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*Long T. Phan, Nicholas J. Carino, Dat Duthinh, and Edward Garboczi*

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## **B.1 Concrete Fire Test Programs in Taiwan**

**T. D. Lin\* and Sam Chou\*\***

### **Introduction**

Small-scale fire test programs involving wooden and plastic materials might have started within universities in Taiwan in the 1960s or earlier, but fire tests of concrete did not begin until late in the 1980s. In 1988, the National Science Council of Taiwan funded National Taiwan Institute of Technology a sizable fire test program to determine the behavior of concrete slabs in fire and the mechanical properties of fire-exposed concrete. Subsequently, several concrete fire test programs were carried out, some projects are still in progress.

Here is the reason why concrete, a non-combustible material, suddenly became a hot topic for fire research in this island nation. The healthy economic growth in the last 20 years has led to enormous volumes of concrete construction. Because of expensive land cost in Taiwan, commercial and residential buildings of 30, 40, and 50 stories have become attractive commodities in the real estate market in cities, suburbs, and even in rural areas as well.

The densely populated living condition facilitated with large quantities of electric and gas lines provide high living standards, but at the same time it poses vulnerable fire hazards to occupants and properties. KTV and MTV entertainment vendors, a recently developed oriental culture, coupled with the enforcement of building fire insurance have propelled the rise of fire occurrences to an alarming stage in recent years.

In responding to this social problem, the Ministry of Interior established a fire research laboratory under the auspices of Architecture and Building Research Institute (ABRI) in 1989 to coordinate fire research programs and conduct fire safety verification tests on commercial building materials. The laboratory has also conducted a wide range of in-house fire test programs covering wood, metal, aluminum, ceramic, glass, plastic, gypsum board, and concrete. Interestingly, concrete fire research has been considered as one of the top priority programs, because it is virtually the most widely used construction material in Taiwan.

### **Fire Research on Normal Weight Concrete**

In addition to the in-house research programs, the fire laboratory provides funding to support 10 to 15 fire related research projects carried out by universities and research institutes each year. Among them, about 10 to 15 % were earmarked for fire research related to concrete. The followings are few sample projects supported by the National Science Council and ABRI, during the period of 1991 to 1996:

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\* President, Lintek International, Inc., Illinois

\*\* Director, Fire Laboratory, Architecture and Building Research Institute, Taiwan

- Experimental studies on thermal properties of normal weight concrete at elevated temperatures.
- Experimental studies on mechanical properties of normal weight and lightweight concrete at elevated temperatures
- Development of post-fire investigation methodologies using the Loss-on-Ignition procedure
- Fire tests of normal weight concrete slabs (1 m wide, 4.5 m long, and 100 to 150 mm thick)
- Fire tests of lightweight concrete slabs (1 m wide, 4.5 m long, and 100 to 150 mm thick)
- Fire tests of concrete-filled steel columns without applied loads

Results of these tests have been published in Chinese technical journals and are available by request.

### **Fire Research on High Strength and High Performance Concrete**

High strength concrete (HSC) and high performance concrete (HPC) have gained substantial attention worldwide in the last 10 years. Without exception, the concrete industry in Taiwan through the domestic R/D and technology transfer has successfully introduced HSC to its domestic construction industry. The use of HSC in the construction of the 85 Story T&C Tower in Kao-Hsiung, the 2nd largest city in Taiwan, is a good example.

Nonetheless, the use of HSC in building construction requires careful studies for it may spall violently in fire. Unfortunately, only limited studies on the related subject have been carried out so far and knowledge gaps in this area are wide open. The fire laboratory of ABRI was aware of the problem and funded a test program to investigate the spalling behavior of HSC/HPC at high temperatures. The test variables included effects of moisture and chemical admixtures on spalling and mechanical properties at high temperatures.

At least two hundred 100 mm diameter by 200 mm high cylinders made with approximately 70 MPa HSC were tested in an electric furnace. The concrete cylinders were divided into groups in accordance with amounts of superplasticizer used to study the effect of the admixture on spalling. The test results verified the explosive behavior of HSC and revealed that the effect of chemical admixtures on the spalling is minimal, but the effect of moisture is obviously severe. In addition, reductions of strength and modulus of elasticity with respect to temperature rise were also studied.

