International Balkans Conference on Challenges of Civil Engineering, BCCCE,
19-21 May 2011, EPOKA University, Tirana, ALBANIA.

Impact of Fire Extinguishing Techniques On Concrete Performance

Amr A. Gamal [1]

[1]*Department of Civil Engineering, BENHA University, Cairo, Egypt*

ABSTRACT

The incidence of fire unfortunately occurs quite frequently in buildings. In some cases it causes collapse of the whole structure. Many researches focused on investigation of the effect of fire on concrete strength. Others focused on the effect of concrete constituents on the fire resistance. Our main aim in this study is to try to find the ideal method for extinguishing fire, with minimum damage on concrete performance. (Concrete will be subjected to fire in different cases and different variables).

The test program in this study focused on the effect of economical methods of extinguishing on the performance of concrete. The parameters considered in this study were: Effect of time on concrete under fire (1 hour, 2 hours and 3 hours). Impact of fire on concrete mixed with admixtures (super plasticizers, air entraining, and set retarders). Effect of using different methods of extinguishing the fire,(air cooling, cold water, hot cooling, cement paste) on physical and mechanical properties of concrete performance. The study also considered investigation of the effect of fire on concrete with different types of cement (ordinary Portland cement and Sulphate resistant cement. It was noted that Schmidt hammer presents an effective tool in preliminary assessment of buildings for fire fighters. The use of Ultra sonic pulse velocity was also successful in evaluation of the degree of damage in concrete.

INTRODUCTION

The incident of fire unfortunately takes place quite frequently in buildings. In spite of the growing awareness amongst the public and various efforts by the authorities concerned with safety, [1-4] statistical surveys still indicate an increasing trend in the number of incidents of fire in all of the industrialized countries of the world. The effect of fire is dreadful. Apart from the high risk of human casualties, loss of property and wealth there are other consequences direct or indirect such as disruption of services, loss of business and job interruption etc. All this effect is expressed in economic and structural terms. [5-9]The actual cost for losses runs into astronomical figures. In the United Kingdom alone the direct and consequential losses due to fire are estimated to be in billions of pounds per year based. Extinguishing theory is built on basics of insulating .The options available are either : Cooling by using water, Prevention of the ignition factor (oxygen). CO_2 has a significant effect on the extinguishing process because it decrease the oxygen in the ignition surrounding and its temperature is very low (under zero) helps in absorption amount of temperature of ignition body. After fire the starts with five minutes, the temperature reaches up to 500 °C and it continues to rise up to, 900 °C in one hour and 1100 °C in four hour. Minimum thickness of concrete cover to resist fire should not decrease than the diameter of the largest diameter of used reinforcement. Some advanced research projects also focused on effect of fire on fibers and polymers [10-11].

Material and Methods

In this project Ordinary Portland cement and sulphate resistance cement were used. The test procedure was divided into five groups using different types of cement, (OPC, SRPC, OPC with Super plasticizer, OPC with air entraining admixtures and OPC with Set retarders). Standard concrete cubes (15x15x15 cm) and standard concrete beams (10x10x50 cm) for flexural testing were used in this program. See Table (1).Each test group was further classified to subgroups to investigate different parameters. The first parameter was the duration of exposure to fire. Specimens from each group were subjected to different durations of exposure (1-2-3) hours at 900°C. The results of these groups were compared to (OPC) reference specimens that were not exposed to fire. The second parameter was the method of fire extinguishing using Cool water, boiled water, Cement Past, and Cooling by air, the aim of this study was to investigate the impact of these cheap methods on the physical and mechanical characteristics of concrete. See Fig (1-5).

