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Initial investigation of generating electricity from concrete

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Abstract

Cement heat of hydration (HH) can be problematic especially in mass concrete structures as it causes thermal stresses that can lead to failure. Previous and current research has focused on minimizing the HH and mitigating its effects. The methods currently used for treating the HH in mass concreting varies between using: adding supplementary material to concrete, precooling of aggregates and mixing water, post-cooling of concrete, insulation of concrete members, and placement of concrete in thin lifts. These methods result in adding more cost and time to the construction project. This research sheds the light on a new approach in treating the cement HH. The paper presents initial experimentations conducted to dissipate the HH from the body of a concrete structure and convert it to electricity. This research should prove useful in laying the foundation for the development of more sustainable construction methods for mass concreting.

Keywords: Heat of hydration; mass concrete; construction methods

1. Introduction

Cement heat of hydration (HH) can cause serious problems in mass concrete structures. The HH can lead to thermal expansions due to the difference in the temperatures inside the concrete and on the surface [1,2,3,4]. The outer surfaces cools faster than the internal concrete, which leads to thermal contractions. This phenomenon induces thermal (tensile) stresses on the surface of concrete, which may lead to the failure of the structure entirely. Most codes require that the temperature difference in concrete members does not exceed 35°F [1, 2]. Another problem exists when the HH increases the internal temperature of concrete above 158°F. This can lead to delayed ettringite formation, which leads to the expansion and cracking of concrete [1, 2].

Although the construction mass concrete members are frequent especially in commercial and institutional buildings (Ex. Sky Scrapers), and infrastructure and heavy construction (Ex. Water Dams), the advancement in the construction methods for mass concreting has been very negligible over decades. The methods of construction used in mass concreting have been: a) insulation of concrete members, b) precooling of the mixing water (mixing with ice and/or liquid nitrogen), c) precooling of the aggregates, d) post cooling of concrete (cooling pipes), and d) placement of concrete in thin lifts [1,2,3,4]. The quantification, problems, and treatment of negative effects of the cement HH have been investigated in a multitude of studies. The majority of these studies regarded the HH as a threat to the structural integrity of the mass concrete members. As such, the approach in dealing with the HH has been directed toward minimizing the heat released, and controlling the concrete temperature. Not only are these approaches costly and time consuming, but also they are unsustainable.

In this proposed research, the authors' philosophy is that the HH is an unutilized source of energy; and they foresee a golden opportunity in converting it to electricity using the available technology in thermoelectric conversion. In the first experimentations, the possibility of capturing the HH and convert it to electricity was proved and demonstrated.

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2. Problem and objective

The main problem that this research is aimed at solving is the negative effect of the HH on the integrity of mass concrete structure as it leads to thermal stresses due to the temperature gradient existent between the surface and the interior of concrete. Another problem that stems from the increase in might occur on the long run is the formation of delayed ettringite which causes expansion and cracks inside the concrete [1,2,3,4].

The proposed construction method serves as a sustainable alternative for the existing methods. The current methods for treating the HH can be classified into construction methods and the incorporation of supplementary cementitious material in the concrete mix. The construction methods category includes techniques such as precooling, post cooling, insulation, pouring concrete in thin lifts. Several studies and articles have addressed these construction methods, as in [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]. Other studies have focused on the effect of supplementary cementitious materials such as fly ash and silica fume on the cement HH, as in [15, 16, 17, 18, 19, 20, 21, 22, 23, 24]. Not only do these traditional methods increase the construction cost and time, but also they have their negative impacts on the environment and the communities surrounding the project location.

The main objective of this research is to investigate the possibility of overcoming the negative effects of the HH by dissipating it from the body of concrete and converting it into a useful form of energy. This should lay the foundation for the development of more sustainable construction methods that can be used for treating the HH in mass concreting.

3. Methodology

This research focuses on the development of a new sustainable construction method for eliminating the negative effects of the HH in mass concrete members by converting it to electricity. In simple words, if the HH could be harvested and converted to a useful form of energy (electricity), then not only the thermal expansion problems would be solved but also additional revenue would be generated, which is the free green electricity. To achieve this goal, the field of energy harvesting and thermoelectric conversion provides a viable alternative to dissipate this heat from the body of a concrete structure and turn it into “green” electricity. Thermoelectric conversion refers to the direct conversion of heat to electricity using thermoelectric converters. There are two types of thermoelectric converters: 1) Thermoelectric Generators (TEG), and 2) Thermoelectric Coolers (TECs). TEGs and TECs can be used in two ways. If the two sides of the TEG or the TEC plate are subjected to temperature difference, voltage will be produced. If voltage is applied across the TEG or TEC peltier, one side will be cold and the other will get hot. TECs are optimized for cooling. They are usually used in making coolers. TEGs are mainly used for electric current generation. A typical TEG peltoer is shown in Fig. 1.

