EXPANSION,EXPLOSION AND CRACKING OF SILICATE CEMENT PRODUCTS IN FIRE

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ABSTRACT

In the past,people always thought that the expansion and explosion and cracking of silicate cement products in fire are only the physical phenomenon of the thermal stress and the internal water vaproing. But in fact, the causes of the expansion and explosion or cracking are complex. Through same experiments, we know that the expansion and the explosion or cracking are cused by not only the physical phenomenon which was stated above, but also the complex chemical phenomenon, or both of them on some condition.

This paper introduces the test and research work of expansion and explosion and cracking of steel building elements and materials in fire,the work is one of the fileds of fire endurance studies for reinforced concrete structure and building material, it has been performed from 1972 in Sichuan Fire Research Institute of China. Through the repeated tests under fire condition and theory analysis to various building struc tures and products that main composition is silicate,we discover some regulars of their expansion and explosion or cracking and know their characteristics of physical and chemical change.

This paper indicates because the characteristics of silicate cement products using in building——such as concrete element or fernish plate, is a threat for fire protection and fire fight, we should do more thorough researches to find the basic reason and preventative methods in order to aviod fire spread and fire fighter being wounded due to the products being damaged during fire.

KEY WORDS

Concrete, Silicate, Fire Endurance, Fire Endurance Limit, Rate of Expansion, Explosion, Crystal Lattice, Crystal Phase Transformation.

INTRODUCTION

1. In the reinforced concrete framework construction building, some elements, such as the beam,plate,column, ect, will be heated partly expand under the effects of high temperature caused by fire. These elements will produce compression stress or shearing stress to the elements that are not heated but linked up with, they will produce tensile stress after water

shock or natural cool. Because of these reciprocated effects of contrary directions forces, it further increases the damage by fire to the building.

2. When a fire brigade puts out a large fire of reinforced concrete building,it is frequently that the floor slab bursts and the fire fighters are injured. Because of the explosion and penetration of the floor slab or wall——sometimes the explosion is contiously and the penetration is not in only one place, it causes the fire in the fire room spreadind to the next room or upper floor through the penetration.

Studying the reasons of these two phenomena occured and seeking the means of provention are of very important significance both for building fire protection design and for fire brigade to put out fire.

MAIN BODY

TEST AND ANALYSIS

1. The Expansion of Concrete Elements

In order to get the convincing test, we test the reinforced concrete column in a combustion test furnace,the furnace temperature is controled according to modeling fire, the column is exposed in fire at its four sides and is loaded at the center in vertical direction. Following are detailed condition:

A. Steel Concrete Column

(a). size: $300\times300\times3700$ (mm)

(b). structure: steel reinforcing bar: $4\phi16$ low carbon steel bar,thickness of outer protection layer 20mm concrete: composed of 500# ordinary protland cement, medium grains of sand and pebble with diameter 5–40mm. The mark of concrete is 200, and chemical compositions are shown in table 1.

Table 1 Main Chemical Compositions of the Cement

Compositions	SiO_2	$R_2O_3+TiO_2$	Fe_2O_3	CaO	MgO	Na_2O+K_2O	Loss by burn
Content(%)	47.18	10.72	6.98	19.99	1.82	3.64	9.17

(c). maintenance: the element is matained for 3 months in the house without wall.

B. Loading

The column is vertical installed in vertical test furnace,from its top, at the center, in vertical direction it is given the load 13 tons.

C. Condition of temperature Rise

Selecting the mark–20 diesel oil as the fuel, the fuel is atomized by a nozzle and spreaded into the funace. The column is exposed on fire in its four sides,controlling the temperature of the furnace according to the standard temperature–rise curre (see table 2).

Table 2 Time–Temperature Curre

Time (min)	5	10	15	30	60	90	180	240	360
Temperature (℃)	535	700	750	840	925	975	1050	1090	1130

D. Result and Discussion

Three times in total column tests have been done. Under the condition of 13 Tons load in

column center, the value of expansion is very big. For example, at ten minutes of the test, the furnace temperature is about 680℃, value of linear expansion of the column has up to 6mm. At the same time, the specimen produces the intensive and the clear and melodious sounds, and one chunk (size about 100×50×30mm) of concrete on the edge of column is bursted away. It should be declared that at this time,680℃ is only the furnace temperature (or surface temperature of column), the inner temperature of column is not 680 ℃. Because of the poor thermal conductivity of concrete, there is a big temperature diffence between the surface and the center of column. We have done the temperature measurment test with the same kind of concrete specimen, the result is: for 100×100×100 (mm) specimen, at ten minutes, the furnace temperature is 700 ℃, but the center temperature of specimen is just 55℃,in other words the value of linear expansion of column don't reach its limit. it shows that: the thermal expansion produced by the column is only the effect of the layer from surface to 50mm inner.