Table 1 Mix proportions for 1 m^3 Concrete W/C 0.5

GROUP	Firing duration hr	TYPE	C Agg. Kg/m^3	F. Agg Kg/m^3	CEMENT Kg/m^3	WATER Kg/m^3	ADMIX. Kg/m^3
G1-1	1hour	OPC ordinary Portland cement	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	-------
G1-2	2 hours	OPC ordinary Portland cement	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	——
G1-3	3 hours	OPC ordinary Portland cement	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	——
G2-1	1hour	SRC sulphate resistant cement	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	-------
G2-2	2 hours	SRC sulphate resistant cement	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	-------
G2-3	3 hours	SRC sulphate resistant cement	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	-------
G3-1	1hour	(OPC)SUPER PLASTICIZER	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	5.425 Kg/cm^3
G3-2	2 hours	(OPC)SUPER PLASTICIZER	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	5.425 Kg/cm^3
G3-3	3 hours	(OPC)SUPER PLASTICIZER	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	5.425 Kg/cm^3
G4-1	1hour	(OPC)AIR ENTRAINING ADMIXTURE	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	5.425 Kg/cm^3
G4-2	2 hours	(OPC)AIR ENTRAINING ADMIXTURE	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	5.425 Kg/cm^3
G4-3	3 hours	(OPC)AIR ENTRAINING ADMIXTURE	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	5.425 Kg/cm^3
G5-1	1hour	(OPC)SET RETARDER ADMIXTURES	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	5.425 Kg/cm^3
G5-2	2 hours	(OPC)SET RETARDER ADMIXTURES	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	5.425 Kg/cm^3
G5-3	3 hours	(OPC)SET RETARDER ADMIXTURES	1200 Kg/m^3	600 Kg/m^3	350 Kg/m^3	175 Kg/m^3	5.425 Kg/cm^3

Fig 1 ConcreteCubes in furnace

Fig 2 Concrete Beams after firing

Results and Discussion

Experimental results regarding the physical and mechanical properties of concrete for the five groups are presented in what follows. The effect of the above mentioned parameters on the compressive strength, flexural strength, Schmidt hammer and Ultrasonic pulse velocity are discussed in what follows.

Compressive strength Results

Effect of extinguishing techniques.

The general trend within each group indicates that the best performance achieved was that of the reference specimens. This was attributed to the fact that these specimens were not subjected to any internal stresses. Subsequently reference specimens did not suffer from any internal cracks, which was also confirmed by the results of the ultrasonic pulse velocity. The second best performance achieved in groups G1,G2 and G3 was that of specimens cooled by air. In that case the reduction in temperature is very slow and gradual resulting in minimal damage during cooling compared to other extinguishing techniques. For group G4 (OPC with Air entraining admixtures) and group G5 (OPC with set retarders), the second best performance was that of specimens cooled using cement paste. This may be attributed to the fact that the use of air entraining admixtures and set retarders, resulted in the weakest concrete among all groups, combined with the low workability in concrete when using W/C 0.5, this led to larger cracks, introduction of cement paste in that case led to the flow of the cement paste into the cracks and led to a positive effect on improving the performance of concrete cubes, compared to other extinguishing techniques. It was also noted that the general idea of using natural water or hot water for cooling of the concrete resulted in the worst results translated into severe drop in the compressive strength.

Effect of time on compressive strength

The general trend among all groups indicates that as firing time increases from 1 hour to 3 hours the compressive strength continues to drop due to the continuous deterioration in the concrete matrix and further spalling and widening of the cracks, this was also compatible with the flexural strength results.

It is evident from the compressive strength results for G1 (OPC) specimens that, for air cooling sub group, the compressive strength decreased with respect to the reference specimens from (7.1%) after firing for one hour. After firing for 3 hours, the compressive strength decreased by (22.18%) after firing for three hour. When using Cold water for extinguishing, the compressive strength decreased with respect to the reference specimens from (21.4 %) after firing for one hour reaching a maximum by (30%) after firing for three hour. For hot water extinguishing the compressive strength decreased with respect to the reference specimens from (17.8%) after firing for one hour and up to (26.5%) after firing for three hour. For cement paste extinguishing the compressive strength decreased with respect to the reference specimens from (20%) after firing for one hour to (57.7 %) after firing for three hour. The same trend of drop in strength with respect to time was also followed among the other four groups. See Fig (3).

