2022 Scienceline Publication

Journal of Civil Engineering and Urbanism

Volume 12, Issue 2: 14-19; June 25, 2022

ISSN-2252-0430

DOI: https://dx.doi.org/10.54203/jceu.2022.3

Study on Compressive of Plypropylene Fibre Concrete at Abnormally Hight Temperature

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RESEARCH ARTICLE

PII: S225204302200003-12

Received: December 06, 2021

Revised: May 25, 2022

Accepted: May 29, 2022

ABSTRACT

The concrete structures will absorb temperature when it is exposed to fire or explosion incident. Depending on the period of time of the absorbtion process, its' temperature could reach over a few hundreds to less than a thousand degrees Celsius, this abnormally high temperature could affect negatively on its. Assessing the bearing capacity of the concrete after the accident is necessary for the structure's safety. This article investigated the compressive strength of two types of concrete (polypropylene fiber concrete and plain concrete – control concrete) that are burned in conditions at three temperature levels (500^{o}C, 700^{o}C, 900^{o}C) and during three periods of burning time (60', 120', 180'). The research results showed that: the fire incidents affected seriously on the compressive strength of both types of concrete; the greatest decrease of the compressive strength is about 70%; the compressive strength of polypropylene fiber concrete decreases with a rate higher than that of ordinary concrete, but their values are not much different.

Keywords: Abnormally high temperature; Burning temperature; Fibre concrete; Polypropylene fibre; Compresive strength.

INTRODUCTION

There were some researches on the strength of concrete subjected to high temperatures, including some remarking results (Georgali and Tsakiridis, 2005). According to Green (1972); Albrektsson et al. (2011); and Fletcher et al. (2016), the elastic module of concrete subjected to high temperatures is reduced by 25% at 400^{o}F, by 55% at 800^{o}F, by 70% at 1400^{o}F. When the temperature growed up highly, cracks usually occurred at a rapid rate and often parallel to the concrete surface, even some aggregates were broken or exploded outwards. Also, when concrete subjected to high temperatures, not only its physical properties such as expansion but its chemical components were changed; at a temperature within 100 ÷ 140^{o}C, the concrete would lose water or cause an accumulation of pressure; at the temperature around 400^{o}C, calcium hydroxide in the cement would cause concrete cracking. Awoyera et al (2014), stated that when the concrete is subjected to the temperatures above 600^{o}C, its strength would be reduced by about 70%. Concrete is still safe to use at the temperature from 450 ÷ 500^{o}C. The study also showed that, at that temprature the moisture of concrete would be removed by high temperture and cracks appeared due to expansion, but the structure was still guaranteed. In fact, the resrearch results on highly thermal impact on the tolerance of concrete were all given from scientific experiments and analysis results, however the number of experiments were still limited. Therefore, there would be still many problems that need further researches to reach the conclusions more definitive and more comprehensive.

This study aimed to investigate the compressive strength of two types of concrete (polypropylene fiber concrete and plain concrete – control concrete) that are burned in conditions at three temperature levels (500^{o}C, 700^{o}C, 900^{o}C) and during three periods of burning time (60', 120', 180').

MATERIAL AND METHODS

Materials

The materials used for the concrete mixes of research included: binder, fine aggregate, coarse aggregate, water, and fibre reinforcement. Their technical properties were detailed as follow: The binder was Portland cement PCB-40 manufactured in Vietnam. The fundamental technical properties of the cement shown in Table 1 were in accordance with Vietnam standard TCVN 2682 (2009).

To cite this paper: Van Thanh D, Van Tinh Ph, and Thinh Cd (2022). Study on Compressive of Plypropylene Fibre Concrete at Abnormally Hight Temperature. *J. Civil Eng. Urban.*, 12 (2): 14-19. DOI: https://dx.doi.org/10.54203/jceu.2022.3

The fine aggregate was yellow sand and the coarse aggregate was crushed stone. Both of them were produced from local sources in Hanoi city, Vietnam. Their technical properites complied with Vietnam Standard (TCVN 7570, 2006). The water was clean and its quality complies with the requirements specified in Vietnam Standard (TCXDVN 302, 2004). The fibre reinforcement was the Polypropylene fibre. Its fundamental specifications and images were shown in Table 2 and Figure 1.

