

PAPER • OPEN ACCESS

Effects of elevated temperature on high performance concrete incorporating of metakaolin and garnet

To cite this article: Nazirah Ahmad Shukri *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **220** 012035

View the [article online](#) for updates and enhancements.

Effects of elevated temperature on high performance concrete incorporating of metakaolin and garnet

Nazirah Ahmad Shukri^{1,2}, Rosli Noor Mohamed¹, Mohd Yunus Ishak¹, Shariwati Mansor¹, Muhamad Sazly Nazreen Mahmood¹, Nazry Azillah¹ and Fazlin Zamri¹

¹Faculty of Civil Engineering, Universiti Teknologi Malaysia.

²Corresponding author: nazirah6758@gmail.com

Abstract. Durability has become one of the major indicators to dictate a good quality of concrete. Rapid growing in construction leads to the demand of high strength concrete which can bear high stress and high resistance towards any hazard and harsh environment thus providing a safe structure. High performance concrete (HPC) has been identified as one of the advanced types of concrete that can fulfill the criteria. Hence, in this study resistance towards elevated temperature of HPC incorporating 10% of metakaolin as part of cementitious material and 50% of garnet as part of replacement of fine aggregates were investigated. Samples of HPC with metakaolin and garnet (HPCMG) and HPC with metakaolin (HPCM) were exposed to different heating temperature of 200°C, 400°C, 600°C and 800°C for duration of one hour. The changes of physical in color and the appearances of cracks in all samples were closely observed. In addition, compressive strength tests according to BS1881-116:1983 and percentage of weight loss for all the samples were also monitored in this study. Results showed that as the temperature increased, significance losses of compressive strength were detected for both HPCMG and HPCM. At the temperature of 800°C, HPCMG degenerated 86.8% of its strength compared to 71.8% for HPCM. As temperature increased, weight loss of HPCM indicated higher reading compared to HPCMG. Major changes of the physical appearances were also detected in both HPCM and HPCGM samples such as cracks and increment in gap width on the samples. This summarized that HPCM has better fire resistance compared to HPCMG.

1. Introduction

High performance concrete (HPC) has been defined by ACI as concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practice [1]. HPC does not only bear high stresses but also benefits in high durability which is one of the important key elements in a safe structure. Previously, design of the concrete mixes used in concrete focus on the strength and workability while less attention was given to the durability. This leads to deterioration, corrosion, bleeding, efflorescence or cracks that appear commonly within few years of construction [2]. Due to this, various studies have been conducted all around the world aiming to achieve a better quality of concrete that not only focus on its strength but also its resistance toward harsh environment. To achieve this, the design of the HPC mixes does not only rely on additions of appropriate amount of chemical admixture and pozzolonic materials but also the substitution of microaggregate that



contributes to filling effect thus will improve compactness of the concrete and slows down the diffusion of ions [2,3]. In this study, metakaolin as part of cementitious material while garnet as part substitution of fine aggregates were used in producing HPC. Garnet, a material that had been utilize in many industrial areas especially as abrasive material. As particle of garnet used in this study are micrometre in size, the HPC to be produced are high in strength. Regardless of many design standards for concrete structures has been updated with properties of detailed material and specification under ambient temperature, codes and standards for high strength concrete in high temperature does not provide reliable material properties [4]. The vapour pressure which exceeds concrete's tensile strength will form pieces of concrete fractures that scattered at high speed that usually accompanied with violent noise. Structural collapse due to substantial loss of serviceability may occur potentially from fire in buildings which not only causes injury but also the loss of lives of occupants and emergency rescue teams [5]. HPC has also been identified as type of concrete to experience dramatis palling failure when exposed to relatively rapid heating of above 1°C/min [6]. Even though HPC has been known to provide a better durability, the fundamental behaviour of HPC at elevated temperature needed to be understood in order for HPC to be applied as a safe structure. Thus in this study, the behaviour of HPC incorporating of metakaolin (HPCM) and HPC incorporating of metakaolin and garnet (HPCMG) towards high temperature up to 800°C were closely monitored in order to understand the changes and behaviour of these samples. The physical changes and compressive strengths of the samples were observed throughout the study.