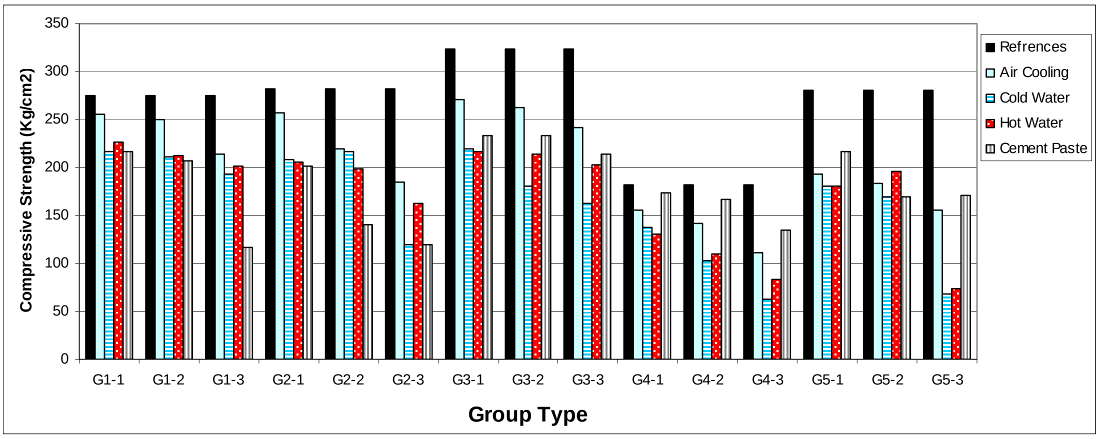

Figure 3 Effect of various extinguishing techniques on compressive strength

Effect of admixtures

The relative comparison between all groups indicates that the best performance achieved was that of specimens in group three (OPC with super plasticizer). This may be attributed to the low workability encountered in other groups; this problem was resolved when super plasticizer was introduced. After firing for one hour the compressive strength ranged from (271-216 Kg/cm2). When specimens were fired for two hours, the compressive strength ranged between (263-180 Kg/cm2). After three hours of firing the compressive strength ranged between (242-162 Kg/cm2). The second best performance was that of G2 specimens with sulphate resistant cement, it seems the existence of super plasticizer in that case improved workability and compressive strength of the concrete matrix. G3 (OPC) specimens showed the third best performance regarding compressive strength. This was followed by group five (retarders) which gave better results tha group four (air entraining). In general most of the specimens for group five ranged from (193-180 Kg /cm2) after firing for one hour. Specimens of the same group fired for two hours gave a strength ranging from (184-170 Kg/cm2). Meanwhile specimens fired for three hours ranged from (156-68 Kg/cm2). The weakest performance encountered among all groups was that of specimens using air entraining admixture, which is due to the nature of this admixture which naturally weakens the concrete cubes in its natural conditions by introducing air bubbles into the concrete. The compressive strength for specimens fired for one hour among this group ranged from (156-131 Kg/cm2). Specimens fired for two hours ranged from (141-103 Kg/cm2). Meanwhile specimens fired for three hours, showed a compressive strength of (135-63 Kg/cm2).

Schmidt Hammer

Schmidt hammer results seem to follow a directly proportional relation ship with the compressive strength, they also provide a good indication of the surface quality of concrete. It was noted that the weaker the Schmidt hammer results the weaker the compressive strength results. It was also noted that as the firing time increases the Schmidt hammer results decreased.

Effect of extinguishing techniques.

