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# Densification of Fresh Concrete by Microwave

**Y.D. Jia[1], E. Gutfreund[1], S. Savvides[1], S. Shi[1], Y. Bai[1]*, M. Fabian[2], T. Sun[2], K.T.V. Grattan[2], C.McCague[3]**

1) University College London 2) City University London 3) Mineral Products Association

**Summary**: Concrete mixes with different fly ash replacement levels, namely 0%, 35% and 55% at a fixed water to binder ratio (W/B) of 0.6 were heated by a tailor-made microwave oven up to 50°C immediately after casting until initial setting in order to remove excessive free water. The compressive strengths of microwave densified samples after 7 days were 3.2%, 7.7% and 29.6% higher than those of oven heated batches. It demonstrated that higher density, lower water absorption and better microstructure were achieved after microwave heating, indicating microwave heating can be a promising technique for densifying fresh concrete.

**Key Words**: Densification, Fly ash, Fresh Concrete, Microwave,

## 1. Introduction

Concrete usually contains more water than needed for its hydration in order to achieve desirable workability. This, however, will increase the porosity of hardened concrete and, consequently, adversely affects its strength and durability.

In order to reduce the excessive free water from fresh concrete, different approaches have been attempted in literature. For example, Bilner removed the excessive water near the surface of concrete using a vacuum pump and a mattress (K.P. Bilner, 1936). Although the vacuum dewatering process can densify concrete and increase the strength and the surface hardness of concrete, the main drawback is that only the near surface region can be improved (Neville, 1995). Permeability formwork, on the other hand, also can be used to reduce the excessive water (Suryavanshi and Swamy, 1997), but similar to the vacuum dewatering process, it can only reduce the water to binder ratio (W/B) ratio within the surface zone of concrete.

A dewatering and densification process by using microwave radiation was first proposed by Wu and co-workers in 1987 (Wu *et al.*, 1987) and later improved in 1994 (Li and Wu, 1994). Due to its volumetric heating property, microwave heating was found to be more efficient in reducing the W/B ratio of bulk concrete. As a result, the concrete can be densified much more effectively. However, one main drawback of their technique is the lack of temperature control during this microwave-based process which could potentially cause the damage to the microstructure of concrete, leading to the concerns over its long-term durability properties.

In this research, concrete mixes with different fly ash replacement levels, namely 0%, 35%, and 55%, at a fixed W/B ratio of 0.6 were heated in a tailor-made industrial microwave oven up to 50°C immediately after casting until reaching initial setting in order to remove excessive free water. The W/B ratio, compressive strength, density, water absorption, AC impedance and ultrasonic pulse velocity were tested and compared to the concrete cured in a thermal oven at the same temperature.

## 2. Experimental methods

### 2.1 Concrete mix proportions

Three concrete mixes with different fly ash levels investigated in this study are shown in Table 1 All the mixes were compacted by a vibration hammer and demoulded immediately afterwards.

**2.2 Microwave heating:** A tailor-made industrial microwave oven equipped with fibre Bragg grating (FBG) sensors for real-time temperature monitoring/control was used. The specimens were heated at 50ºC with a maximum microwave power of 400W until reaching initial setting in order to avoid any potential damage to the concrete matrix.

**2.3 Oven heating**: To compare with microwave heating, additional concrete specimens were also cured in a thermal oven using the same temperature and curing duration as that of the microwave.

## 3. Results and discussion

### 3.1 W/B ratio reduced by microwave heating

It is clear from Figure 1 that the W/B ratios of the specimens heated in the microwave oven were reduced from the initial stage. Compared with the specimens heated in the thermal oven, a greater decrease of the W/B ratio was achieved from the specimens heated in microwave which could be attributed to the volumetric heating of microwave, leading to more water being evaporated from inside of concrete than the oven heating.

### 3.2 Effect of densification on compressive strength

After densificitation, the samples were subsequently wrapped with wet hessian and then cured in a sealed bag at 20ºC±2 ºC for 7 days before being crushed for compressive strength. Figure 2 shows that the 7-day compressive strengths of the concretes densified by microwave were 3.2%, 7.7% and 29.6% higher than those corresponding samples heated in thermal oven with 0%, 35% and 55% fly ash, respectively.

