Construction and Building Materials 69 (2014) 26–31

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of cyclic loadings on heated self-compacting concrete

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HIGHLIGHTS

- SCC behavior under cyclic loading is like normal concrete in the same conditions.
- Elevating temperature affected on the cyclic loading test's results.
- SCC higher compressive strength is more sensitive to the elevating temperature.
- Elevating temperature before cyclic loading, change of materials specifications.

ARTICLE INFO

Article history:
Received 17 March 2014
Received in revised form 15 July 2014
Accepted 16 July 2014
Available online 5 August 2014

Keywords:
Self-compacting concrete
Heating
Cyclic loading
Stress–strain curve
Compressive strength

ABSTRACT

This experimental study examines the effect of cyclic loadings on heated self-compacting concrete (SCC). One hundred and eight standard cylindrical specimens and one hundred and eight cubic specimens were tested. Compressive strength of the concrete specimens was within the normal range with strengths of 25, 35, and 45 MPa. Test speed was within the quasi-static range. The cyclic loading was imposed within the compressive area. The concrete specimens were heated to 23 °C, 100 °C, 200 °C, 400 °C, 600 °C and 800 °C and then were exposed to monotonic compressive loading or cyclic loading. The stress–strain diagram, compressive strength, and SCC behavior under the cyclic and monotonic loadings before and after heating were compared. The results show that the heated concrete has a lower compressive strength. The heated concrete exhibits more strains in the cyclic loading. Development of cracks in all the heated and unheated specimens under cyclic loading is different.

1. Introduction

Designing fire-resistant structures requires experimental studies. Structures may be exposed to seismic loading after fire or they may expose to seismic loading at the same time. This may happen due to explosions, volcanoes and earthquakes in specific places and the structure may be exposed to a fire and cyclic loading. Analysis of behavior of a structure due to temperature change and accidental fires requires examining various factors. Physical and chemical properties of the materials and concrete used in a structure are changed due to high temperatures. Compressive strength and the modulus of elasticity of concrete reduce due to heat [1–10]. Some studies also discussed the effect of heat on tensile strength and stress–strain diagram. Due to changes of specifications of concrete, materials used, and differences in size of specimens, it is less likely to compare the obtained results accurately [11–14]. Modeling, compressive strength analysis, the modulus of elasticity, and stress–strain relations of concrete are necessary for designing fire resistant structures [15–22]. The available models attempted to examine and predict concrete behavior under different temperatures with respect to mix type, aggregates type, concrete admixtures, and size of specimens.

With respect to the specifications of SCC, the demand to use it has been increased. Depending on the relevant conditions, admixtures and plasticizers are added to concrete. This concrete is compressed under the influence of its weight and there is no need to apply more vibration anymore. There are many studies on using SCC with respect to the type of lightweight and normal aggregates. The use of lightweight aggregates that float in a concrete mix may damage monotony of concrete and the effect of heat and mechanical specifications will be very different [23–30]. Some of the studies also offered models to study behavioral difference among the effects of aggregates on SCC. As mentioned earlier, this research discusses the combined effect of heat and cyclic loading on the heated concrete. In fact, cyclic loading by itself has a wide variety of conditions.

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http://dx.doi.org/10.1016/j.conbuildmat.2014.07.040
0950-0618/

Simulation of stress–strain curves is one of the methods for predicting concrete behavior in cyclic loading. Under uniaxial monotonic loadings, stresses are controlled and strain changes are calculated with using this method usually. However, concrete strain is changed in a controlled manner in cyclic loadings. This might be due to different reasons, such as type of the equipment under test or better control of concrete deformation. Of course, in both cases, stress–strain diagram of the concrete is modeled with respect to the changes imposed on force and deformation of a concrete specimen. The modeling show different results with respect to the type of loading and type of specimens in a laboratory. Although deformation of concrete loading and unloading diagrams is different within the pressure range, a series of specific rules and behaviors are maintained in the overall form of the diagrams, which has fixed relations in most cases.

The studies conducted by Sinha et al. [31] can be considered as the first experimental studies on concrete behavior under cyclic loading. They discussed concrete behavior under cyclic loading. They carried out their studies experimentally on 48 standard cylindrical specimens. Compressive strength of the cylindrical specimens ranged 20–28 MPa. The studies showed that a cyclic loading curve does not pass through monotonic loading curve. The curve was introduced as a envelope curve. Karsan and Jirsa [32] developed the earlier experimental results within the compressive range. Their research was carried out on 46 short rectangular column specimens. Loading of the specimens was under the effect of a cyclic loading along the main axis of a column and column behavior was studied on the plate of the same axis. Finally, they presented a model for the envelope curve of concrete stress–strain diagram in a cyclic loading. Their study showed that the reloading curves and unloading curves meet at some points, a series of which is called common points limit. There is almost a certain distance between this curve and the envelope curve. Buyukozturk and Tseng [33] developed the earlier studies on concrete behavior in a cyclic loading. These studies discussed the effects of increasing strain and energy level with respect to loading gradient. Yankelevsky and Reinhardt [34,35] presented a simple non-linear model for stress–strain diagram of concrete in a cyclic loading with respect to the effects of history of the previous loading. Their model is in two separate forms for compressive [34] and tensile [35] loadings states. Of course, these simple models are formed as a tangent line on the envelope curve in press section.