The general trend within each group indicates that the best performance achieved was that of the reference specimens. These results were also assured by the results of the ultrasonic pulse velocity. See Figure (4). Air cooling technique maintains to be the best technique for groups G1,G2 and G3. Since the reduction in temperature is very slow and gradual resulting in minimal damage during cooling compared to other extinguishing techniques. The best performance achieved was that of Group 2 specimens (Sulphate resistant cement). Air cooling in this group ranged from (30-22).The second best performance was that of G3 (OPC with super plasticizer), air cooling in this group ranged from(26-23) . For Group1 (OPC) air cooling ranged from (20-18). For Groups 4 (OPC with Air entraining admixtures and Group 5 (OPC with set retarders) cement paste gave more encouraging results. This may be attributed to the fact that the wide cracks created in groups Group 4 and Group 5, enables cement paste to fill into these cracks and also fills the voids created by the spalling of the aggregates, which reflects into a harder concrete surface than the other extinguishing techniques. This does not necessarily reflect that the core of the concrete cube is as strong as the surface. Group 5 showed a better performance than Group 4.

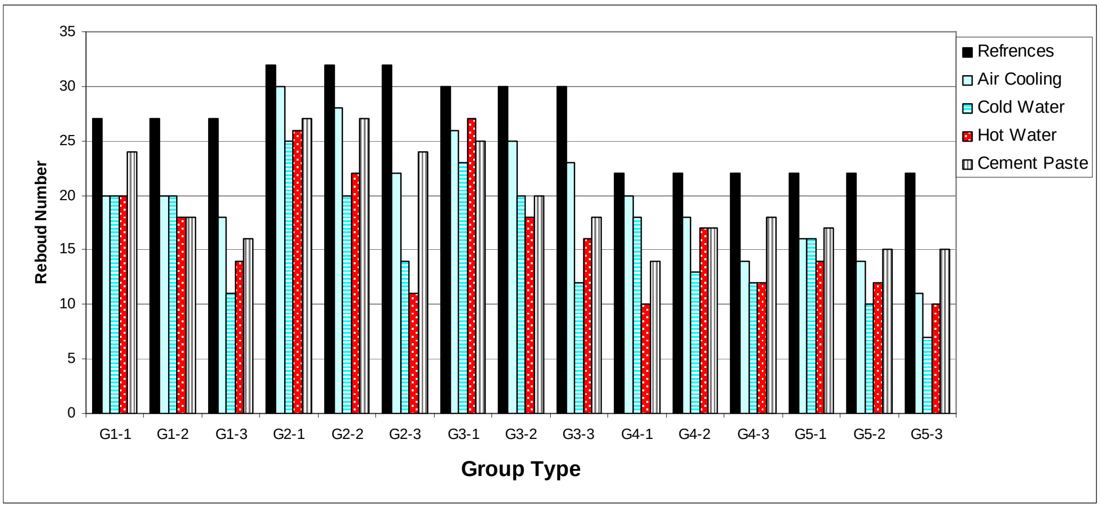

Figure 4 Effect of various extinguishing techniques on the rebound number

Effect of Time on rebound number

It was noted that as the duration of exposure of the concrete specimens to fire increases, the rebound number decreases, which was also in agreement with the compressive strength results. For group 1 after firing specimens for 1 hour the rebound number decreased by (11.1%-25.9%) compared to the reference specimen. As the firing time increased to 2 hours the rebound number decreased to (25.9%-33.3). After firing for three hours the rebound number continues to decreases to reach (33%-59.25%). The same trend of reduction in the rebound number as duration of fire increases from 1 hour to three hours was observed in all groups. Compatibility of the Schmidt hammer results and their ease of use are encouraging factors for setting guide lines for their use before more detailed repair plans are introduced. Even fire fighters may use them before working on buildings.See Figure 4

Flexural Strength

Flexural testing was performed using two point loading. All specimens were test under same conditions. Flexural Strength results showed that the performance of the reference specimens was by far better than the performance of any specimens subjected to fire. The method of extinguishing played a significant role in deterioration of the tensile performance of concrete. The best and cheapest method of extinguishing for all groups was by air cooling. The best performance among all groups was G1-1 and G2-1, which showed was followed by G3-1 . Meanwhile, the weakest performance was that of specimens G4 and G5 fired for three hours.

