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Experimental investigation of thermal expansion and concrete strength effects on FRP bars behavior embedded in concrete

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HIGHLIGHTS

- The thermal expansion behavior of GFRP, CFRP, AFRP and BFRP bars was determined.
- The deformation in FRP embedded concrete under effect of temperature was determined.
- The effects of different concrete strengths and different types of fiber were determined.
- It can reduce thermal expansion induced deformation using high-strength concrete.

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ABSTRACT

One of the reasons behind the widespread use of the reinforced concrete system as a construction system is that steel bars and concrete show similar elongation and shrinkage behaviors under heat. In recent years, the use of FRP in the construction industry has increased, and is now being produced in the form of bars and used in concrete. Thus, it is important to know the thermal expansion behavior of FRP bars within concrete.

In this study, the thermal expansion coefficient was determined for FRP bars with four different fiber types (Glass, Carbon, Aramid, and Basalt), and their behavior within concrete was examined. Firstly, the thermal expansion coefficients of FRP bars were determined through experiment. In order to find the compatibility of the bars with concrete under heat change effect, prismatic concrete samples of three different strength classes were produced, and FRP were placed inside of these samples together with the steel bars. Concrete samples reinforced with bars were repeatedly exposed to increasing temperatures in order to observe any deformations formed in concrete. Thus, we determined how fiber type, concrete strength, and temperature change periods affected FRP bar-embedded concretes under the effect of thermal expansion, and compared that with steel bar-embedded concrete.

1. Introduction

In addition to working well together, steel and concrete have similar thermal expansion behaviors, which allowed them to be safely used for many years. However, the corrosion of steel bars is one of the most important problems in the construction industry. In reinforced concrete structures, steel bars may corrode due to sea water, or due to environmental factors such as freeze-thaw cycle (in particular). This causes damage in reinforced concrete structures, and requires time-consuming and expensive rehabilitation work.

Researchers and users require new materials to be used in reinforced concrete structures due to the corrosion problem of steel bars. As production technologies advance, it is now possible to use Fiber Reinforced Plastic (FRP) materials for bar production. FRP composites can be used in bar production due to their lightweight nature as well as their resistance to corrosion.

The use of FRP composites in the construction industry had started with the purpose of strengthening building elements, and later has become an alternative to existing building elements such as steel or wood [1,2]. Following their years of use in other areas in the past, today these materials are also used to produce building elements through pultrusion. The performance of FRP composites in the aviation industry in particular has paved the way for their entry to the construction industry [3–5]. The production of FRP composites as a fabric has allowed them to be used to strengthen reinforced concrete elements, while their production as profiles has allowed them to be used as structural members. Finally, the production of FRP composites as bars has allowed them to be used

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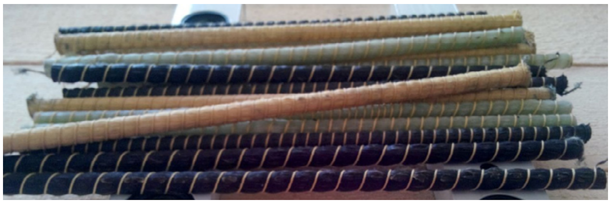

Fig. 1. FRP bar samples.

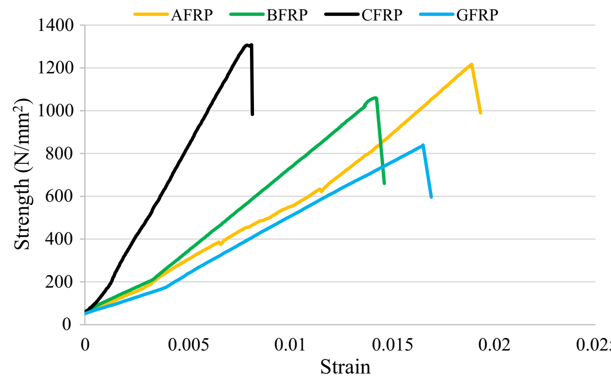

Fig. 2. FRP bar stress-strain curves.

Fig. 3. Heated and cooled FRP bars.

Fig. 4. Length change measurement.

within concrete. The most commonly used FRP types include Glass Reinforced Plastic (GFRP), Carbon Reinforced Plastic (CFRP), Aramid Reinforced Plastic (AFRP), and Basalt Reinforced Plastic (BFRP). FRP bars are preferred due to characteristics of lightweight, corrosion resistant, low thermal conductivity and magnetic.

On the other hand, the most significant drawback of these composites is that they are not ductile as steel. Also, their behavior with concrete in the case of considerable temperature changes is an important subject when they are used within concrete. Thermal expansion behavior is a significant parameter for the strength of concrete. The behaviors of concrete and FRP bars under the effects of thermal expansion make it necessary to investigate this subject in detail. The materials used in structures are desired to have similar elongation and shrinkage characteristics due to thermal expansion (i.e. seasonal temperature fluctuations, machines that produce heat, fire). Unlike traditional steel bars, FRP composites are anisotropic, which means that they have different longitudinal and transverse thermal expansion coefficients. The longitudinal thermal expansion coefficient of FRP bars depends upon the fiber type, whereas the transverse thermal expansion coefficient depends on resin [6].

There are numerous studies on the behavior of FRP composites under the effect of temperature. Some of these studies are on mechanical behavior and strength loss of FRP composites [7–19] or on the bonding surface with concrete [20–22]. There are some studies investigating the behavior of FRP bars in the case of temperature change. Zaidi et al. numerically investigated deformations between FRP bars and concrete due to temperature. The authors examined cracks in concrete that were induced by high temperature. They had also investigated how the diameter of the FRP bar behaved at temperatures of up to +60 °C using finite element analysis [23]. Masmoudi et al. investigated thermal expansion of GFRP bars embedded in concrete. They conducted experiments on cylindrical concrete samples in order to reveal the effects of concrete cover thickness and GFRP bar diameter. The authors performed analysis related to cracking and concrete cover thickness as a result of exposure to temperatures ranging between −30 °C and +80 °C [24]. Bellakehal et al. investigated how concrete slabs reinforced with FRP bars behaved under the effect of constant loading and temperature. Concrete thickness, FRP bar diameter, and temperature change from −30 °C to +60 °C were selected as variables in the study, in which the results of experimentation and analysis were discussed [25]. Zaidi and Masmoudi numerically analyzed the thermal behavior of the concrete encasement around the FRP bar in cold regions. The authors applied the finite element method to cylindrical concrete samples [26]. Galati et al. investigated the effect of temperature on the interface between FRP bars and the

Table 1
FRP bars properties.

	Steel	GFRP	CFRP	AFRP	BFRP
Specific gravity	7.82	1.88	1.48	1.44	1.61
Longitudinal Fiber Rate (%)	–	69.7	73.5	72.3	76.2
Tensile Strength (N/mm^2)	599	883	1304	1224	1021