Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 10 (1976)

Artikel: Experimental study on explosive spalling of lightweight aggregate concrete in fire

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DOI: https://doi.org/10.5169/seals-10441

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Experimental Study on Explosive Spalling of Lightweight Aggregate Concrete in Fire

Etude expérimentale de l'écrasement du béton d'agrégats légers dans un incendie

Experimentelle Untersuchung über explosionsartiges Ausplatzen von leichtem Beton in Brandfällen

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1. Introduction

The fire resistance of a structural concrete element is defined as a time, being the period for which an identical test specimen complies with prescribed requirements when subjected to specified conditions of heat and load, and an actual assessment is in accordance with a testing method, JIS (Japanese Industrial Standards) A 1304, in Japan.

The typical performance criteria in this testing method are temperature of steel reinforcement in the element, deformation, surface temperature of unexposed side etc., consequently, all designing of fire resistance is based on the criteria.

To discuss the fire resistance of structural concrete element, however, the phenomenon of explosive breaking off or spalling of concrete in fire cannot be excluded, which has been regarded considerably important especially in lightweight aggregate (expanded shale) concrete. The investigation into the cause of this phenomenon seems not enough so far to make a real performance evaluation of concrete element. In this context an experimental investigation was made under the simulated condition of fire pertaining to the expected three main factors on the spalling, property of aggregate, amount of free water in concrete and mechanical restraint.

2. Factors Regarded

2.1 Type of aggregate

It has been said that the property of aggregate at elevated temperature can be linked up directly with spalling of concrete.(1)

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4 types of aggregate were selected in this experiment on the basis of their property at elevated temperature, i.e. heat resistance, both for ordinary aggregates (N,N') and for lightweight ones (L,L'). N and L are aggregates having rather high heat resistance, N' and L' having lower one. Heat resistance of aggregate was defined as a ratio of number of damaged particles in the total by counting when exposed to an atmospheric condition at 800°C for 30 minutes in an electric oven (1). Heat resistance of selected aggregates is shown in Table 1 with other properties.

Table 1 Properties of Aggregates

Aggregate and its nomination \ Properties			Heat resistance	Specific gravity	Water absorption (24hr)	Water absorption (when used)	Fineness modulus
Coarse Aggregate	Ordinary	N	7.2 - 10.0	2.63 - 2.65	0.7 - 0.9	0.7 - 0.9	6.59 - 6.66
		N'	10.0 - 19.8	2.63	0.8 - 1.0	0.8 - 1.0	6.50 - 6.59
	Lightweight (Expanded Shale)	L	3.0 - 5.0	1.22 - 1.28	11.5 - 12.2	21.2 - 25.1	6.36
		L'	13.0 - 20.0	1.23 - 1.30	8.4 - 8.5	11.2 - 25.2	6.39 - 6.51
Fine Aggregate	Ordinary		-	2.55 - 2.57	1.8 - 2.1	1.8 - 2.1	2.80 - 3.34
	Lightweight (Expanded Shale)		-	1.53 - 1.59	13.9 - 17.1	11.2 - 19.0	2.77 - 2.92

2.2 Amount of free water

Increase of water vapour pressure can be naturally considered to give the influence of spalling (2), therefore, the amount of free water in concrete was controlled in the range of 60 to 180kg per cubic meter of concrete.

Specified level of free water in test panels (as in 3.1) could be obtained being cured for ten days, sealed by polyvinyl sheets after concreting in laboratory, for ensuring a uniformity of strength behaviour of all panels, and air dried at room temperature.

Panels necessary to be decreased the level of free water, they were dried at an atmospheric condition at 70 to 80°C until the specified level, following above curing conditions.

Amount of free water was determined by the direct measurement of weight change of concrete blocks, 30 x 30 x 6cm, made of the same batch and cured under the same condition as each panel, of which four sides were sealed for prevention of evaporation.

2.3 Restraint condition of test panel

The restraint condition (3) was divided into four levels according to diameter of reinforcing bars (deformed) in the ribbed part of test panel classified as D-10, D-13, D-19 and D-22, the number after each hyphen stands for nominal diameter in mm..