2. Materials and method

2.1 Materials

Materials used in this study were ordinary Portland cement (OPC) conforming to BS12: 1991, sand, granite with maximum size of 10mm, garnet with maximum size of 600µm as part of fine aggregates material, metakaolin as part of cementitious material and Glenium Ace 389 superplasticizer. The mix designs for HPC with metakaolin namely HPCM and HPC with metakaolin and garnet namely (HPCMG) are listed in Table 1.

Table 1. Mix Designs.

| Sample | Cement (kg/m ³) | W/B ratio | Metakaolin (kg/m ³) | Granite (kg/m ³) | Sand (kg/m ³) | Garnet (kg/m ³) | SP (kg/m ³) |
|--------|--------------------------------|--------------|------------------------------------|---------------------------------|------------------------------|--------------------------------|----------------------------|
| HPCM | 513 | 0.32 | 57 | 985 | 535 | - | 0.015% |
| HPCMG | 513 | 0.32 | 57 | 985 | 267.5 | 267.5 | 0.015% |

2.2 Methodology







Both HPCM and HPCMG samples were prepared in cubes of 100 x 100 x 100mm sizes with 10 samples of HPCM and HPCMG each. All the samples were removed from the mould after 24 hours and were cured in water for 14 days before the samples were continued to be air cured in the laboratory for another 14 days before the samples were tested. After 28 days, the samples were tested for elevated temperature test. Both samples of HPCM and HPCMG were placed in the furnace with steady thermal condition of 7°C/min at 200°C, 400°C, 600°C and 800°C. After one hour duration in the designated heat, the samples were removed from the furnace and to be let cool in the room temperature before the samples were monitored for physical changes and compressive strength test.

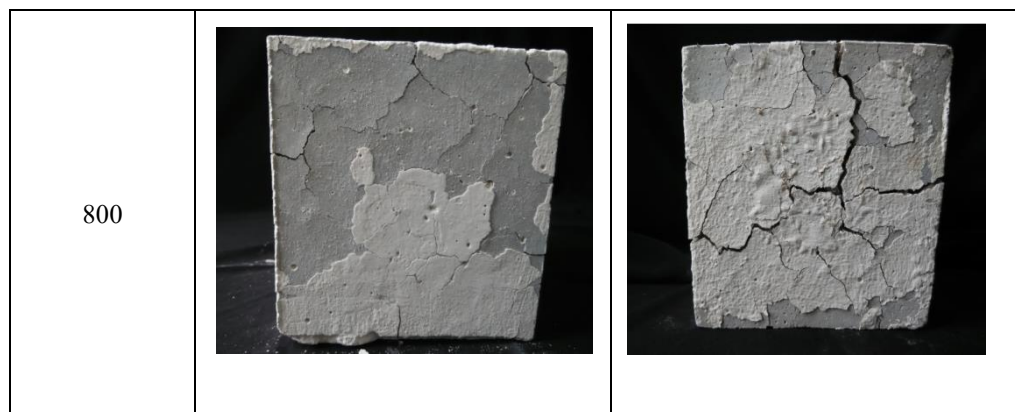
3. Experimental Results

3.1 Physical Changes

All the samples were evaluated for their physical changes after they were exposed to elevated heat and the changes were recorded in the Table 2.

Table 2. Physical Changes of Samples.

| Temperature | HPCM | HPCMG |
|-------------|---|--|
| 200 |  |  |
| 400 |  |  |
| 600 |  |  |



As can be reviewed from Table 2, the appearance of cracks increased for both HPCM and HPCMG. At 200°C, the appearance of fine cracks has been identified for both HPCM and HPCMG. However, the fine cracks appeared in HPCMG were longer as few fine cracks were connected compared to individual cracks appeared in HPCM sample. At 400°C both HPCM and HPCMG colour of samples changed to brownish and appearance of additional fine cracks were spotted. When the samples were exposed to 600°C, the fine cracks were more visible especially in the sample contains garnet, HPCMG. The fine crack lines were connected to each other and fragmented compared to HPCM. Severe damage were noted in both samples when they were exposed to 800°C especially HPCMG as massive cracks were detected with the maximum opening gap of 17.54mm which showed early sign of spalling to occurred. This indicated that HPCMG has lower fire resistance compared to HPCM as major physical changes happened after exposed to the elevated temperatures. As the pore pressure in the samples increased as heat increased, thus making the vapour pressure continue to increase to the limit where internal stresses exceeded tensile strength of HPC thus resulting in cracks and spalling [6]. Due to higher compactness of HPCMG which leads to higher stresses caused by the heat, a greater amount of cracks and severe damage were recorded compared to HPCM.

