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Strength and Durability of Composite Concretes with Municipal Wastes

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The influence of different types of polyethylene (PE) substitutions as partial aggregate replacement of microsteel fiber-reinforced self-consolidating concrete (SCC) incorporating incinerator fly ash was investigated. The study focuses on the workability and hardened properties including mechanical properties, permeability properties, sulfate resistance, and microstructure. Regardless of the polyethylene type, PE substitutions slightly decreased the compressive and flexural strength of SSC initially; however, the difference was compensated at later ages. Scanning electron microscope (SEM) analysis of the interfacial transition zone showed that there was chemical interaction between PE and the matrix. Although PE substitutions increased the permeable porosity and sorptivity, it significantly improved the sulfate resistance of SCC. The influence of PE shape and size on workability and strength was found to be more important than its type. When considering the disposal of PE wastes and saving embodied energy, consuming recycled PE as partial aggregate replacement was more advantageous over virgin PE aggregate-replaced concrete.

Keywords: chloride ion permeability; durability; fiber-reinforced composites; municipal fly ash; self-consolidating concrete (SCC); sulfate attack; transport properties; waste management; water-cementitious materials ratio.

INTRODUCTION

In the last decades, sustainable development in the construction industry has been gaining increasing attention. Sustainable development can combine economic growth and environmental protection by conserving natural resources and saving embodied energy. Recycling of waste materials has been accepted as one of the most beneficial options to achieve sustainable development for construction industry.[1] Depending on the availability and price, several industrial wastes can be used as parts of the binder—for example, cement and the filler (natural aggregate). For example, industrial by-products such as fly ash, municipal fly ash, ground granulated blast-furnace slag, and silica fume have been used in the construction industry as cement replacement or supplementary cementitious materials.[1] Recycled concrete,[2] which is produced from demolishing concrete structures and recycled polymers[3] obtained from waste polymers, are the most common wastes used as natural aggregate substitutes in the building industry.[4,5]

The construction industry has been using recycled polymeric wastes as aggregate and fiber because of its economic and ecological advantages.[3,6-8] Different types of polymeric wastes, such as polypropylene (PP),[9,10] polyethylene (PE),[11-13] and polyethylene terephthalate (PET)[14-18] have been used as filler in concrete. However, most studies were conducted for conventional concrete, and polymeric wastes were used as fine aggregate replacement. Therefore, little information is presently known regarding the use of polymers as coarse aggregate in the formulation of new concretes, especially self-consolidating concrete (SCC).

Qatar has been one of the largest producers and consumers of polymers in the Gulf region.[19,20] Effective disposal of polymeric wastes is constrained by their non-biodegradable nature and emission of dangerous gases when combusted. Therefore, landfilling and incineration are not good alternatives for polymeric waste disposal. To solve the polymeric waste disposal problem, recycling has been supported by the Qatar government, but recycling is still limited with small and private recycling plants.[19]

Due to the rapid growth in construction facilities, significant amounts of natural aggregate and cement are consumed in Qatar.[21] The quality and quantity of locally mined aggregates in Qatar is limited; therefore, there is a shortage of raw material, especially natural aggregate, in the construction industry of Qatar.[22] In spite of scarcity of the natural resources, Qatar National Standards for Construction and Buildings (QCS) limits the amount of imported aggregates used in construction facilities.[23,24] Therefore, to sustain this requirement, creating new resources for aggregate and cement—that is, production of secondary raw materials—is vital for the construction industry of Qatar. Furthermore, cement production is known as one of the causes of globally increasing CO_2,[25] so consumption of less cement could result less CO_2 emissions. To develop a sustainable construction industry in Qatar, natural aggregate and cement consumption should be reduced by replacing them with waste materials when applicable.

