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Rebound hammer test to estimate compressive strength of heat exposed concrete

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HIGHLIGHTS

- Variation of the rebound values of RC beams after heating was investigated.
- Rebound degradation was less than that of compressive strengths of concrete core.
- XRD showed increased calcium carbonate which may increase concrete surface hardness.
- A regular conversion of rebound values is not safe to predict the concrete strength.
- Rebound values can be used to compare concrete damage and temperature, not strength.

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ABSTRACT

The residual concrete strength is required for evaluating the safety of reinforced concrete structures after fire. Based on the surface hardness of concrete, a rebound hammer test has been used to evaluate the compressive strength at the ambient temperature and after fire. However, only few studies are available on the limitations of such indirect testing of concrete strength after fire. In this research, variations in the rebound from reinforced concrete beams before and after heating to 800 °C were investigated and compared with strength of the concrete core. The variations were plotted with average temperatures of the test specimens based on a validated finite element model. At a given temperature, the ratio of rebounds was significantly higher than the ratio of compressive strengths. The rebound did not clearly change in the temperature range up to about 420 °C. X-ray diffraction (XRD) and scanning electron microscopy (SEM) were also carried out on the concrete samples. X-ray diffraction showed gradual reduction in portlandite content and increased calcium carbonate. SEM investigations indicated that fire exposed concrete tends to have smaller pores. This may be due to formation of calcium carbonate, which also increases surface hardness of the concrete, similar to carbonation effects. Therefore, the rebound decreased less than the compressive strength.

1. Introduction

During fire concrete is exposed to high temperatures that cause severe breakdown of concrete structure. Both physical structure and chemical composition of heated concrete are affected. Drying shrinkage, chemical decomposition, and internal micro cracking take place, reducing durability and load-bearing capacity of the concrete [1,2]. Mechanical properties of the concrete may be significantly degraded, especially the modulus of elasticity and the tensile strength. Consequently, in addition to aesthetic damage, functional damage of the concrete structures may occur.

Many factors such as concrete strength, water to cement ratio (W/C), type of aggregate, etc., contribute to concrete strength reduction under fire. However, the maximum temperature reached within a concrete cross section is the main determinant of concrete strength. The maximum temperature generally relates to the fire severity and duration [3]. Fast heating rate tends to induce spalling, especially of high strength concrete (HSC). Therefore, the strength degradation of HSC was higher than in cases of normal strength concrete (NSC) [4–6]. To form HSC, high cement content and the lowest possible W/C are required. Therefore, higher cement content and lower W/C can also increase strength degradation. Furthermore, cement content also relates to chemical decomposition. Due to thermal incompatibility between cement paste and aggregates in the concrete, the strength of concrete decreases

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more with siliceous aggregates than with carbonate aggregates [7,8].

Condition assessment of concrete after fire is a requirement for rehabilitation of such structures. To assess the load carrying capacity of the damaged structures, the residual strength after fire is a key factor. Depending on severity of the case, partial or total repair or replacement of the damaged structures are required. Destructive techniques (coring tests) as well as nondestructive techniques (NDT) have been practiced to assess in situ the compressive strength of concrete in reinforced concrete (RC) structures. The coring tests are reliable in evaluating the compressive strength. However, for a small beam or column, such as 20 × 20 cm or 20 × 30 cm size, coring tests are difficult and may damage the structures. Therefore, the use of such tests may be limited in assessing compressive strength of concrete in some RC members. In addition to pulse velocity tests and drilling resistance tests, the Schmidt rebound hammer test is an alternative non-destructive testing method. Since the rebound hammer test is a simple and low-cost method, the test is well-known and in common use.

Interpretation of the Schmidt rebound hammer test is based on a clear relation between concrete compressive strength and surface hardness of the concrete, reflected in the rebound number obtained from the test. The rebound values relate mainly to concrete condition at the near-surface layer, approximately to depths not exceeding 3 cm [8]. Based on linear and nonlinear regression analyses of the measured compressive strength of concrete and the rebound number, empirical relationships have been widely proposed as predictive equations that estimate the compressive strength of unheated concrete [9,10]. Note that the regression models generally are based on strength of 28 days old concrete at ambient temperature. Many studies [11,12] have investigated the reliability of the compressive strength estimates from the rebound hammer test. Lower W/C ratio provides higher rebound value. However, variation of the rebound value with the W/C ratio is similar to the general variation of concrete compressive strength with the W/C ratio, but less pronounced [13]. Different cement type and amount of concrete can affect the rebound value by up to 50 percent [14]. However, cement fineness only slightly affects the rebound [15]. For the same concrete compressive strength, the rebound of concrete with siliceous aggregate is generally higher than with limestone aggregate [13,14]. Since carbonation increases surface hardness of concrete, the rebound is also increased [16,17]. Moisture in the concrete can decrease the rebound by up to 20 percent [18]. Under laboratory conditions, accuracy of predictions based on the rebound hammer test for concrete specimens cast, prepared and tested lies between ±15 and ±20% [19]. The prediction accuracy in an RC structure is ±25% [19,20]. Overall, the rebound hammer test can help estimate the compressive strength of unheated concrete or normal concrete at ambient temperature.

