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Coupled effect of coarse aggregate and micro-silica on the relation between strength and elasticity of high performance concrete

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HIGHLIGHTS

- Strength and MOE of HPC from heavy and normal weight aggregates coupled with micro-silica.
- Requirement for construction projects to use locally available building materials.
- Comparison of experiment results with ACI prediction models enhanced for accurate prediction.

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ABSTRACT

This paper examines the relation between strength and elastic modulus of high performance concrete (HPC) tailored from various heavy and normal weight aggregates coupled with the effect of micro-silica as a supplementary cementitious material (SCM). Elastic modulus of concrete is an important mechanical property and plays an important role for the calculation of deformations in the structural components. Experimentation was conducted in precise laboratory environment and all other parameters were kept constant in the mixtures. This investigation was prompted to supply the construction industry with appropriate information on how specific properties of HPC mixtures can be improved using local normal and heavy weight aggregates and incorporating supplementary cementitious materials. In other words, this paper will encourage the local aggregate consumption in mega projects that to be constructed for special purposes. In this investigation, dissimilar types of normal and heavy weight coarse aggregates were used. It was found that it is worthy to study experimentally the relation between strength and MOE of HPC when different types of coarse aggregates are used for an indicated HPC mixture with a corresponding combination of supplementary cementitious material. The comparison of experiment results with the ACI prediction models showed that the models should be enhanced for accurate prediction for the effect of aggregate type with and without the use of micro-silica as supplementary cementitious material. An assessment of the need for an aggregate and micro-silica based modification to the ACI models is also proposed. The experimental work conducted in this investigation confirmed that the type of aggregate and its combination with a supplementary cementitious material would have important influence on the HPC characteristics. Hence, the use of appropriate values for the strength-MOE relation for a HPC mixture based on the nature of used aggregates and SCM is recommended. However, such values might be not available in some cases, if so the experimental trend lines presented in this study can be used to calculate them.

1. Introduction

High performance concrete (HPC) is always termed as the concrete which meets the requirements of performance of its intended use. ACI defines high performance concrete as a concrete mixture which can meet precise requirements of performance and uniformity that cannot be achieved with the conventional ingredients

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as well as conventional placing, mixing and curing conditions [1]. The design and construction of the high performance concrete structural members is mainly the function of material properties of the high performance concrete. Requirements of HPC may involve enhancements of certain mechanical and material properties of concrete. elastic modulus and f_c' could be attributed as one of those properties. Since aggregate properties can differ from source to another, it is important to experimentally determine the properties of the ingredients used to produce HPC. for this purpose, a specified mix design is needed to incorporate local aggregate and other SCM materials. It has been recognized that the strength and elasticity of HPC are functions of aggregate and SCM used in the mixture [2–13]. However, so far, this effect is only partially accounted for in commonly used design methods for evaluating strength and MOE of HPC and needs to be further deep investigations for a variety of materials. Also, no research was found pertaining to the effect of aggregates under consideration for this research with and without their interaction with the silica fume (micro-silica) for their influence on strength and MOE relationship of HPC. This investigation was prompted to encourage the use of local normal weight aggregates in mega construction projects that to be constructed for special purposes or to use special aggregates with supplementary cementitious materials to improve specific properties of HPC. Generally, HPC mixes contains lower water-binder ratio ranging 0.25–0.40 and super plasticizers are used to achieve good workability. Moreover, supplementary cementitious materials are integral part of high strength and HPC [11,14].

According to Fuminori and Takafumi [15], elasticity modulus of concrete is commonly represented as a function of its ultimate f_c'. As many investigators have proposed relationships to predict the elastic modulus of concrete, only few of them are considered to cover the entire data. Authors attributed to that fact that the properties and proportions of aggregate and binders affects the mechanical properties of concrete.