3. Test Panels and Fire Test

3.1 Test panels

Dimension of test panels were 1m x 1m x 6cm made of reinforced concrete surrounded by 12 x 12cm ribs, as shown in Fig. 1.

Concrete used was divided into 4 types (N, N', L, L') according to the types of aggregate, each having cement content 340 to 350kg/m^3 (ordinary portland cement), slump about 18cm and water cement ratio 50%.

3.2 Fire test

Fire tests were made by means of the furnace as shown in Fig. 2, which can get the Standard time/temperature curve (Fig. 3) as specified in JIS A 1304, Method of Fire Resistance Test for Structural Parts of Buildings, the period of heating was 60 min..

All the series of tests were conducted at Fire Test Laboratory of Building Research Institute.

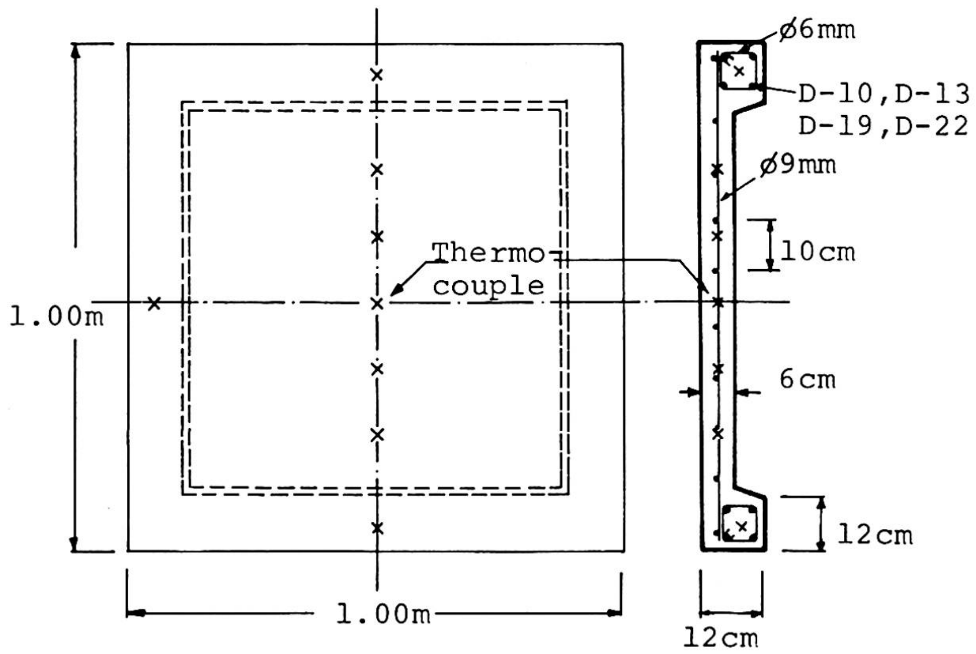


Fig. 1 Test panel

Fig. 2 Furnace for fire test

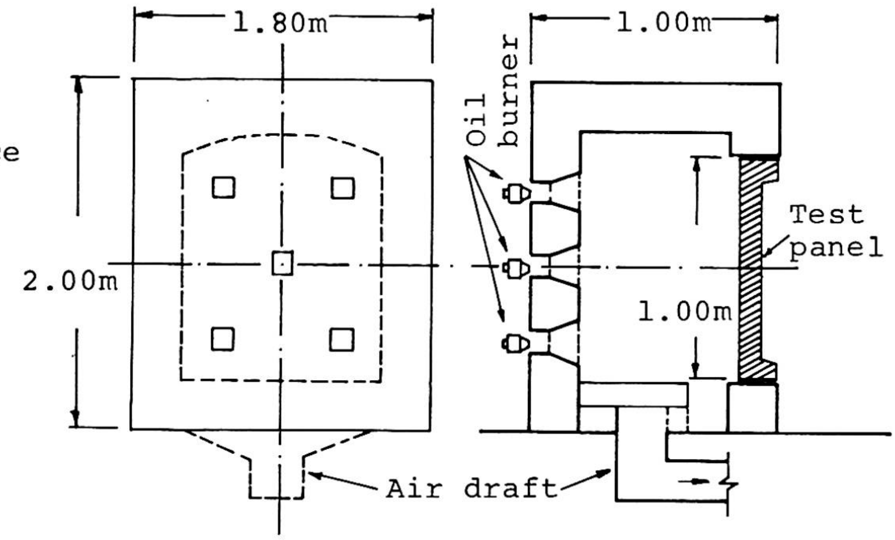
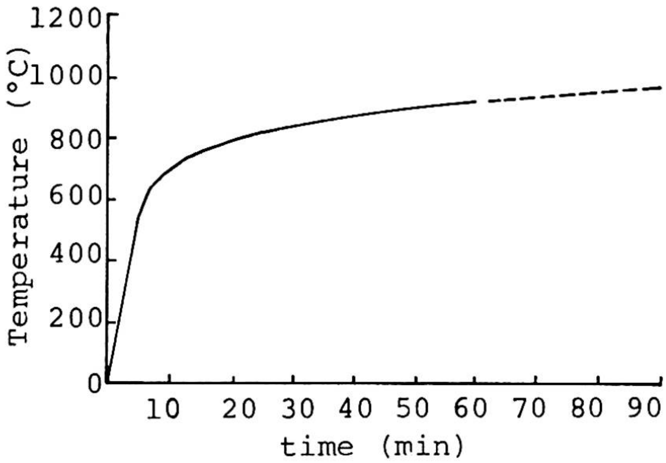


Fig. 3 Standard time/temperature curve (JIS A 1304)



4. Results and Discussion

Data obtained from the series of experiments spalling out of 52 panels are shown in Table 2, Fig. 4 and 5.

Evaluation criteria for spalling in this test are based on the mode of falling off by visual observation and area and volume of the part being spalled of panels.