Bahn and Hsu [36] carried out parametric and experimental studies on concrete under the effect of cyclic loading. The results led to overall control of cyclic stress–strain curve. The specimens were tested as 76*152 cylinders. They used four loading models. The reverse relationship between plastic strain and mean of unloading and loading curve gradient is among the results of the studies, Vecchio and Collins [37] carried out an experimental study on concrete behavior under different loadings. Later, these studies were continued by Palermo and Vecchio [38] in the theoretical section. The models also point out the relationship between loading and unloading curve with the created cracks. They tested 30 reinforced concrete specimens and examined the cracks developed on the concrete surface. The studies indicated that concrete reloading provides an appropriate response in a linear manner and concrete loading within tensile range is non-linear. Sakai and Kawashima [39] studied behavior of reinforced concretes. The results obtained from the 28-day concrete specimens were used in these tests. In their research, they pointed out the monotony of the gradient of initial curve and the initial loading and showed that the unloading curve is concave from the initial point.

Mander et al. [40] developed a stress–strain model of concrete in a uniaxial compressive loading. These loadings deal more with the range between tension and compression. Their experiments were carried out on beams and columns. Martinez-Rueda and Elnashai [41] modified the reloading curve using a linear relation. This line was considered between the zero stress points and reloading strain; whereas, the unloading curve is placed between unloading strain and stress–strain curve in a monotonic loading. Mansour and Hsu [42] developed concrete behavior modeling with respect to a series of experimental results within the tensile and compressive range. These equations discuss linear models of reloading and curve models for loading. Elnashai and Martinez [43] and Sima et al. [44], were among those who presented cyclic loading models on concrete.

Effects of cyclic loading on heated concrete structures are studied in some researches. Huo et al. [45] studied the effect of cyclic loading on the concrete-filled steel columns under the effect of heat. In this research, fire and axial compressive load were imposed on the column at the same time and then the effect of lateral cyclic loading was studied. The results indicate the damage to the CFT columns. Baile and Yaqub [46] studied the effect of lateral cyclic loading on heated concrete columns. Concrete columns used in these experiments were mended by FRP after being heated and then lateral cyclic loading was imposed on the columns.

As noticed, many studies were conducted separately on the effect of heat and lateral loading on concrete. There is a wide range of studies with respect to the type of the applied concrete. The present research attempts to study some of the combined effects of heat and cyclic loading on SCC behavior.

2. Experimental work

This experimental study discusses the effect of cyclic loading on SCC after heating. The experiment parameters include the effect of heat and the effect of cyclic loading. Stress–strain diagram of compressive strength and concrete behavior were studied in these experiments.

2.1. Materials

The concrete mix used in the experiments consists of crushed gravel, micro silica, plasticizer, cement and water. They were prepared from local sources (Table 1).

2.2. Specimens

One hundred and eight (section diameter: 150 mm, high: 300 mm) standard cylindrical specimens and one hundred and eight (150 mm) cubic specimens were tested. The compressive strength of the specimens manufactured with respect to the different mix plans at 23 °C are 25, 35, 45 MPa (Table 2). Specifications of the manufactured concrete mixes are categorized in three different groups. The amount of micro silica and plasticizer in these mixes are changed and other proportions of materials have fixed amounts.

2.3. Curing

First, aggregates were poured in a mixer as saturated surface dry (SSD) and cement and micro silica were added to it. After mixing for one minute, a mixture of water and plasticizer was added to it. The mixtures were poured in cylindrical and cubic molds and kept in the molds for 24 h. The specimens were taken out of the molds and kept for 26 days in a pool containing a mixture of water and some lime for reducing alkaline condition. The specimens were kept at laboratory temperature (23 °C) for one day. They were subjected to heating, loading and testing. Actually, the air holes in the specimens were not dry but the effects of that water is negligible [28,47–49]. The specimens were allowed to cool naturally to room temperature.

Table 1
Specifications of materials.

Materials name	Materials type	Qualification
Aggregate	Gravel	Bulk: 1750 kg/m^3; Maximum size: 19.5 mm
Water	Normal	PH: 7; low mineral
Cement	Type 1	Setting time: 135 min, compressive strength: 325 kg/cm^2
Add materials	Micro silica	Density: 2110 kg/m^3
	Plasticizer	Density: 1200 kg/m^3