HIGH-SPEED WATER JET TO REMOVE CONCRETE IMPAIRED BY HIGH TEMPERATURES

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Abstract- The paper describes analysis of behavior of cement based composite materials (concrete) exposed to high temperature. Recommendations for minimization of damage of thermally loaded structures are proposed and possibilities of renovation of fire damaged concrete using the technology of high speed water jet to remove damaged layers are given.

Keywords- Concrete, Fire, High Temperature, Water Jet.

I. INTRODUCTION

Concrete has many properties which are advantageous from the point of fire resistance. It is nonflammable and it has low thermal conductivity [1]. However, concrete structures, which are not designed with respect to fire resistance, show considerable level of damage after thermal load. It is particularly the explosive spalling caused by a combination of increasing pressure in internal pores and inner pressure tensions caused by thermal expansion of material due to high temperature. The result is weakening of cross-section of given reinforced concrete structure and exposing the steel bars to high temperature [2], above the critical value [3].

Resistance of steel reinforced concrete structure to high temperature can be defined as its capability of keeping its original function, bearing capacity, protecting reinforcement and protecting nearby areas from toxic gases in the case of a fire. Effects of high temperature on concrete is a complex phenomenon depending on several aspects:

- composition of concrete (water cement ratio, type and content of aggregate, type of cement or presence of fine fibers);
- density and homogeneity of concrete;
- intensity of thermal load on concrete structure during fire.

II. DAMAGE AND PROTECTION OF CONCRETE

2.1. Damage of concrete caused by high temperatures and fire

The basic questions of influence of high temperature on concrete involve not only complex identification of changes in cement matrix, but also transport phenomena. Analysis is complicated by the fact that cement based concrete is a composite material consisting (among others) of two considerably different components: mastic cement and aggregate. Moreover, mineralogical compositions of various types of aggregate differ. Heated up minerals show various metamorphosis changes that are typical and different for each of the minerals. The sum of many changes taking place in heated up concrete manifests as changes of physical, thermal and mechanical properties.

Action of high temperature on concrete results in gradual deterioration of its quality. The structure of mastic cement collapses and its bearing function is lost. Safety or durability of concrete structure then depends on the strength of concrete during the time of exposition to heat or how the strength is changed by heat and cooling down (when putting out the fire). Rate of heating the concrete, maximal temperature and time of exposition are crucial. Heating of concrete structure above all reduces strengths (both compressive and tensile). Changes vary depending on composition of cement and solid elements, intensity of heat and time of exposition.

Changes going on in concrete structure during action of high temperature:

100 °C – 300 °C:

- free water in concrete structure is released;
- surface can be damaged by micro-cracks
- compressive strength may increase (so-called quasi-strengthening), however, tensile strength and elasticity modulus are reduced. 300 °C – 1 200 °C:
- explosive spalling of surface layers of concrete;
- considerable reduction of strengths and damage of concrete structure in the form of cracks;
- considerable reduction of elasticity modulus;
- increase of concrete creep above 1 200 °C:
- total reduction of strengths and dissociation of the concrete structure;
- melting of concrete structure.

2.2. Possibilities of protection of reinforced concrete structures

Several means of preventing or moderating the impacts of thermal load of concrete are used. Protection systems can be divided into two larger groups: active and passive [4]. Active systems are supposed to reduce temperatures as much as possible to reduce their action on surface of concrete structures. These systems are mainly sprinklers or other fire extinguishing means of various types.

Passive systems directly resist to acting high temperatures and fire. These are manly systems of heat barriers. Most frequently used systems are heat resistant coatings, insulating face panels or sprayed mortars with various modifications to increase their resistance to high temperature. One of the passive systems is the design of fire-resistant concrete mixture as such, which can be achieved first of all by addition of dispersed reinforcement of polypropylene fibers [2].

To prevent considerable damage of steel reinforced concrete structure, it is necessary to observe following conditions:

- preventing explosive spalling of surface layers of concrete;
- limiting of temperature below 300°C – design strength of concrete will not be reduced;
- limiting of temperature acting on steel reinforcement below 450°C – design strength of steel reinforcement will not be reduced.

III. RENOVATION OF STEEL REINFORCEMENT STRUCTURES AFTER A FIRE

Concrete structures exposed to high temperatures or a fire can be extensively damaged and finely the structure can collapse (Fig. 1, Fig. 2). Maximal temperatures and time of exposition are crucial for extent and degree of degradation of a concrete structure. However, these important parameters are mostly unknown after a fire; therefore diagnostics of exposed structures is necessary. Based on the diagnostics, extent of damage of the concrete structure is determined and the way of renovation of the structure is proposed. Speed and effectiveness of renovation of damaged structure and consequent reintroduction of standard traffic is very important for minimization of economic loss caused by the fire. Renovation of a fire damaged concrete structure is considerably less costly than a demolition and building a new structure.



Fig. 1.Demonstration of structural damage after the fire – reinforced concrete ceiling [5]



Fig. 2. Demonstration of structural damage after the fire – reinforced concrete column [6]

The first step which has to be taken before starting any renovation of a steel reinforced structure is correct and effective removal of incoherent and deteriorated parts or layers of concrete. Several methods can be used for removal of damaged layers. The basic method is manual chiseling with pneumatic or electric hammers. Sanding can also be used (non-coherent layers are removed by means of a stream of compressed air with grains of siliceous sand) or with a high speed water jet technology.

