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Dynamic behavior of porous concretes under drop weight impact testing

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ABSTRACT

Porous concrete is used as a construction material in various applications mainly as a permeable cementitious material. However, its response under impact loading is generally not considered. Due to the high percentage of its intentional meso-size air pores, porous concrete has a moderate static strength compared to normal concrete while its dynamic performance is distinctive. Owing to its characteristic of forming multiple cracks, it fractures into small fragments when exposed to impact loading. Therefore, with the aim of designing a special type of concrete to be used in protective structures, porous concrete was investigated. In this study, the impact strengths of different types of porous concretes were analyzed in correlation with their mixture compositions and production technique. The dynamic experiments were performed using a drop weight impact test set-up while the measurements were taken through Laser Doppler velocimetry. According to the results obtained, the aggregate properties and compactive effort, which are coupled to porosity, are the main factors that affect the dynamic performance of porous concrete.

1. Introduction

Porous concrete is a special type of cementitious material composed of gap graded aggregates, covered with a thin layer of cement paste, assembled by the cement paste layers partially being in contact. Porous concrete incorporates a high amount of intentionally included air voids that makes its physical characteristics markedly differ from normal concrete. Therefore, it is currently being used in various applications that require permeability, noise absorption or thermal insulation [1–4]. Due to its high intentional meso-size air pore content, porous concrete has a moderate static strength compared to normal concrete while its fragmentation behavior under dynamic loading is considerably different from that of normal concrete.

A research project was undertaken aiming to design a special type of cementitious material that fractures into small fragments under impact loading, to be used in protective structures such as safety walls for important structures such as embassies or storages for explosives. The purpose behind investigating the possibilities of making such a concrete that fractures into small fragments is the fact that in case of an explosion, the large fragments of concrete that are formed can also be fatal for the exposed environment. Due to its high intentional meso-size air pore content, porous concrete has a moderate static strength compared to normal concrete while its fragmentation behavior under dynamic loading is considerably different from that of normal concrete. Therefore, it was investigated in the scope of this research. In cementitious materials that also contain aggregate inclusions, microcracks typically initiate from the aggregate-cement paste interface due to high stress concentrations caused by the stiffness mismatch between the aggregates and the cementitious phases, as well as the weak interfacial bonding. These microcracks propagate and coalesce under increased loading. Under dynamic compressive loading, failure happens as a result of ultimate coalescence of these cracks. Because these cracks produce the post-failure fragments, the fragment size is directly related to how the cracks are distributed at coalescence [5–7]. In porous concrete, the initiation of the cracks is expected to be similar to that of normal concrete. However, because there is a very high amount of intentional voids present and because the cement paste bridges that bond coarse aggregates are very thin, the cracking patterns are affected by the geometry of the present phases. Therefore, porous concrete tends to fail at these numerous weak bridges between the aggregates which makes its ultimate behavior different from normal concrete. The fragments after an impact test being small in size can be explained by the presence of these weak bridges. Because pores are essential for the required dynamic performance of the material, in the process of modifying the mixture components, the main focus was to en-

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hance the static strength while maintaining a sufficient level of porosity. In porous concrete, the void content can be adjusted by modifying the aggregate proportions and properties as well as the level of compactive effort while the lack of fine aggregates is the main reason behind the enhanced void structure [8].

In order to produce porous concretes with the aimed static and impact strengths and to have reproducible results, all the important parameters have to be well-controlled. Therefore, the properties such as aggregate grading and characteristics and the compactive effort which are very effective on the ultimate material properties, have to be clearly elaborated. The aggregate properties influence the workability and the rheological properties of normal concrete as well as porous concrete. It is commonly accepted for normal concrete that well graded aggregates having particles of a wide range of sizes increase workability as they generally facilitate the flow of particles up to a threshold, provided that there is a sufficient amount of cement paste with a suitable workability present in the mixture [9]. As the aggregate grading affects the packing of particles, it also influences the efficiency of compaction because small particles are manipulated more efficiently into the voids between the larger ones [10]. Size of the particles also influences the properties of porous concrete in the sense that it is one of the main factors that control the pore size distribution such that an increase in aggregate size results in an increased median pore size. This effect is easily observable in mixtures with single sized aggregates. However, it should also be noted that there is no significant difference in the total pore volume between mixtures containing single-sized aggregates in different sizes where a porosity of typically between 21% and 24% can be expected [4]. Morphological properties of aggregates also affect the rheology and the mechanical properties of normal and porous concretes. Rounded aggregates provide a lower viscosity than angular ones and result in an increased packing. The flakiness is more likely to cause the particles to be oriented in one plane under compaction force. However, increased texture and enhanced angularity contribute to concrete strength due to two considerable factors which are particle-to-particle mechanical interlock and increased total surface area available for the adherence of the cement paste [9,11]. The different mechanical properties of the aggregates also have an influence on the strength of porous concrete even for aggregates that have the same texture [11]. Because the workability of fresh porous concrete is highly lowered, compaction is essential during casting. Meanwhile, the effect of prolonged compaction time causes a significant decrease in workability and a corresponding decline in compactibility due to the initiation of setting in the cement paste and moisture loss at the high amount of air exposed surface of porous concrete [8,12]. Therefore, the admixtures used in a porous concrete mixture should be precisely adjusted.