In fact, the behavior of HSC in fire is extremely complicated. Small cylinder tests can only give quantitative answers, not realistic solutions. Full-scale fire tests of structural elements are definitely desirable. For this reason, the fire laboratory of ABRI funded the National Chiao Tung University (NCTU) to collaborate with the fire laboratory of the National Research Council of Canada on a fire test program involving 15 full-sized columns (305 mm x 305 mm x 3810 mm) made with HSC having strength greater than 70 MPa. Various mixtures incorporating siliceous aggregate, siliceous aggregate + steel fibers, carbonate aggregate, carbonate aggregate + steel fibers were used to manufacture these column specimens.

In return, NCTU will test approximately three hundred 100 mm by 200 mm cylinders made with HSC having similar compositions as those of the column specimens to determine their stress-strain relationships at various elevated temperatures.

The collaboration is based on work exchange without monetary transaction between both parties. The agreement for the joint research program was signed for 3 years (Mid 1996- Mid 1999) and can be extended under a mutual agreement. The obtained test data will be shared by both parties and published jointly.

### **Near-Term Programs**

The fire laboratory of ABRI considers concrete fire research an important technical contribution to the concrete industry. It has decided to proceed with its second 5-year research program (1997-2002) in which projects related to concrete and steel are listed below:

1. Fire resistance of HSC/HPC structural elements
2. Fire resistance of normal weight concrete structural elements
3. Fire resistance of steel structural elements
4. Fire resistance of steel/concrete composite structural elements
5. Post fire evaluations

The selection of these subjects is based on the domestic construction needs.

### **Long Term Programs**

The fire laboratory of ABRI anticipates to continue its commitment to concrete fire research. Depending on budget allocated and domestic needs, future research topics will be selected from the followings areas:

#### *1. Materials for HSC*

- a) Effects of cements such as ordinary portland cement, alumina cement, and refractory cement on the fire performance.
- b) Effects of aggregates (carbonate, siliceous, and lightweight) on fire endurance.
- c) Effects of chemical admixtures (sulphonated naphthalene, formaldehyde condensates, sulphonates melamine formaldehyde condensates, modified lignosulphates, and others) on the fire performance.
- d) Effects of mineral admixtures such as fly ash, silica fume, slag cement.
- e) Effects of rebars (plain, deformed, epoxy/zinc coated ) and fibers (steel, glass, carbon, polypropylene) on the fire performance.

#### *2. Physical and Thermal Properties of HSC*

- a) Paste: Drying shrinkage often results in micro-cracks in paste. These micro-cracks extend to form larger cracks attributed to vapor pressure/thermal stresses during fire.

- b) Aggregate: Volume stability and physiochemical reactivities of different aggregates at elevated temperatures deserve in-depth studies.
- c) Concrete: Thermal expansion, conductivity, specific heat, vapor pressure, and physiochemical stability affect the fire performance.

### 3. *Mechanical Properties of HSC*

Modulus of elasticity, strengths (compressive, tensile, bond, and shear), and stress-strain relationships are important variables in predicting the fire resistance of HSC structures.

### 4. *Small-scale and Full-Scale Fire Tests*

Preparation of cylinders including high temperature resistant capping, positioning of unbonded pads, ground/lapped end-surfaces are essential factors for viable test data. Well thought-out test procedures are extremely important. Full-scale fire tests are very expensive and require sophisticated test equipment and facilities. A good test plan and a careful execution of the plan is absolutely necessary. In full-scale fire tests, furnace temperatures must be regulated to closely follow the standard time-temperature curve specified. Temperature measurements for the test specimen must be accurately taken. Selection of test loads must meet the code requirements and closely simulate the actual loads in the building during fire.

### 5. *Mathematical models*

Finite element and finite difference methods are generally used to develop computational models to predict the structural behavior of HSC in fire. The development of these models requires data obtained in items 1 to 3 of this section. General engineering theories and rational design methods can be applied in these studies. Design details such as bar sizes and spacing, development length, and concrete covers all have noticeable effects on the fire performance of reinforced concrete.

### 6. *New Design Concept*

Performance-based design is a new concept and may offer a better engineering solution for fire resistance than the prescriptive design procedure.

### 7. *Interaction and public awareness*

It is important to provide ACI committee 318 and major foreign design code committees with the research results obtained from the envisioned HSC fire test programs. We hope the major building codes may include provisions related to HSC in the near future.

## **Conclusion**

High strength/high performance concrete has commercial and engineering potentials. It has already changed concrete construction procedures for non-fire hazardous infrastructures. However, use of HSC in building construction faces serious safety problems because of the building official's concern over the explosive spalling behavior in fire. International collaborative efforts are required to undertake this expensive fire test endeavor. Realizing the importance of HSC fire research, the fire laboratory of ABRI envisions the need to make contributions toward this specific research area.