### 3.3 Density and water absorption

Figure 3 and Figure 4 show that the concretes heated by microwave have a higher density and a lower water absorption. These results can also be attributed to the lower W/B ratio of concrete received after densification. It's important to note that the concrete with a higher replacement level of fly ash will have a better improvement.

### 3.4 AC impedance and Ultrasonic pulse velocity test

As shown in Figure 5, compared to thermal oven, a greater increase in the bulk resistance can be observed from the samples heated in the microwave, indicating a better densification effect has been achieved from microwave. Similar finding can be obtained from the ultrasonic velocity results in Figure 6.

## 4. Conclusions

Densification of fresh concrete by microwave heating technology with temperature control could result in lower W/B ratio, higher strength and better microstructure. It was also found that the concrete with a higher replacement level of fly ash had a better improvement in strength, density, water absorption and ultrasonic pulse velocity.

## 5. Acknowledgements

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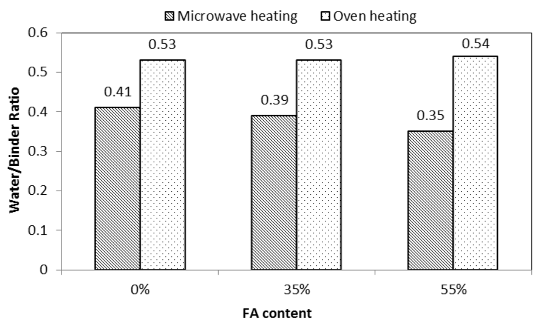
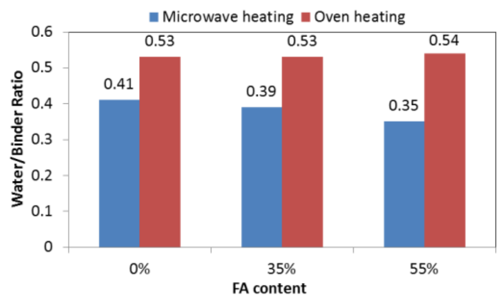
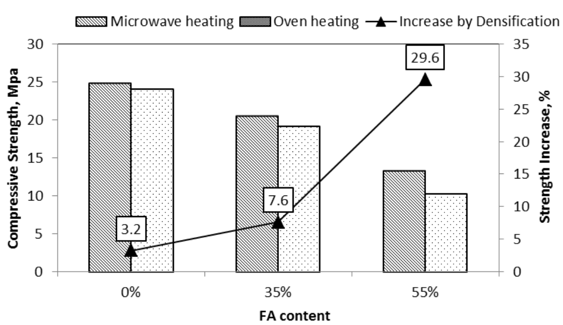
**Table 1 Concrete mix proportions**

| No. | Fly Ash replacement level | PC kg/m³ | Fly Ash kg/m³ | Coarse Agg. kg/m³ | Fine Agg. kg/m³ | Water kg/m³ | W/C |
|---|---|---|---|---|---|---|---|
| 1 | 0% | 235 | 0 | 1170 | 813 | 141 | 0.6 |
| 2 | 35% | 153 | 82 | 1170 | 813 | 141 | 0.6 |
| 3 | 55% | 106 | 129 | 1170 | 813 | 141 | 0.6 |



