Performance of FRC and GPC for High-Rise Construction: Case Studies

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Abstract. This paper aims to compare Fiber Reinforced Concrete (FRC) and Geo-Polymer Concrete (GPC) for high-rise construction. In doing so, 8 case studies from the USA and Australia are reviewed. The ever-increasing use of material processing linked to environmental degradation has encouraged industries to seek alternative materials. Both FRC and GPC are examples of such alternative materials. Their composition of these materials is derived from manufacturing, building and construction excess. Concerns remain, however, regarding these material's abilities such as strength, when compared to the traditional i.e. concrete, steel etc. This paper reviews select case studies where FRC and GPC materials have been used. In addition, their overall structural integrity was also observed. This paper then scrutinized their Structural Health Monitoring (SHM) to uncover their specific structural performance. Subsequently, this paper found that for both FRC and GPC extreme weathering conditions may affect their structural performance. Finally, case study review also indicates additional comprehensive research is required to review such relationship.

1. Introduction
Gharehbaghi and Scott-Young [1] argued that due to on-going environmental degradation, comprehensive environmental impact assessment and mitigation planning is desirable for all construction projects. Environmental degradation has indeed proved bothersome for engineers and planners [2-5]. Indeed, such dilemmas are one main driver for seeking alternative construction materials [6-9]. FRC and GPC are two leading examples of alternative materials.
FRC is a material which utilizes Fiber as its bonding agents [10]. GPC on the other hand, makes use of polymers to replace cement as a binder in concrete [5,11]. Cuerca [12] highlighted that both of these innovative materials are increasingly utilized in high rise construction. Researchers including Gustavo [13] and Hugo [14] demonstrated that both materials can withstand required structural loads. Conversely, such both FRC and GPC are also subject to some skepticism when compared with the traditional Reinforced Concrete (RC) [15]. In light of these competing views, this research aims to provide additional microscopic comparison of both FRC and GPC for the high-rise construction. In doing so, 8 case studies from USA and Australia will be examined.
2. Literature review and background

Gharehbaghi and Cheany [10] propositioned that establishing structural performance is a vital issue to guide the use of FRC. Although there are many literatures discussing such focus, the most important aspect of FRC is structural performance [16-20]. Questions around the wide-scale use of FRC stem from FRC mechanical composition [21,22]. In addition, Gharehbaghi et al. [23] also highlighted that FRC bonding processes such as fiber type, i.e. steel, glass are important aspects of structural performance.

On the other hand, unlike Portland Cement (PC), GPC were initially used in producing precast and pre-stressed concrete [24]. Gharehbaghi [5] highlighted that, initially GPC involved developing ultra-quick early high strength cement with room temperature curing. He further propositioned that, such procedure has the ability to allow for speedier bonding process. In addition, while the primary advantage of GPC is greenhouse gas emission reductions, it also provides the potential to utilize waste materials and processing by-products. Nonetheless, GPC possess a good strength and durability characteristics. Obstacles for GPC usage remain, however, and include, industry unenthusiastic perceptions which lead to statutory and regulatory issues [15,25,26].

Due to ever increase of environmental impacts because of manufacturing processes together with increase cost in such industrialization, alternative materials such as FRC and GPC are gradually developing into alternative solutions [27-31]. Structural Health Monitoring (SHM) is one method to simplify the use of FRC and GPC for high-rise construction. SHM generally refers to damage detection and preservation regimes. It is determined to act as a good structural monitoring technique (Hibbeler and Sekar, 2014). SHM can also be used to determine FRC and GPC performance for high-rise construction. SHM is comprehensive and can also determine the overall wear-and-tear rate of structures [32,33]. Succar et al. [34] noted that high-rise structures in particular are subject to long-term life cycles - their main cause of deterioration. Gharehbaghi and Scott-Young [35] suggested that SHM might even be detrimental for unconventional materials. Since both FRC and GPC can be categorized as such materials, SHM is presently problematic. Inventive damage detection strategies together with modern and simulated SHM would thus beneficial for FRC and GPC [37-39]. Importantly, both FRC and GPC may be subject to additional degradation processes including excessive heat, weathering and so on. Nevertheless, for high-rise construction, both FRC and GPC can ultimately provide an economical option where compared to RC and PC. However, a careful investigation needs to be carried out to further compare FRC and GPC.