Most of the specimens after firing for three hours, were not suitable for testing, since they were already damaged. As the duration of exposure of the concrete specimens increased from one hour to three hours, concrete specimens suffered from severe deterioration. See (Fig.5). For group 1 after firing for 1 hour, the ultimate failure load decreased from 27.3%to 54.5%with respect to the reference specimen. For group 2 after firing for 2 hours, the ultimate failure load decreased from 63.6% to 81.8%.After firing for three hours, the ultimate failure load decreased from 81.8% to 97.8%. The same trend mentioned above, was observed in all groups.

Groups (4), OPC with air entraining admixtures decreased from 42.8% to 71.4%. Meanwhile Group (5), OPC with set retarding admixtures Decreased from 28.5 % to 85.7 %. Most of the specimens, which were initially weak in compression, were also not suitable for testing after two hours of firing. The initially weak Tensile Properties of concrete resulted in non conclusive data except for those of reference Specimens which were not subjected to fire. For the case of Reference Specimens it was noted that the flexural performance at room temperature reflected the performance of compressive Strength at room temperature for group two and three (Sulphate resistant cement and OPC with super plasticizer) which showed the best performance among all groups.

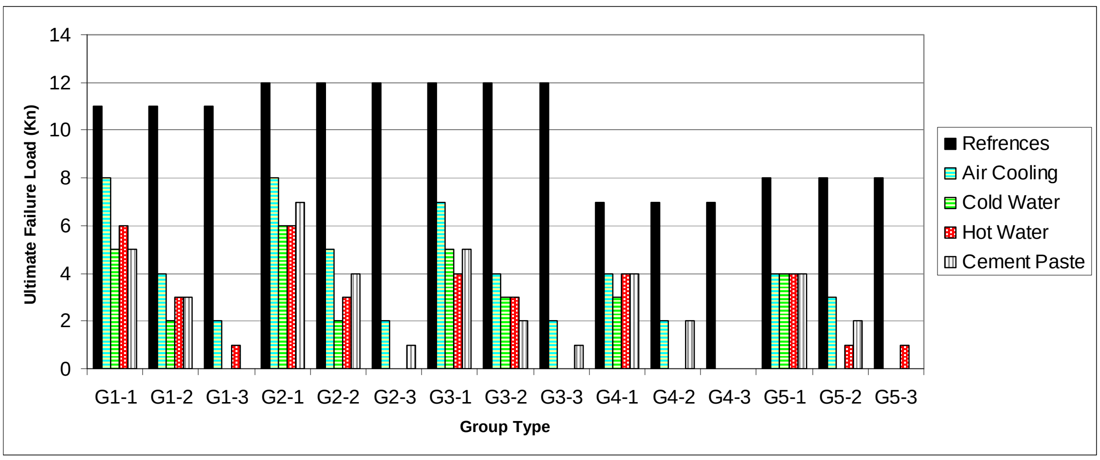

Figure (5) Effect of various methods of extinguishing on Ultimate Flexure failure load

ULTRASONIC PULSE VELOCITY

Standard beams (10x10x50 cm) subjected to ultrasonic pulse velocity testing. Specimens were left for 24 hours before they were tested using Ultrasonic Pulse Velocity. In most of the cases, the best performance among all groups was that of G2 specimens (sulphate resistant cement), which ranged from (114- 700) microseconds depending on the duration of firing and G3 (OPC with super plasticizer), which ranged from (104 -658) microseconds. Concrete specimens of G5, ranged (174- more than 910) microseconds and G4 (192- more than 980) microseconds, showed the weakest performance.

The general trend among all groups indicates that the (UPV) time for reference specimens ranged from (104-192) microseconds, depending on the group type. Air entraining admixtures showed the longest duration. Meanwhile using OPC with super plasticizer showed the shortest time interval of (104) microseconds. This may be attributed to the fact that OPC with air entraining admixtures contains large amount of air bubbles, which reduces the speed of the signal within the concrete. Meanwhile concrete specimens with super plasticizer showed high workability and required minimum effort for compaction resulting in dense concrete as shown by the data of the UPV. In most of the cases, air cooling showed the second best performance after the reference specimens giving a range of (190-617) micro seconds taking into account the duration of firing. The worst performance was that of the cold water cooling which gave a range of (223-above 980) microseconds. Continuous deterioration in the concrete was monitored as the duration of exposure of the concrete specimens increased from one hour to three hours. Ultrasonic pulse velocity was successful in monitoring internal damage occurring in the concrete. See Table (2).