When the test is carried out to 240 mintues, the mean value of expansion in three tests is about 35mm, the expansion is up to the limit, then the column shrinks gradually until lost its loading capability.

Table 3 the fire test records of the reinforced concrete column

Record Items		Mean Tem. of furnace (℃)			Linear Exp. Value of Column (mm)			Remark
Test Times		1st	2nd	3rd	1st	2nd	3rd	
	10	683	670	680	6	6	6	
	20	781	755	765	10	10	15	Ie very test, from the begin to 20 min, there are the clear and the continnous burst sounds, after 20 min, there is no burst sound, the column lose their loading capability at 515, 440, 433 min respectively.
Test	30	851	843	840	19	12	18	
	60	928	912	925	28	28.5	27	
	90	977	965	973	32	33.5	30	
Time	120	1008	1010	1010	33.5	34.5	32	
	150	1028	1030	1030	34	34.5	34	
	180	1053	1048	1050	34	34.5	32	
(min)	240	1085	1130	1090	35	34.5	35	
	360	1130	1157	1125	33	29	31	
	420	1150	1160	1138	26	8	19	
	450	1162			23	-22		
	515	1170			-26			

For comparing the expansion values of different materials,we have done two fire endurance tests of brick column under the same condition. Following are test information.

(a) Size of specimen: 370×370×370 (mm)

(b) Manufacturing: ordinary red brick as the construction material,mixed morter(ratio: 1:1:3) as the cohesion agent, nofinishing layer on column, two months natural dry before testd.

(c) Loading: vertical 13 tons

(d) Fire exposure: four sides

The results of test shown in table 4.

Table 4 Fire Records of Brick Column

Test Item.	Test Time	time (min)	30	60	120	180	240	300	360	389.5	390
T (℃)	1st		820	940	1011	1052	1090	1110	1132		1135
	2nd		840	928	1010	1055	1090	1112	1132	1138	
Value of Expansion (mm)	1st		1.1	1.4		0.8	-2.5	-4.5	-11.2		-19.4
	2nd		1.4	1.7	1.4	0.8	-0.8	-3.7	-9	-19.4	

Comparing the fire endurance of two kinds of column, it can be seen clearly that the values of expansion are different due to the different materials. The maximum value of linear expansion of concrete column is 35mm, the rate of linear expansion is 0.95%; the maximum

value of linear expansion of brick column is just 1.7mm, its rate of linear expansion is 0.064%, there is a big difference between them.

These two kinds of columns both follow the rodinary physical principle of "expanding when heated and con traction when cooled" , but the big difference of their expansion values is not only the physical factor but the factor of the difference butween their chemical composition. In general, inorganic nonmetallic materials should finish their physical expansion before reached their fire enduauance limit. After the liquid phase formed, they will squirm contract along the compressed direction,the test results of brick column fire endurance limit is the ample evgidence of it. (see fig.1); for the chemical expansion, the expansion is finished in the range of crystal lattice transformation temperatures. The basic composition of the testd concrete column is quarts sand, under the condition of sharp temperature rising, quarts will produce transformation of crystal phase and produce intension expansion, it is one of its mainly characteristics and is also the basic reason that the concrete column produces so intension linear expansion under fire condition (Table 5). When the test temperature is more than 1000 ℃, the chemical changes of quarts in high temperature have mostly finished, therefor the expansion suspend.

The main composition of machine-made red brick is Al_2O_3, the next one is SiO_2, most of them exit in the form of molai crystal ($3Al_2O_3 \cdot 2SiO_2$), some of Al_2O_3 and SiO_2 molt together and change into glass phase in the process of the red brick calained. For the red brick made column,there is no the chemical expansion existing. This show that the leading factor of concrete element expansion is the chemical expansion produceed by the transformation of quarts crytal lattice.