3.2 Compressive strength

Compressive strength of both samples of HPCM and HPCMG were observed after the samples were exposed to the heat up to 800°C. Figure 1 showed the compressive strength of HPCM and HPCMG samples after been exposed to the stated temperature.

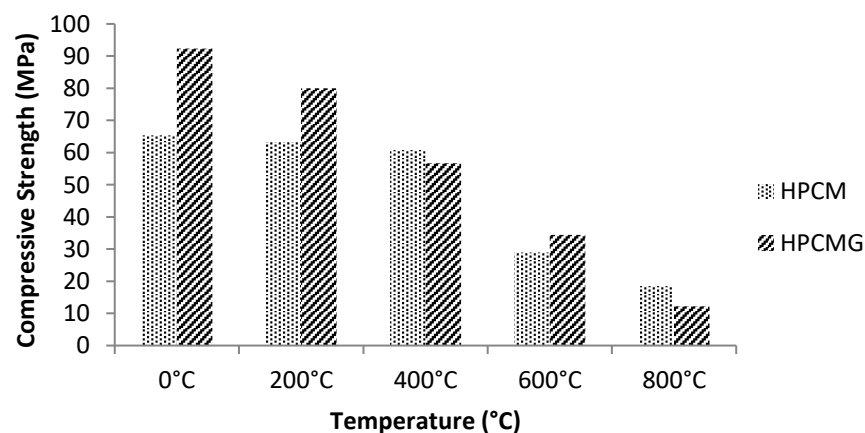


Figure 1. Compressive Strength After Exposed to Elevated Temperature.

Figure 1 indicated that both samples recorded continuous loss of strength as the temperature continuously increased until 800°C. Compressive strength of HPCMG were reduced from 92.28MPa to 12.22MPa at 800°C which marked the loss of strength by 86.8% while the strength loss noted in HPCM was 71.8% at the same temperature from 65.37MPa to 18.44MPa. The loss of strength also can also be visualized from the physical changes that had been discussed earlier that showed the major deterioration happened when the samples were heated to 800°C. The decrease of strength for both HPCM and HPCMG has been identified at the temperature of 200°C. One of the factors that had been identified to contribute to the scenario is the chemical degradation of the cement paste that mainly starts from 180°C [7]. The process of dehydroxylated $\text{Ca}(\text{OH})_2$ and dissociation of CaCO_3 to CaO and CO_2 accompanied with re-crystallisation of non-binding phases from hydrated cement occurred at 600°C to 800°C which is known as the collapsed of structural integrity and loss in compressive strengths [8]. These results compromised to previous researches conducted by applying several materials in their mix namely metakaolin, silica fume and fly ash which stated the range of strength loss of 63.8% to 88.3% [5,6,9].

3.3 Percentage of weight loss

Weight and of both HPCM and HPCMG were also observed before and after elevated temperature test. The losses of sample's weight were indicated in the Figure 2.

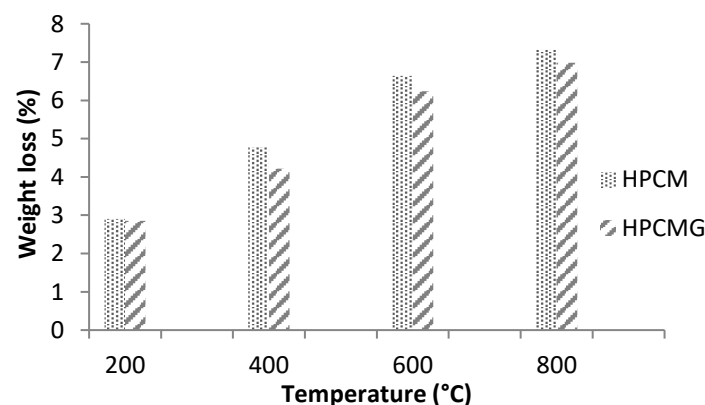


Figure 2. Weight Loss Percentage of Samples.