Table 1. Typical properties of cement PCB-40

N^o	Typical properties	Request
1	Compressive strength	
	3 days (± 45 minutes)	≥ 21 N/mm^2
	28 days (± 8 hours)	≥ 40 N/mm^2
2	Setting time	
	Initial	≥ 45 min
	Final	≤ 375 min
3	Fineness:	
	The amount of 0,09mm sieve	≤ 10 %
	Blain rate	≥ 2800 cm^2/g

Table 2. Properties of Polypropylene fibre

Properties	Value
Density	0.91 g/cm^3
Ultimate elongation	15%
Diameter	18 ÷ 48μm
Fibre length	6 ÷ 19mm
Melting point	160 ÷ 170^{0}C
Tensile strength	≥ 460Mpa
Resistance to acid and base	Good
Young's modulus	≥ 3.5GPa
Water absorption	N/a
Health risk	Safe, non-toxic

Figure 1. Polypropylene fibre

Study plan

Combining both of theoretical calculation methods and experiment to design the basic components of concrete. Based on actual conditions, the tested sample groups were set up for two influencing factors: burning temperature and burning time at distinct levels. Using the furnace to heat the sample groups at 3 high temperature levels respectively: 500^{o}C, 700^{o}C and 900^{o}C; during in 3 time intervals respectively: 60 minutes, 120 minutes and 180 minutes. The tested sample groups were shown in Table 3. After the samples had been heated, their compressive strength were determined immediately in a period of time not longer than 3 minutes.

Table 3. Plan for test sample groups

N^o	Sample notation: Fibre concrete	Sample notation: Control concrete	Temperature ^{0}C	Time, minute
1	M_s-500-60	M-500-60	500	60
2	M_s-500-120	M-500-120	500	120
3	M_s-500-180	M-500-180	500	180
4	M_s-700-60	M-700-60	700	60
5	M_s-700-120	M-700-120	700	120
6	M_s-700-180	M-700-180	700	180
7	M_s-900-60	M-900-60	900	60
8	M_s-900-120	M-900-120	900	120
9	M_s-900-180	M-900-180	900	180

M_s - fibre concrete; M - control concrete; 500, 700 and 900 - temperature levels at 500^{o}C, 700^{o}C and 900^{o}C; 60, 120 and 180 - periods of burning time 60 ', 120' and 180 '.

Compressive strength test

The determination of the compressive strength of concrete was performed according to Vietnam standards (1993): the shape of concrete samples was 10cm-edge cube. The hydraulic press machine used for compressive strength test is shown in Figure 2.

Figure 2. Hydraulic pressure machine used for compressive strength test

RESULTS AND DISCUSSION

Concrete mixture selection

B15 grade concrete used as the target design for both of fibre concrete and control concrete. The polypropylene fibre content used for $1m^3$ of concrete was 1.6 kg (Van Thanh et al., 2016). The design of concrete mixture followed the method combinated from experiment and theoretically calculation (Duy Huu et al., 2011); designed results were shown in Table 4.

The testing results

The testing results express the effects of burning temperature and burning time on compressive strength of fibre concrete and control concrete were shown in Table 5 and Table 6.

Analyzing the effects of burning temperature and burning time on compressive strength

Based on the experimental results, the effects of the burning temperature that is during each burning time period on the compressive strength of two concrete types were depicted from Figures 3 to Figures 5.

The effects of burning time period that was at each burning temperature level on the compressive strength of two concrete types are shown from Figures 6 to Figures 8.

From the experimental results and the graphics showed that: the higher the burning temperature was or the longer the burning time was, the strongly the compressive strength of the concrete decreased. Comparing with the compressive strength of the same concrete type not burned at the 28 day-age (Table 4), the minimum reduction was at 500^oC burning level and during 60 minute burning period while the maximum reduction was at 900^oC burning level and during 180 minute burning period. The minimum reduction was 29.68% (from 21.8MPa to 15.33Mpa) with control concrete and 35.13% (from 23MPa to 14.92MPa) with fibre concrete. The maximum reduction was 68.62% (from 21.8 MPa to 6.84Mpa) with control concrete and 71.41% (from 23MPa to 6.58Mpa) with fibre concrete.