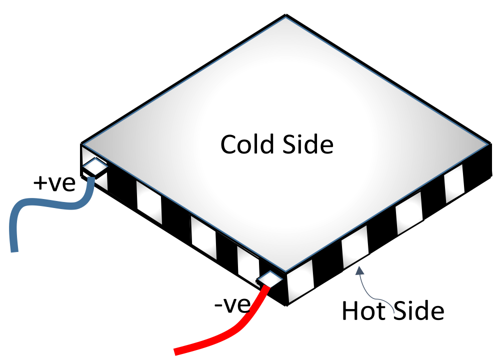

Fig.1: TEG peltier

4. Experimentation

A series of experiments were conducted to better understand and optimize the use of thermoelectric generators (TEG) and Thermoelectric Coolers (TECs) peltiers. Peltier is the TEG or the TEC module used for thermoelectric

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conversion as shown in Fig.1. Different types of TEGs and TECs from different manufacturers in China, USA, and Canada were investigated for their potential use in the proposed construction method.

4.1. Initial experimentation

In the initial experiments, the objective was to test the suitability of TEG and TEC peltiers for the proposed research. In these experiments, a source of heat was used to directly heat the hot side of a single peltier. Candles or hot water were usually used in exploratory experiments. A heat sink was placed on the other side of the peltier (cold side) to create a temperature gradient. The two ends of the peltier were connected to a load (multimeter or LED light) as shown in Fig. 2. Cooper and Aluminum heat sinks were used for cooling the peltiers. The conclusion of the initial experiments was that TEG peltiers are more efficient than TECs in generating voltage and current. Also, it was found that it is really hard to maintain a steady volt or current over a long period of time. Copper heat sinks proved to be more efficient in dissipating the heat than aluminum heat sinks.

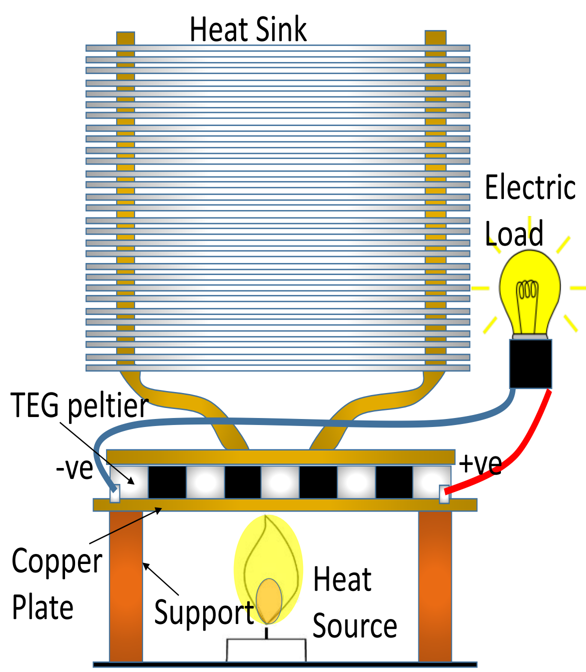

Fig. 2: Typical Heat Harvesting Setup

4.2. Conversion of heat of hydration to electricity

The conclusions of the initial experiments served as bases for designing the first experiment conducted for harvesting the heat of hydration from the core of concrete and its conversion to electricity using thermoelectric electric generators. For this experiment, the construction of a raft (matt) foundation was simulated. A rectangular plastic container was filled with cement paste. The dimension of the pseudo-raft foundation was of a dimension of (17 x 13.5 x 4.5 inch). The total amount of cement used was 59 lb, and the W/C ratio was 0.3. The W/C was selected particular low to minimize the heat of hydration released. It is known that the higher the W/C ratio, the higher the hydration, and the higher the heat released. As such, to prove the concept that the HH can be harvested form the core of concrete and converted to electricity, the experiment was designed to represent the worst-case scenario. First, the quantity of cement used was so little compared to real life application. As such, the amount of heat release was estimated to be insignificant and too little to be harvested. Second, the W/C was reduced purposely to reduce the amount of heat released to make it even more difficult to generate electricity since sufficient heat is required for the the TEG to work properly.

Copper heat pipes were inserted inside the paste to harvest the heat. The copper pipes were 200 mm in length and 10 mm in diameter. The pipes were bent to form 45°angle with the surface of the cement paste to maximize the contact with the zones of the highest temperatures across the horizontal and vertical dimensions of the cement paste, as shown in Fig. 3. Each 4 pipes were grouped together to form a base that has dimensions of 40 x 40 mm for TEG peltiers. Six bases were formed to accommodate 6 TEG peltiers. The peltiers were divided into two sets. Each three TEG peltiers were connected in series; the two sets were then connected in parallel.

The temperature inside the concrete started to rise gradually. Usually, the temperature reaches its peak after 6 to 7 hours of mixing cement with water. After 6 hours, the temperature recorded on the surface of the copper heat pipes using an infrared thermometer was above 60°C. The hot side of the TEG peltiers was placed directly on top of the pipes; the volt and the ampere were then recorded (1 Volt and 0.1 ampere). Copper heat sinks were placed on top of the cold side to create a temperature gradient, which raised the output electricity to 5 volts and 1.2 amperes.