Table 2 Average readings in ultrasonic pulse velocity signal in Micro seconds.

Group	Reference	Air Cooling	Cold Water	Hot Water	Cement Paste
G1-1	135	190	360	252	195
G1-2	135	365	770	274	475
G1-3	135	617	870	500	600
G2-1	114	141	223	190	182
G2-2	114	187	504	205	298
G2-3	114	500	700	455	405
G3-1	104	190	250	191	200
G3-2	104	204	610	222	512
G3-3	104	360	645	470	658
G4-1	192	247	400	294	360
G4-2	192	400	980	397	497
G4-3	192	680	Not available	740	770
G5-1	174	250	515	370	225
G5-2	174	500	942	410	910
G5-3	174	617	not available	740	not available

CONCLUSION

1-Compressive strength indicates that for Ordinary Portland Cement, Sulphate resistant Cement and Ordinary Portland cement with super-plasticizer concrete specimens, the best method of extinguishing was by air cooling.
2- For groups with air entraining admixtures and set retarders cement paste was more suitable.
3-increase in Duration of exposure of concrete specimens to fire, decreased the compressive and flexural strength, with excessive spalling observed and severe damage observed.
4-Schmidt hammer results were compatible with compressive strength testing. It also proved to be an effective tool in preliminary assessment of buildings for fire fighters.
5- Ultrasonic pulse velocity was very effective in providing a distinction between the different extinguishing techniques as well as the variations in performance within each group itself.

REFERENCES

[1] Joint Committee of Institution of Structural Engineers and concrete Society, Design and detailing Of concrete structures for fire resistance, Interim Guidance, London, 1978.

[2] British Standards Institution, CP 110. Part 1: 1972(as a mended 1980). The structural use of concrete, London, 1980, 156 pp + amend (1980).

[3] COMITE EUROPEEN DE NORMALISATION. Pr EN 1992-1-2 Euro code 2: Design of concrete structures. Part 1.2: General rules - structural fire design, Brussels, 2002.

[4] ACI Committee 544, 544.5R-10:" Report on the Physical Properties and Durability of Fiber-Reinforced Concrete". Technical Documents. Document 544510.March 1, 2010.

[5] Abeles P. w. and Bardhan -Roy, B.K., prestressed concrete designer's handbook, 3rd Edn, Viewpoint publication, Eyre & spottiswoode publications Ltd, Leatherhead, , PP.456-571(1981).

[6] Walden.D. (Fire in high-rise building). Poprints from fire journal & fire technology fire protection Association. 470 ATLAIC Avenue, Boston (1974)

[7] KHOURY, G. Effect of fire on concrete and concrete structures, Progress in structural engineering and materials, Vol. 2, 2000.pp.429-447.

[8] PURKISS, J. High-strength concrete and fire, CONCRETE magazine, Vol. 34, No. 3, March 2000, pp.49-50.

[9] Alberto Meda, Pietro G. Gambarova, and Marco Bonomi."High-Performance Concrete in Fire-Exposed Reinforced Concrete Sections". Structural Journal. Document 99-S29. Vol.99. Issue 3 May 1, 2002.

[10] Hui Wang, Xiaoxiong Zha, and Jianqiao Ye. "Fire Resistance Performance of FRP Rebar Reinforced Concrete Columns" ACI IJCSM Document 030205 Vol.3. Issue.2 December 31, 2009.

[11] Venkatesh Kodur, Luke Bisby, and Mark Green ."FRP Retrofitted Concrete under Fire Conditions". ACI Concrete International. Document CI2812 Vol.28 Issue 12 December 1, 2006.