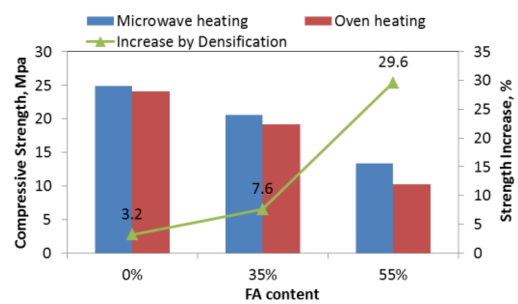
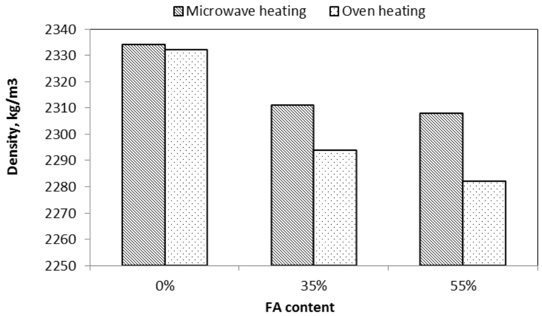
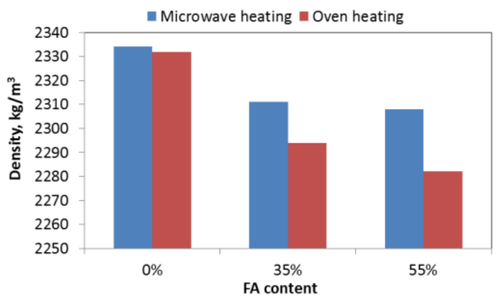
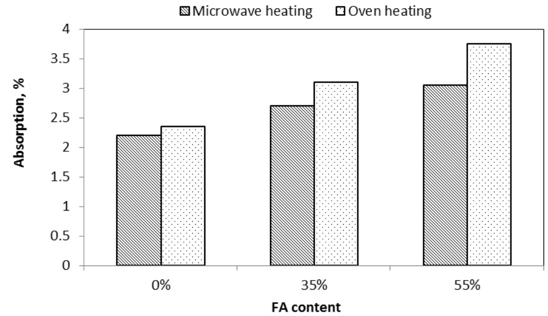




**Figure 1 W/B ratio after heated by different methods**

**Figure 2 Compressive strength at 7 days**



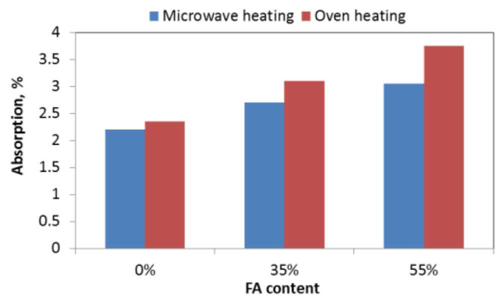
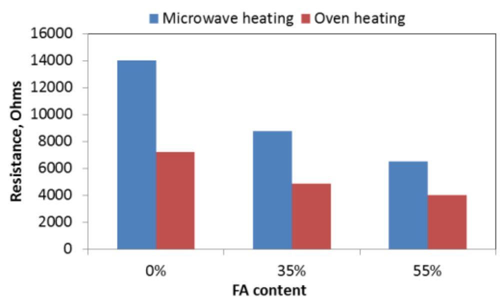
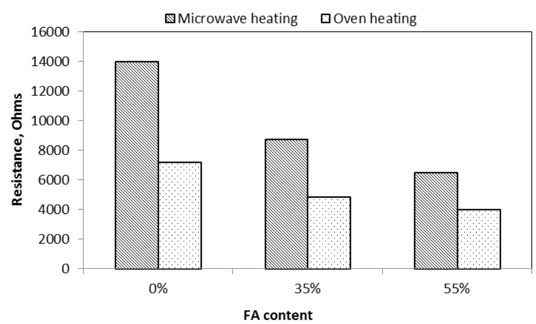
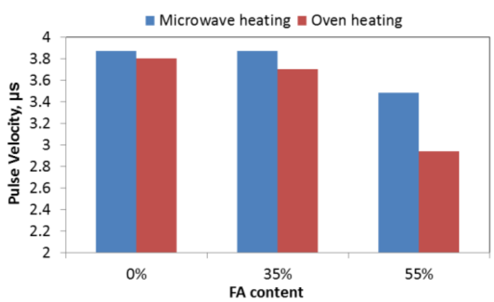




Figure 3 Density at 7 days

Figure 4 Water absorption at 7 days



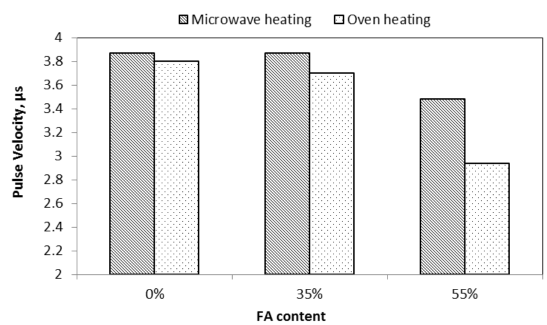




Figure 5 Resistance from AC impedance at 7 days

Figure 6 Ultrasonic pulse velocity at 7 days