As business as usual, the designer demands information on the strength-MOE relation in order to estimate the deformation of structural HPC elements under conditions of service. Shah and Ahmad [16] outlined that if MOE is not determined by experimental testing, two empirical relationships can be used for design calculations. The empirical relationships are summarized in two formulas; the first one which is as per ACI 363 [17,18] as well as the formula given by ACI 318 code [19]. Russel [20] reported that considerable controversy surrounds in the use of the equation recommended by ACI 318 code [19] for calculating the elastic modulus. This equation was developed by Pauw [21] for a concrete has maximum f_c' of 38 MPa. At the time of its development no standard test was adopted for determining the elastic modulus. Also, there was a lot of variation as to the definition of the term elastic modulus itself, whether, initial, tangent, or secant modulus [21]. Also, examination of high strength concrete reported by Carrasquillo et al. [18] concluded that the elastic modulus of concrete is overestimated for concretes with f_c' above 40–45 MPa when ACI 318 expression [19] is used [22]. Hence, a modified form should be recommended for the concrete mixtures with higher f_c' up to 100 MPa that can predict a lower elastic modulus than the one by ACI 318 [19]. In contrast to that, data published by Cook [23] indicated that the equation given by ACI 318 [19] undervalues the elasticity modulus for the higher strength concretes [1]. Swartz et al. [24] stated that the elastic modulus measured for higher strength concretes are generally greater than those predicted by the ACI formula. Furthermore, it was noted that this contradicts findings presented by ACI 363 [17], and found that the elastic modulus may be estimated by the ACI 318 formula [19]. Swamy [25] showed that for high strength concrete the elastic modulus did not increase in proportion to strength development and the maximum moduli obtainable are of the order of 45 to 50 GPa.

Cetin et al. [6] and Myers et al. [26] described that elastic modulus of high performance concrete cannot be represented using a single equation with sufficient accuracy, and the strength-modulus relation should be confirmed by conducting trial field batching. They also said that the mechanical properties of concrete greatly influenced by the mineralogical characteristic of coarse aggregate. Also, they found that, type and content of aggregate affects the strength-MOE relation for high performance concrete. Based on the above, this investigation aims at determination the influence of type of coarse aggregate with and without the presence of micro-silica on the strength-MOE relationship of HPC by controlled laboratory experimentation. Also, to validate the use of ACI 318 [19] and ACI 363 [17] for predicting the strength-MOE relation for high performance concrete produced from local aggregate and specially imported materials.

2. Experimentation

2.1. Mix proportions and material properties

Properties of the ingredients of high performance concrete are discussed and explained in this Also, it covers the procedures for strength and elasticity testing of HPC. The ordinary Portland cement (Type I) from local cement plant has been used in this investigation. Basic tests were also conducted on cement such as specific gravity (3.15), consistency (23.7%), initial and final setting time (50 min and 350 min) respectively. The testing program showed that the percentage of main compounds were (C3S = 50.6); (C2S = 19.1); (C3A = 9.8); (C4AF = 10.9); refer to Table 1 for more details. Moreover, silica fume (micro silica) complying with the requirement of ASTM C 1240 [27]. As per the manufacturer and supplier data sheets, micro silica has a silicate content of SiO_2 = 93.20% and specific gravity of 2.27 respectively, Table 2 shows the chemical composition of micro silica.

In this investigation, High range water reducing admixture conforming to the requirements of ASTM C494 [28] type F was used with specific gravity of 1.1 and contains 36% solids respectively.

To deeply study the effect of aggregate type and micro silica, for the experimental program, the water/cement ratio (w/c) was varied from 0.25 to 0.40. The coarse aggregate used in this investigation consists five different types of normal and heavyweight aggregates. Normal aggregate was obtained from three different sources at three different areas/cities of Saudi Arabia. The first type of aggregate was obtained from Riyadh and named RY aggregate. The second one was brought from Makkah and named MK aggregate while third one was sourced from Abha area and named AB aggregate. The other two types of aggregate are special heavyweight aggregate imported from abroad. They are Barite (BR) and

Table 1
Physical and chemical properties of cement.

Composition	Mass (%)	Physical Properties	
Silicates	19.96	Specific gravity	3.15
Aluminates	5.99	Consistency	23.7%
Fe_2O_3	3.59	Setting time Initial	50 min
Calcium oxide	62.75	Setting time final	350 min
Magnesium oxide	0.59		
SO_3	2.73		
Alkalis	0.2		
Tri calcium silicates (C3S)	50.6		
Di calcium silicates (C2S)	19.1		
Tri calcium aluminates (C3A)	9.8		
C_4AF	10.9		