3.1.Possibilities of application of the water jet technology on concrete structure damaged by heat

During renovation treatment, the damaged layer is usually removed and a layer of new material is coated to ensure protection of the structure or even improve its statics characteristics. The technology of high-speed water jet (HSWJ) can remove damaged parts of concrete very fast and effectively and treat the surface even on places which are difficult to approach and under extreme conditions. The main aim of the technology of water jet is selective removal of damaged or incoherent concrete down to the “sound” concrete.

High speed water jet is widely used for removal of damaged or degraded layers of concrete during renovation works nowadays. This technology is recommended for removal of surface layers and treatment of layers before renovation in many countries.

For correct use of the high speed water jet technology it is necessary to define degree of degradation of concrete and required depth of removal of damaged layer. As already described, the extent and type of concrete structures damage are dependent on many factors, not only on the factor of the actual heat treatment (the temperatures, residence time, direct flame) but also on the actual concrete structure (active × passive protection; concrete composition - aggregates, binder, additives, the pore structure of the concrete).

IV. TREATMENT OF CONCRETE DAMAGED BY HIGH TEMPERATURE

Problems of using the technology of HSWJ on steel reinforced concrete structures affected by high temperatures has been solved in long term by the collective of authors at the Institute of Technology of Building Materials and Components, Academy of Sciences of the Czech Republic, as a part of the project GACR P104/12/1998 „Study of interactions of components of cementitious composites exposed to high temperatures".

Research started within the project in 2012. After thorough literary search about the solved problems, an analysis of input component was carried out (binder – aggregate, binder – cement, additions, dispersed reinforcement). The focus of the analysis of input materials was selection of most appropriate components for designing of cement based composite material resistant to heat. Based on the literary search, appropriate diagnostics procedures were selected and designed, methods for evaluation of damage of aggregate and concrete exposed to high temperature were proposed and methods for determination of surface failures of concrete exposed to high temperature were set (Fig. 3). This method is based on color differentiation between undamaged surface of concrete sample and damaged concrete (spalled parts, cracks), from which the percental proportion of damaged surface is calculated.

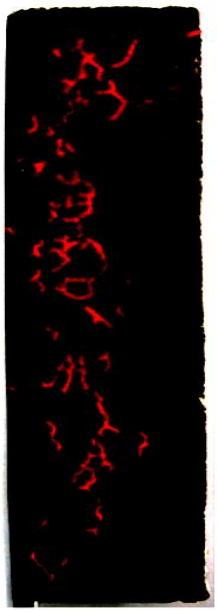


Fig. 3. An example of determination of percental proportion of damaged surface

Prepared concrete samples were thermally loaded at various modes. At the initial stages, the samples were thermally loaded in an electric laboratory furnace (heat acting on samples in all directions); thermal load had various intensities, isothermal dwells, gradual and controlled build-up of temperature to required values as well as shock thermal load. At subsequent stages, samples were thermally loaded with direct flame (Fig. 4). Then, samples of larger dimensions were thermally loaded (up to maximal size of thermally loaded area 1000 x 1000 mm) in a gas furnace (Fig. 5).

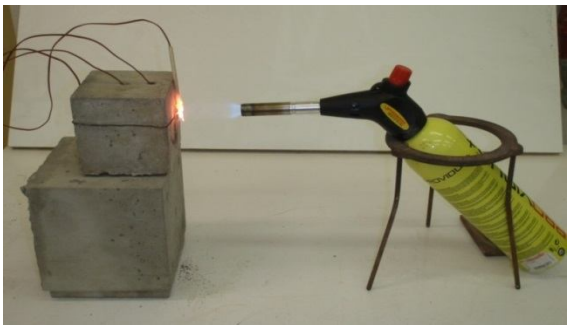


Fig. 4. Assembly for loading direct flame on smaller samples



Fig. 5. Gas furnace for testing larger samples (samples in slabs forming cover plate of the furnace)

After thermal load, the samples were subjected to diagnostics, their damage was examined and their properties determined. Some of the sets of samples were selected for application of HSWJ. Then, testing of removal of damaged concrete with HSWJ was carried out: various types of water jet were tested as well as modification of their properties (method of generating HSWJ, speed of movement above concrete surface, water pressure, distance from the sample). After the HSWJ application extensive diagnostics was made again, including evaluations of the volume of the removed concrete (Fig. 6).

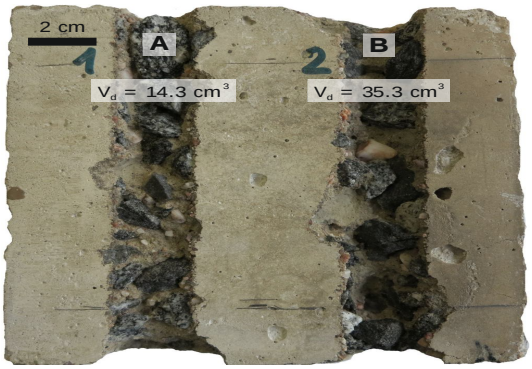


Fig. 6. Comparison of kerfs created by continuous flat water jet (A) and pulsating flat water jet (B) in concrete after heating to 600 °C (Vd - disintegrated volume, equivalent nozzle diameter: 2,05 mm, standoff distance: 40 mm, water pressure: 30 MPa, traversing velocity: 1 m.min-1)

CONCLUSIONS

For correct and effective use of the HSWJ technology, it is necessary to carry out adequate diagnostics of the structure damaged by high temperature (determine real properties, extent and degree of damage) and based on the parameters, appropriate method of application of HSWJ has to be selected (type of water jet, method of generating HSWJ, rate of application or water pressure).

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