The influence of burning temperature could be explained: the abnormally high temperature is not good for the normal performance of concrete as well as many other materials. At the burning temperature, the linking water in the cement stone will be separated causing that leads the cement stone to shrink. Consequently, the cracks appear; the higher the temperature, the faster the destruction; the structure of the concrete will be damaged.

The influence of the burning time period can be explained: when the concrete encounters high temperatures, during the first time the outermost layer of the structure is damaged, it forms a porous membrane that insulates and hinders the thermal process transmitted inward. However, this effect is only guaranteed during a certain period of time. When the burning temperature is active for a long time, the effect of the membrane will become meaningless; high temperature will gradually spread deep into the concrete structure and damage the cement stone bond (Georgali and Tsakiridis, 2005); therefore, the concrete strength will be fallen off rapidly.

From the experimental results and the graphics showed that: under the effect of burning temperature and burning time period, the compressive strength decrease of the non-fibre concrete samples is smaller than that of fibre concrete samples. However, they were still approximately the same. This could be explained by two reasons:

Firstly, the heat resistance of polypropylene fibres is poor with melting temperature below 200^oC (Table 2). Therefore, when the temperature rises for a long time, the fibre will melt, break, and so on. That not only makes reinforcement effect of fibre lose, but also creates small gaps (left by the molten fibre) interleaved and widely distributed within the concrete. For a certain extent, these gaps will reduce the bearing capacity of the concrete. However, because the fibre content used is not large and the space left is not much, the impact level was also negligible: the test results (tables 5 and 6) showed that in the same burning condition the average compressive strength of fibre concrete samples decreases more than that of the plain concrete samples. Howerver, these reductions are approximately equal.

Secondly, the initial compressive strength of fibre concrete is higher than that of plain concrete (23MPa and 21.8MPa) because of the reinforcement properties of fibre. But, the fire resistance strengths of the two concrete types were not distinct (according to the results of the experiment and analysis mentioned above). Therefore, the fibre concrete would have a higher rate in strength reduction after burning.

The effect of burning temperature and burning time period on the tolerance level of fibre concrete and control concrete could often be described by the synthesis graphic shown in Figure 9.

From the graphic in figure 9, it is easy to see that: the temperature and time period of fire greatly affect the compressive strength of both types of concrete. At different levels of burning temperature and burning time period, the compressive strength of polypropylene fibre concrete is always smaller than that of control concrete; however, the difference was not much. Through this, it could be seen that the use of reinforced polypropylene fibre in concrete would not significantly affect on the reduction of the compressive strength of the concrete structure when the building was burned.

Table 4. The designed result of fibre concrete and control concrete

Items	D (kg/m^3)	S (kg/m^3)	C (kg/m^3)	W (l/m^3)	P (kg/m^3)	R_b (MPa)
Control concrete	1197	747	300	210	0	21.8
Fibre concrete	1197	747	300	210	1.6	23.0

D= coarse aggregate; S= fine aggregate; C= cement; W= water; P= polypropylene fibre; R_b= compressive strength of concrete at 28-day age.

Table 5. The results of the test on polypropylene fibre concrete

N^o	Sample notation	Compressive strength, Mpa			
		Sample 1	**Sample 2**	**Sample 3**	**The average**
1	M_s-500-60	14.29	14.79	15.68	14.92
2	M_s-500-120	12.80	13.10	13.33	13.08
3	M_s-500-180	11.13	11.31	12.07	11.50
4	M_s-700-60	12.11	12.32	11.65	12.03
5	M_s-700-120	11.13	10.74	9.90	10.59
6	M_s-700-180	9.01	9.58	9.23	9.27
7	M_s-900-60	9.02	8.87	9.21	9.03
8	M_s-900-120	7.16	7.50	7.42	7.36
9	M_s-900-180	6.15	6.87	6.71	6.58

Table 6. The results of the test on control concrete

N^o	Sample notation	Compressive strength, Mpa			
		Sample 1	**Sample 2**	**Sample 3**	**The average**
1	M-500-60	14.36	15.78	15.85	15.33
2	M-500-120	13.25	14.68	13.85	13.93
3	M-500-180	11.66	12.18	11.25	11.70
4	M-700-60	13.22	12.85	12.86	12.98
5	M-700-120	11.42	10.75	11.37	11.18
6	M-700-180	9.79	9.14	10.03	9.65
7	M-900-60	9.16	9.28	9.36	9.27
8	M-900-120	7.12	7.98	7.51	7.54
9	M-900-180	6.94	7.31	6.27	6.84