This small "concrete battery" was used to light 4 LED light bulbs at the same time, turn a small motor on, and charge a cell phone. Future experiments will focus on achieving the research objectives which focuses on finding the most effective way of harvesting the HH, quantifying and maximizing the electricity generated, using Type III cement, and exposing a broad spectrum of the society to innovative methods of sustainability.

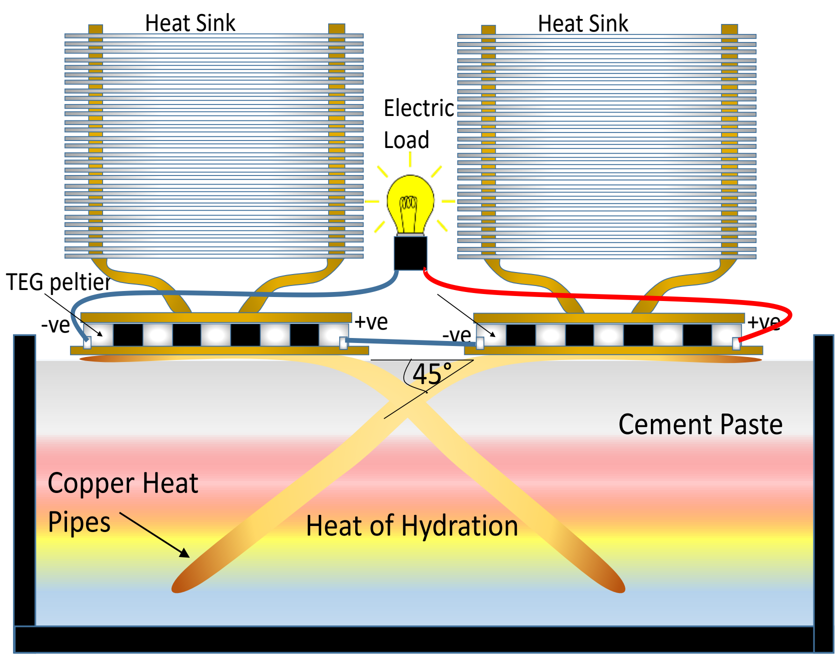

Fig. 4: Generating electricity Using HH

5. Discussion

The proposed method is expected to expedite the construction through the efficient harvesting of the HH. For instance, this will allow the continuous placement of concrete rather than placing it in thin lifts [25]. This in turn will save a lot of time and cost and will minimize the impact on the environment, economy, and society. Cost savings will be realized through the minimization of the idle time resources, and the need for additional material such as cooling pipes or insulation sheets for the concrete members. For example, the Hoover Dam required about 582 miles of cooling pipes [26, 27].

The proposed method contributes to the protection of the environment - unlike other construction methods- as it does not require any energy for operation. On the contrary, this method will generate energy.

Another point is that the proposed method will not only dissipate the HH from the core of the concrete structure but it will also convert it to electricity avoiding its release in the atmosphere, which contributes negatively to the problem of global warming. Each gram of cement – When hydrated- releases 3 calories of heat in the atmosphere [28, 29]. A cubic meter of concrete contains 400 Kg of cement on average. This means that 1 m3 of concrete can generate 23 Watt hour using thermoelectric generators working with 5% efficiency. On average, a cell phone requires 5 watts for 50 minutes to charge completely. As such, the electricity that can be generated from 1 m3 of concrete using thermoelectric conversion can be used to charge 4 cell phones fully.

The effectiveness in the continuous harvesting of the HH proposed in this research will encourage the use of Type III cement (high early strength), and taking advantage of its benefits. This will lead to rapid construction which will minimize time, money, and the negative impacts on the environment. Similarly, the proposed construction method will encourage the research for the development of nano cement, which is expected to have a lot of benefits, but its main problem will be the huge amount of HH that will be released [30, 31, 32].

A very important point that signify this research is its interdisciplinary nature. The application of heat harvesting and thermoelectric conversion in construction operations has been very limited. This opens the door to researchers to use the same or similar concepts in other application in construction, such as the thermoelectric application in geothermal piles.

6. Conclusion

This research proposes the development of a new sustainable mass concreting construction method. The proposed method utilizes the available technology of thermoelectric conversion to dissipate the heat of hydration from the core of concrete and convert it to electricity. The further development of this method can have several advantages that contribute to solving several problems associated with the construction industry. The first problem that the proposed method can contribute positively to is the minimization of material use such as supplementary cementitious materials or cooling pipes to treat the heat of hydration. In turn, this will minimize the construction cost and time. The second advantage is the promotion of green construction and reduction of CO2 emissions. The generated electric energy can be stored and used for site operations. This will save on carbon fuel and promote greener and more sustainable construction especially in remote construction sites. The proposed construction method can lead to the minimization of the contribution of the cement heat of hydration to global warming by converting some of this heat to electricity rather than releasing it in the air. Finally, if this research proved successful, it would encourage the development of nano cement, which is expected to have a lot of benefits, but its main problem will be the huge amount of HH that will be released.

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