As a simple method, the rebound hammer test has been applied to evaluate the compressive strength after fire [8,21], even though the rebound hammer test is less reliable than pulse velocity tests and drilling resistance tests [22,23]. Since the near-surface layer of heated RC members is the most severely damaged by the fire, the rebound hammer test is expected to provide low compressive strength estimates, i.e., conservative predictions. Only limited investigations on the prediction accuracy of the rebound hammer test for concrete after fire are available. Experiments on small concrete cubes were used to study the residual rebound number of concrete after fire [8,22]. In these studies [8,22], decreased rebound was found for concrete cubes heated to over 300–400 °C. Hardening and drying of layers near the surface were the proposed reasons for no significant changes in the rebound of concrete when heated up to 300 °C [3]. Furthermore, it was observed that the decrease in rebound was proportionally less than that in compressive strength. However, small concrete specimens may not properly represent practical large concrete members.

The scope of this work is to investigate the variation of rebound and limitations of the rebound hammer test for estimating strength of reinforced concrete members after fire. The rebound hammer test and the compressive strength test, by coring of reinforced concrete beams, were conducted before and after exposure to high temperature. Furthermore, to determine the mechanisms by which elevated temperature affected rebound, X-ray diffraction (XRD) and scanning electron microscopy (SEM) studies were also carried out on the concrete after heating. This investigation supports safety evaluations of compressive strength, for decisions on repairing or other actions on RC structures after fire, by using the Schmidt rebound hammer test.

2. Experimental details

Reinforced concreted beams were cast and tested in this investigation. Beam specimens were prepared and cast with a design mix used in typical current concrete structures of Thailand. The binder was ordinary Portland cement, Type 1. Coarse aggregate was crushed dark grey limestone composed of about 40–45% calcite. Fine aggregate was natural river sand mostly containing quartz and less feldspar and mica. The maximum size of the coarse aggregate was 25.4 mm. The mix proportions in the concrete were binder content 300 kg/m^3, fine aggregate 900 kg/m^3, coarse aggregate 1100 kg/m^3 and water to cement ratio 0.65. The grading curve of the aggregate mixes is in range of grading limit based on ASTM C33 [24] as presented in Fig. 1. The slump value of the mixed concrete was about 80 mm based on ASTM C143 [25]. No admixture was used. Chemical composition of the cement used is given in Table 1 and mineralogical composition based on Bogue calculation is given in Table 2.

The dimensions of the test beams were 150 × 300 mm, 200 × 400 mm and 250 × 500 mm in cross-section, 1500 mm in overall length, and 1350 mm in supported span. Each beam was reinforced with four 12 mm-diameter deformed bars, two bars on both top and bottom. The stirrups from 6 mm-diameter round bars had 150 mm spacing along the beam length. The clear concrete cover of the main reinforcing steel is 25 mm. Five standard concrete cylinders of 150 × 300 mm were also molded and used for direct compressive strength testing. All of the concrete beams and the cylinders were cast and cured at room temperature. Immediately after demolding, all beams were covered with plastic wrap to

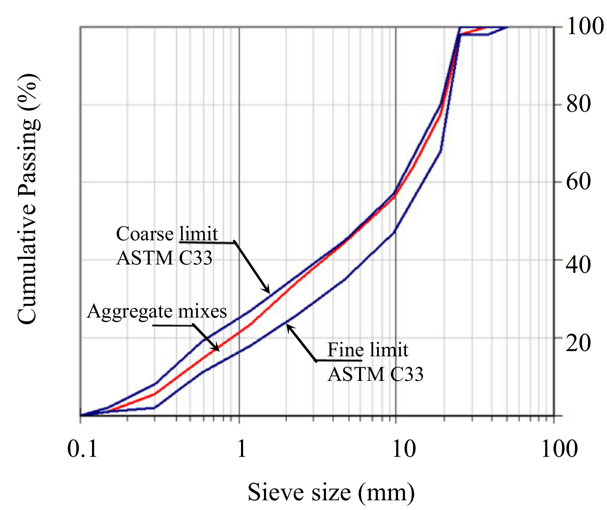

Fig. 1. Grading curves of the aggregate mixes.