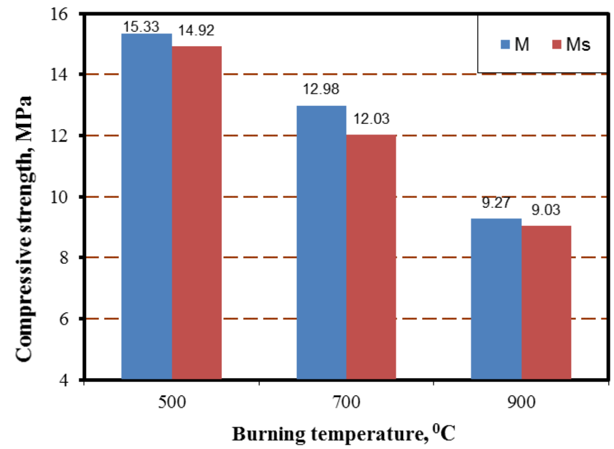

Figure. 3. The relationship between burning temperature and compressive strength when burning time period is 60 min

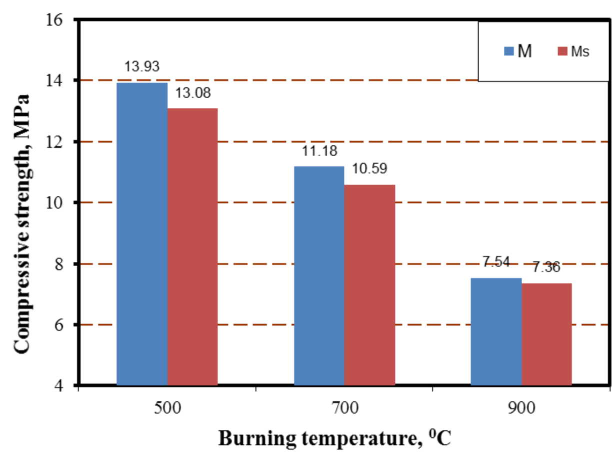

Figure. 4. The relationship between burning temperature and compressive strength when burning time period is 120 min

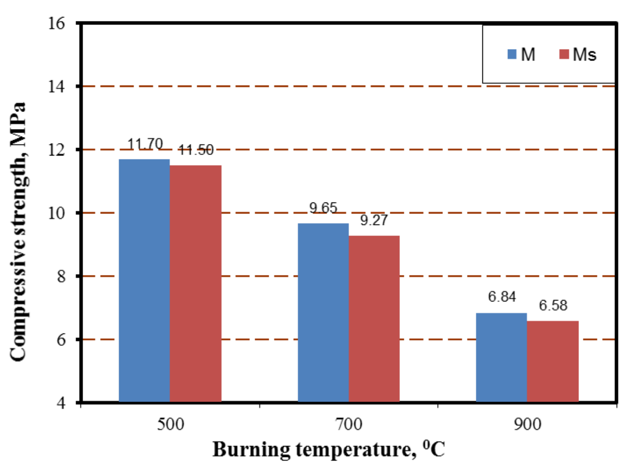

Figure. 5. The relationship between burning temperature and compressive strength when burning time period is 180 min

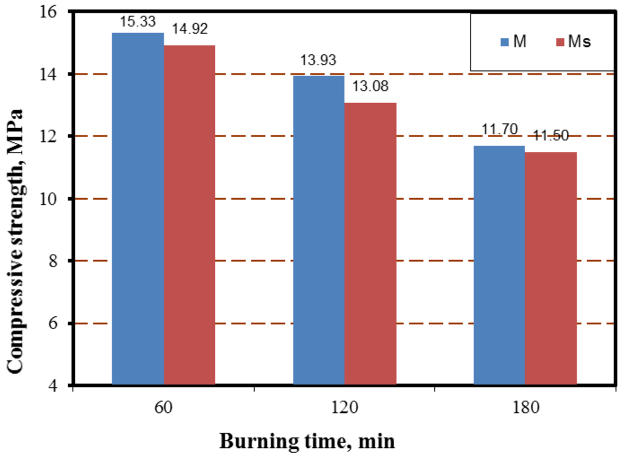

Figure. 6. The relationship between burning time period and compressive strength when burning temperature level was at 500^{o}C