In this experimental study, impact strengths of different types of porous concretes with varying mixture compositions and production techniques were tested. The effects of different factors on the properties of porous concrete were investigated. Dynamic experiments were performed using a drop weight impact test set-up utilizing Laser Doppler velocimetry (LDV) as the monitoring technique. LDV is a diagnostic technique for measuring the velocity based on the Doppler principle of monitoring the change in the wavelength of the reflected laser light as a function of the relative velocity of a moving object [13]. While LDV has been used in applications where different materials have been tested under dynamic loading [14–16], drop weight impact testing is used in studies where dynamic performance of cementitious materials is investigated [17,18]. In the current study, LDV has been selected to be used in monitoring the particle velocity history of the impactor surface at the interface between the impactor and the concrete targets. During the drop weight impact experiments, the failure patterns were also monitored through high speed photography while the post-failure fragments were analyzed in terms of their sizes [19].

2. Experimental investigations

2.1. Materials

In order to achieve a highly porous structure, both the mixture design and the casting procedure of porous concrete have to differ from those of normal concrete. In the porous concrete mixtures produced in this study, aggregates were either at one (2–4 mm or 4–8 mm) or two (2–4 mm and 4–8 mm, each 50% by mass) standard size ranges. Cement paste content was highly decreased compared to that of normal concrete mixtures. The aggregate and cement contents of porous concrete are more efficiently expressed in terms of the aggregate to cement ratio by mass which was 5.7 in all the mixtures produced for this investigation. Two different types of aggregates (crushed basalt and river gravel), two binders (cement and silica fume), three different aggregate gradings and two levels of compaction were involved in the production.

In making the mixture design of porous concrete, the most critical requirement is to produce a cement paste of a standard consistency. The standard consistency of a cement paste for porous concrete, which can be defined as the cement particles being sufficiently distributed in the paste with a controlled workability, facilitates the formation of an evenly distributed cement paste phase throughout the specimen without the accumulation of access cement paste at any location especially at the bottom portion. Consistency of cement paste is dependent on various parameters such as the type of binder, water to cement ratio and the admixtures. Keeping the water to cement ratio constant at 0.30 for the strength requirements, the amounts and types of admixtures were adjusted according to the types of binders used. While the amount of superplasticizer is the most decisive parameter, the set retarder is also essential for maintaining the workability throughout the casting process that also involves a prolonged compaction. The summary of the compositional properties of the mixtures is given in Table 1.

The cement used was CEM I 52.5 Rapid hardening cement with a specific gravity of 3.13 g/cm^3 and Blaine fineness of 5330 cm^2/g. An undensified type of silica fume, with a SiO_2 content of 97%, was used for replacing cement in some mixtures. A polycarboxylic ether type of superplasticizer and a set retarder that provides a workability time of up to 3 h were used as admixtures. Crushed basalt with a specific gravity of 3.0 g/cm^3 and river gravel with a specific gravity of 2.60 g/cm^3 were sieved in size groups of 2–4 mm and 4–8 mm before use. Water to binder ratio was kept at 0.3 in all the mixtures.

Preparation of the porous concretes was done following a standardized procedure. If the mixture contains silica fume, cement and silica fume were first mixed in a separate mixer for mixing powders for five minutes prior to mixing with water. This was done to eliminate the agglomerates in the silica fume. Following the dry mixing, the dry binder content was mixed with water, superplasticizer and set retarder in a separate mixer for three minutes to make the cement paste. Consequently, the cement paste was mixed with the aggregates in a third and larger size rotary mixer for three minutes.

Compaction is essential in the casting of porous concrete while the type of compaction technique used is very effective on the ultimate porous concrete properties [11]. In this study, two compaction techniques were used, which were hand compaction using a steel cylinder and a special machine compaction technique using an impact hammer that displaces both in the vertical direction and vibrates at the same time while the hammer was also rotated,