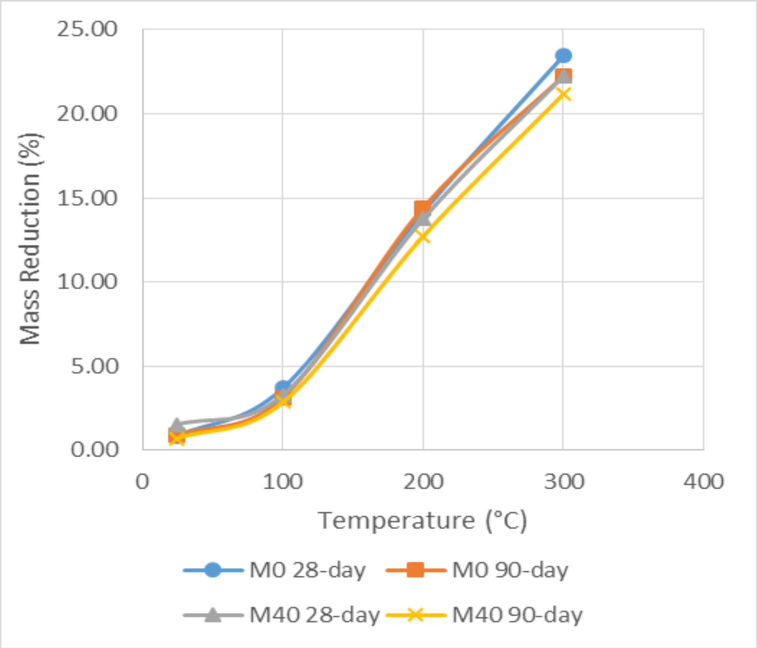

**Figure 3.** Weight loss.

## 4. Conclusion

This paper has presented the effect of elevated temperature on compressive strength and mass loss of LWSCC. From the experimental studies, the following conclusions can be drawn:

1. When subjected to elevated temperature, the rate of strength reduction is less when concrete is aged.
2. The OPS based LWSCC experiences strength reduction of nearly 84% and 79% at 28-day and 90-day age respectively when subjected to 300°C.
3. The incorporation of fly ash in OPS based LWSCC is able to improve its residual strength at elevated temperature. With 40% fly ash incorporated, the concrete experiences strength reduction of nearly 72% and 66% at 28-day and 90-day age respectively.
4. The mass loss of concrete increases with the rise in temperature. The incorporation of fly ash is able to slightly reduce the mass loss at elevated temperature.

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