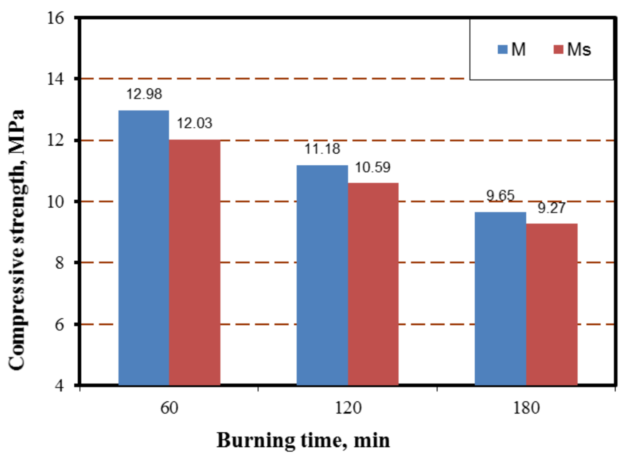

Figure. 7. The relationship between burning time period and compressive strength when burning temperature level was at 700^{o}C

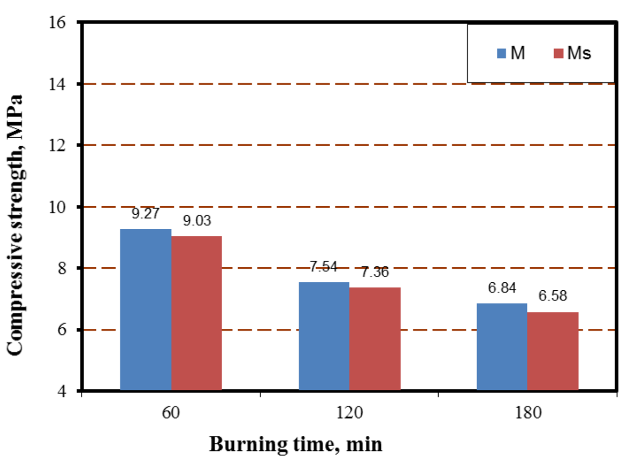

Figure. 8. The relationship between burning time period and compressive strength when burning temperature level was at 900^{o}C

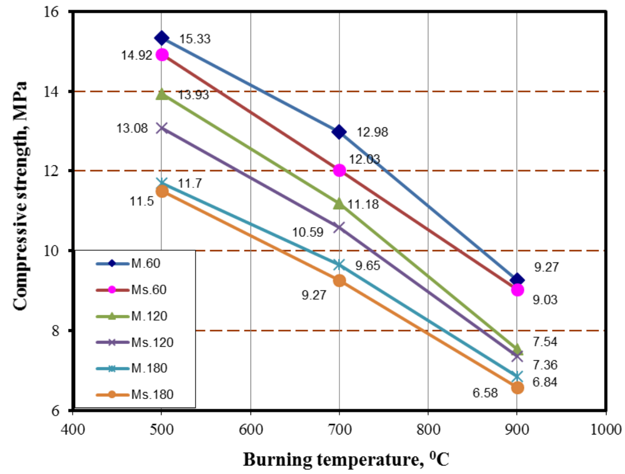

Figure. 9. The synthesis of the relationship between burning time period, burning temperature and the compressive strength of fibre concrete and control concrete

CONCLUSION

Burning temperature and burning time period greatly affect on the compressive strength of the concrete. Under the effect of increasing temperature and time of combustion, the compressive strength of the concrete will decrease drastically. After burning, the compressive strength of fibre concrete is smaller than that of control concrete; howerver the difference is not much. This showed that the use of reinforced polypropylene fibre in the concrete would not significantly affect on the reduction of the compressive strength of the concrete in the structure when the building is burnt.

Within the research limit, with B15 concrete, when the burning temperature is about 500 ÷ 900^{0}C and the burning time period is about 60 ÷ 180', the compressive strength of concrete was reduced by about 30 ÷ 70%. Through this, it is necessary to carefully consider the reuse of bearing structures made of concrete after the work has been burnt.

Competing interests

The authors declare that it has no competing interests.

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