After been exposed to elevated temperature, the weight losses of HPCM and HPCMG at 200°C were 2.9% and 2.85%. At 400°C the weight loss of HPCM was 4.78% compared to HPCMG with 4.22%. The trend of weight loss was also similar for temperature of 600°C and 800°C where HPCM indicated higher weight loss of 6.64% and 7.32% compared to 6.24% and 6.98% for HPCMG. When exposed to the higher temperature of 600°C and 800°C, moisture content from fine pores of cement paste and aggregates will be lost thus contributing to weight loss of the samples. The dehydration of hydration product (C-S-H) structure was also a factor for the weight loss. The result obtained in this study was similar to the study by Mohammad in 2018 stated that concrete consists of spent garnet indicated lower weight loss in elevated temperature test as spent garnet is more stable at higher temperature compared to fine aggregates [8].

4. Conclusion and suggestion

1. The paper presents the behaviour of HPCM and HPCMG in terms of physical changes, compressive strengths and weight loss when exposed to elevated temperature that exceeded 800°C.
2. The physical changes observed in the study showed that HPCMG to be less fire resistance compared to HPCM. This is due to the higher degree of compactness in HPCMG thus increased the stress generated from the heat to exceed the tensile strength of the concrete. This can be clearly seen in

the HPCMG sample that been heated at 800°C consisted of massive cracks which indicated early sign of spalling as compared to HPCM at the same temperature which showed less deterioration. However, there were no sign of explosive spalling occurred during the study.

3. Even though HPCMG which contributed to higher compressive strength compared to HPCM, it showed total loss of strength much higher than HPCM up to 86.8% compared to 71.8% when heated to 800°C.

4. The weight losses of HPCM were higher compared to HPCMG.

5. The data gained in the study are in the good agreement as previous experimental studies.

6. In order to understand the behaviour of the samples thoroughly, microstructure test are essential to be conducted as this will enhance the understanding of behaviour changes when the samples were exposed to heat.

5. References

- [1] ACI Committe 318 2005, Building code requirements for structural concrete (*American Concrete Institute, Framington Hills, Michigan*)
- [2] P.K Chang, Y.N. Peng, C.L. Hwang 2001, A design consideration for durability of high-performance concrete, *Cement & Concrete Composites* vol 23, p375-380
- [3] Y.N Chan, X. Luo, W. Sun 2000, Compressive strength and pore structure of HPC after exposure to high temperature up to 800°C, *Cement and Concrete Research* vol 30, p247-251
- [4] M.Bastami, A. Chaboki-Khiabani, M. Baghbadrani, M.Kordi 2011, Performance of high strength concretes at elevated temperatures, *Scientia Iranica A* vol 18(5) ,1028-1036
- [5] C. Khananji, F. Ali and A. Nadjai 2016, Explosive spalling of ultra-high performance fibre reinforced concrete beams under fire, *Journal of Structural Fire Engineering* vol 7, pp328-348
- [6] L.T Phan, J. r. Lawson, F. L. Davis 2001, Effects of elevated temperature exposure on heating characteristics, spalling and residual properties of high performance concrete, *Materials and structure* vol 34, p83-91
- [7] M. Tsimbrovska, P. Khalifa, D. Quenard, J.F Daian 1997, High performance concretes at elevated temperature : permeability and microstructure, *Int Association For Structural Mechanics In Reactor Technology* 5, pp 475-482
- [8] Kishor Kulkarni 2011, An Overview of High Performance Concrete At Elevated Temperatures, *Int Journal of Engineering and Technology* 1(1), 48-60
- [9] Chi-Sun Poon, Salman Azhar, Mike Anson, Yuk-Lung Wong 2001, Performance of metakaolin concrete at elevated temperatures, *Cement & Concrete Composites* vol 25, pp83-89
- [10] Mohammad Iqbal Bin Khiyon 2018, *The Effects Of Spent Garnet In High Strength Concrete Subjected To Elevated Temperature*, Universiti Teknologi Malaysia, p116