3. Research methodology

The research conducted follows both qualitative and quantitative approaches. The main methodology employed, however, is a case studies approach. Taking high-rise construction as their focus, these case studies are located in the USA and Australia. Other methodology that will be used to further enhance the research include archival analyses. Subsequently, most of the data will be archival analysis and data examination. This include, log-books, SHM schematics and reports and so on. In addition, industry-based reports were also accessed to further appraise these findings.

4. Case studies

To systematically compare FRC and GPC for high rise construction, 8 case studies of high-rise buildings were evaluated. A summary of the case studies is provided in table 1.

| Structure | Age (years) | Number of storeys | FRC          | GP            | SHM performance                  |
|-----------|-------------|--------------------|--------------|---------------|----------------------------------|
| USA-Buil1 | 5           | 7                  | Floor slabs  | External panels | Minor surface cracks on one of the floors |
| USA-Buil2 | 6           | 8                  | External walls | Internal walls | Satisfactory and enduring        |
Overall, both FRC and GPC were utilized for either non-load or low-load bearing structural components. The SHM were further utilized to recommend maintenance regimes and inspection intervals. Sensor Connect Software was also used for specific structural integrity analysis. Most of the buildings reviewed are new-<7 years old. Furthermore, building SHM performance were predominately and consistently satisfactory. SHM logs were used to collect sensor data from all 8 buildings. Such data was then analyzed on a high-end platform. All the buildings utilized Steel as the source of their FRC. Importantly, all the buildings were Monocoque structures. USA-Buil4 though, had some minor structural performance issues, due to extreme weather alteration between cold to hot. As Gharehbaghi and Rahmani [36] noted, both FRC and GPC may demonstrate similar inadequacies when exposed to continuous, extreme altering weathering. Although one such case found in this research, this is not a strong vindication of such proposition. Moreover, the fiber bonding process could also be affected by extreme altering temperatures. On the other hand, the rest of the buildings were all satisfactory and enduring, although USA-Buil1 had some minor surface cracks. To further assess these case studies, their geographical locality and environmental conditions need to be also investigated.

5. Findings
Figure 1 shows the result of the weathering condition investigation.

![Figure 1. Weathering condition comparison.](image_url)

Whereas mild weather alterations include predictable seasonal conditions, severe variations include extremes of the historical distribution such as stern temperature discrepancy and so on. Further, the geographical locality and building location also influenced the weathering conditions. As it can be noticed both USA-Buil1 and USA-Buil4 were subject to severe weather variations, particularly temperature changes. These extreme temperature changes were estimated between (approximately) -15°C to +40°C. Such weather changes are abnormal for the specific geographical locality, and therefore might explain the SHM result for both USA-Buil1 and USA-Buil4. Nonetheless, USA-Buil1 seems to
outperform USA-Buil4. Close investigation found that USA-Buil1 had additional structural reinforcement especially for Seismic activities. Finally, Sensor Connect analysis results were used to recommend appropriate maintenance and rehabilitation regimes to prolong the buildings life.

6. Conclusion
Although not new, both FRC and GPC are gradually gaining popularity in building industry predominantly for high rise construction. Although there have been numerous studies in justifying the Fiber Reinforced Concrete (FRC) for general construction, this paper provided several case studies (from Australian and United States) to support its usage specifically for high rise construction. This paper also reviewed the performance of FRC and GPC specifically for high-rise construction. Concerns, however, regarding the material's strength abilities when compared to the traditional i.e. concrete, steel etc arose. Although both FRC and GPC have been researched extensively, this paper used case studies further review the performance of both materials. Overview, SHM analysis discovered, in 8 buildings sampled, that extreme weather conditions may impact the performance of both FRC and GPC structures. The review present above indicates the need for, more comprehensive research which includes bigger sample sizes to review such relationship.

7. References
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