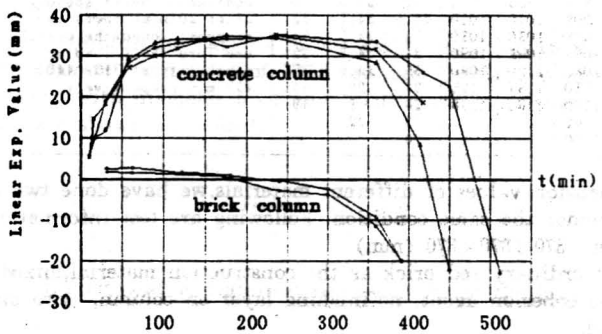

fig. 1 Expansion Curre of Reinforced Column and Brick Column

Table 5 Table of Quarts Crystalphase Transformation

Transformation of Crystal Phase	Transformation Temp.(℃)	Change in Volumn(%)
β Quartz→ α Quartz	573	0.82
Y Scale Quartz→ α Scale Quartz	117	0.2
β Quartz→ α	180~270	2.8
β Scale Quartz→ α Scale Quartz	163	0.2
α Quartz→ α Scale Quartz	870	18
α Quartz→ α	1000	15.4
α Quartz→Quartz Glass	1000	15.5
Glass Quartz→ α	1000	-0.9

2. The Explosion of Concrete Element

It is the common phenomenon that concrete elements explode in fire.Many tests and studies show that beam,column,wall, criling ect which are made of ordinary portland concrete will produce explosin or burst in varying degrees under the fire temperature conditions, but if the elements are specially treated,such as prestressed concrete or nonprestressed porous floor slab, they will not produce explosion and bore holes. in addition, some concrete elements which have loose texture and less unit weight such as aerocrete wall and plate will not produce explosion too. This is because the special production process has destroyed the conditions of concrete explosion under the fire.

Following ordinary portland cement element are easy explosion and boring hole : perfabricated or cast in site concrete floorslab, roofslab, froagh file and asbestos cement ceiling. (Table 6)

Table 6 Test of Element Explosion

Element	Thickness of element (mm)	Time to Explosion	Tem. of Explosion (℃)	Degress of Explosion
Ordinary reinforced concrete floorslab	70	19' after test	600	a chunck of concrete in 700×400×35(mm) volume burst away from the side of explosion to fire
Prestressed reinforced concrete floorslab	20	9'20' after test	700	explosion and bore hole
Prestressed reinforced concrete trough tile	25	5'55' after test	610	explosion and bore hole
Asbestos cement ceiling	6	between 1'30'and 2'30'after test		explosion and bore hole

For exploring the reason of explosion from the charcteristics or materials, we have done the tests of explosion characteristics on the asbestes cement board that main composition is SiO2. Table 7 is the results of test.

Table 7 Explosion Characteristic Tests of Asbesttos Cement Board

Thickness of bound (mm)	Rate of water Content (%)	Times of Test	Times of explosion and bore hole	Times of explosion and cracking
10	12.5	21	5	16
10	10	2	0	2
10	9.5	2	0	2
6	12.5	9	6	3
6	9.6	3	0	3
6	9.1	1	0	1
6	8.2	1	0	1
6	6.9	3	0	3
6	2.6	1	0	1
3	6.9	3	0	3
3	12.5	3	2	1
3	2.6	3	0	3

The results of tests shown that the key reason to produce explosion and boring hole of elements is the rate of water contents. Because the rate of water content is high, the inner water will change into high pressure steam under the effect of high temperature, and when the proessure of steam is higher than the pressure - resistance capability of the materials,it certainly produced the intense explosion. If the board is thicker, it is not easy to be penetrated by explosion; but if the borad is thinner, it is easy to bebored holes by explosion.

From the explosion tests of the asbestos cement boards with different rate of water content,we can seet hat when the rate of water content is less than 10 percent,it will not produce holing explosion. The another certificated fact is that the burst of silicate products is independent of the rate of water content, no matter the rate of water content high or low, will produce brittleness burst, the basic reason for this is under the intense temperature rising condition, the intrinsic crytal lattic of SiO_2 is destroyed and another crytal lattic is is formed rapidly, this process will produce crevices coercively, and at the same time gives out the clear and melodiose burst sounds, the volume expand with this process. The faster of the temperature rising,the faster of the transformation, the larger of the expansion. The burst phenomena of every test is accordance with this characteristic of siliceous building materials, we manufactured the walls with the blue store that the silicon content is more than 95 percent, and done the fire endurance tests under the fire condition. After the test 2 to 3 minutes, on the surface of the walls give out the intensive and clear and melodious burst sounds. When the test goes on to 7 to 10 minutes, and the furnace temperature is about 700℃,the blue stones produce burst explosion and the crushed stones burst in disorder in the furnace. Several times blue stone walls tests had to suspend because the thermocoples in the furnace are bricken up by the crushed stones.

CONCLUSION

1. The leading factor of silicate cement products expansionis the crytal phase chemical changes of the inner silicate materials at high temperature.
2. The leading factor of silicate cement products explosion is the physical effects that are caused by the process that the physical water retained in the products becomes the high pressure steam at high temperature.
3. The cracking phenomenon of silicate cement products is created by the crytal phases chemical changing which is caused by SiO_2 crytal phase transformation at high temperature.

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