As shown in these results it can be defined that the amount of free water is affected considerably, that is say, the spalling can not be observed in the most panels at a level of 140kg/m^3. Spalling can be observed increasingly in the range of 120 to 130kg/m^3 of free water, and excess spalling can be seen in more than 160kg/m^3.

On the contrary it can be considered that there is no direct effect depending upon the type of aggregate, and influence of heat resistance of aggregate can be slightly recongnized in ordinary concrete however is not clear in lightweight aggregate concrete.

Regardless of the amount of spalling, phenomenon of falling off in lightweight concrete differed in its mode, likely small amount but successive falling off was observed compared with ordinary concrete.

View point of the influence of restraint condition, it is not so clear in this experiment as shown in Fig. 5.

Table 2 Test Results

		H.R. of Coarse Aggregate	Restraint	Amount of Free Water									
				60	80	100		120		140	160		180
Ordinary Concrete	N	7.2-10.0	D-10			○			○	⦶			
			D-13			○			○				
			D-19			○	○	⦶	⊕	⦶	◑		
			D-22							⊕			
	N'	10.0-19.8	D-10			○			○	●			
			D-13			○			○				
			D-19			○		○	◑	◑	◑		
			D-22							◑			
Light-weight Concrete	L	3.0- 5.0	D-10	○	○		○			○			●
			D-13	○	○		○						●
			D-19	○	○		○	○		○	●		●
			D-22							○			
	L'	13.0-20.0	D-10		○					⦶		●	
			D-13		○							●	
			D-19		○			○		⊕	⊕	●	
			D-22							◑	⊕		

○ No spalling
⦶ Slight spalling
⊕ Rather slight spalling
◑ Fairly heavy spalling
● Excessive spalling

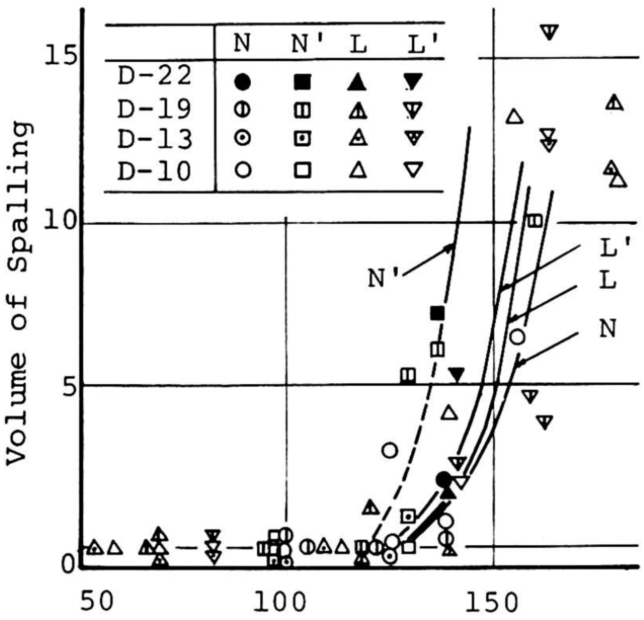


Fig. 4 Volume of spalling related to amount of free water for each type of concrete.

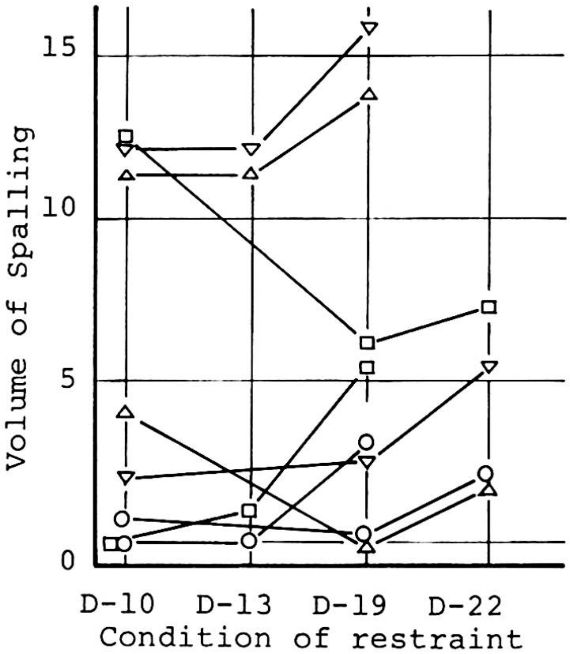


Fig. 5 Volume of spalling related to condition of restraint.

5. Conclusion

From all results obtained in this investigation and the limited data presented in this paper, the following statements can be made;

Explosive spalling point of view amount of free water plays a prominent part in the overall factors and the difference depending upon the type of aggregates does not effect very much.

And finally the explosive spalling can be avoided or minimized in both ordinary and lightweight aggregate concrete when the level of free water in concrete is decreased below the range of 120 to 130kg/m^3.

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SUMMARY

An experimental investigation of explosive spalling of light-weight aggregate concrete compared with ordinary concrete was made related to the property of aggregates, amount of free water in concrete and condition of restraint being expected three main factors of spalling. The results shows that free water plays a prominent part in overall factor, and that the spalling can be avoided when the amount of free water is decreased below the range of 120 to 130 kg per cubic meter of concrete.

RESUME

Une étude expérimentale de l'écrasement du béton d'agrégats dans un incendie a été faite en comparaison du béton ordinaire. On a fait varier la propriété des agrégats, la quantité d'eau libre à l'intérieur du béton et l'intensité de contrainte des éprouvettes. Les résultats montrent que la quantité d'eau libre joue le rôle le plus déterminant parmi les trois facteurs, et que l'écrasement peut être évité si la quantité d'eau libre est diminuée au-dessous de 120 à 130 kg/m3.

ZUSAMMENFASSUNG

Es wurde eine experimentelle Untersuchung über das explosive Ausplatzen von leichtem Beton, verglichen mit gewöhnlichem Beton unter Berücksichtigung der Aggregats-Eigenschaften, des Freiwassers im Beton und des Beanspruchungsgrades der Probestäbe als der drei zu erwartenden Einflussgrössen vorgenommen. Die Resultate zeigten die ausschlaggebende Rolle des Freiwassers; das Ausplatzen lässt sich vermeiden, wenn der Betrag an Freiwasser unterhalb des Bereichs von 120 bis 130 kg pro Kubikmeter Beton liegt.