Self-consolidating concrete has several advantages with respect to conventional vibrated concrete: high workability, low segregation, no need for compaction, and a reduction in manpower and equipment needed.[26] To obtain these advantages, SCC needs more cement, which in turn increases its cost and its impact on the environment due to CO_2 emission. Several studies in the literature showed that limestone powder, natural pozzolans, ground granulated blast-furnace slag, silica fume, and coal fly ash can be used in SCC to reduce the cement amount.[27-32] On the other hand, there are only few studies regarding the consumption of incinerator ashes in SCC in the literature. For example, Collepardi et al.[33] applied some pretreatment methods for ground bottom ash

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(GBA) collected from municipal solid wastes incinerators (MSWI), used it in SCC, and obtained good performance in terms of the mechanical and durability properties. Municipal fly ashes (MSWI FAs) usually do not meet the required criteria of ASTM standards,[34] usually failing one or more of the standards' criteria. Many studies in the literature showed that, although municipal fly ash do not meet all the required criteria of ASTM standards, they can be used either in cement production or in conventional cement-based materials for the benefits of environment and economy.[35-46]

The main aim of this study is to determine the influence of incorporating different type of polyethylene in virgin and recycled form (Qatar municipal waste [QMW]-derived) as 10% by weight of coarse aggregate replacement on the properties of microsteel fiber-reinforced SCC. For the first time, the combination of the two by-products (silica fume and locally produced MSWI fly ash) is used together to reduce the amount of cement and fine filler used to obtain SCC. The workability and mechanical and durability properties of cement-silica fume-MSWI fly ash SCC with respect to the type of PE are investigated. In addition, microstructures of hardened SCC mixtures are studied to examine the interaction between the PE and the matrix.

RESEARCH SIGNIFICANCE

The pressure from the increasing scarcity of natural resources required for designing concretes, as well as the growing amount of domestic wastes collected by the municipal corporations worldwide, presents a problem as well as an opportunity for engineers. Efforts to reuse useful domestic wastes in construction activities are gathering momentum across the globe. The current work focuses on understanding the mechanical and durability characteristics of steel fiber-reinforced SCC using waste materials from Qatar municipal wastes (QMWs).

EXPERIMENTAL PROGRAM

Material properties

The cement used in all mixtures was locally produced ordinary portland cement (OPC) CEM I 42.5R, which corresponds to ASTM Type I cement. MSWI fly ash was collected from Qatar's Domestic Solid Waste Management Centre's (DSWMC) flue gas treatment system. DSWMC is a refuse-derived incineration facility in which municipal waste is presorted to remove glass, plastics, and ferrous and nonferrous metals prior to incineration. After this pretreatment, municipal waste is directly incinerated at a minimum temperature of 850°C (1123 K). Approximately 1500 tonnes of municipal waste is incinerated daily, of which 16% and 4% ended up as bottom ash and fly ash, respectively. For neutralization of acidic gases, lime is added in air pollution control units. Prior to the bag house filters, powdered active carbon is introduced into the flue gas stream.[47]

The particle size distribution of OPC and MSWI fly ash were determined by laser diffraction technique and given in Fig. 1. Together with MSWI fly ash, silica fume (GMS85) was used in all mixtures. The particle size distribution of silica fume was not determined, as it is already known that GMS85 silica fume is finer than both OPC and MSWI fly ash (99% of silica fume was reported ≤ 45 μm [1771 μin.] by the manufacturer). The chemical and physical properties of the cement, MSWI fly ash, and silica fume are given in Table 1. The chemical compositions of silica fume were obtained from the manufacturer and those of cement and MSWI fly ash were measured using a wavelength-dispersive X-ray fluorescence (XRF) spectrometer. The percentage of loss on ignition (LOI) at 750°C (1023 K) and specific gravity was determined according to ASTM C311.[48] The insoluble residue and fineness was measured according to ASTM C114[49] and ASTM C204,[50] respectively.

As seen in Table 1, the very low silica content of local MSWI fly ash may limit its consumption as pozzolanic material in concrete, while its high lime content may contribute to the cementitious properties.[40] The strength activity index (SAI) of MSWI fly ash with portland cement was 64%, which is less than the minimum requirement for pozzolanic material according to ASTM C618.[51] Therefore, in this study, the main role of MSWI fly ash was to increase the fineness and cohesiveness of SCC, while silica fume was used as pozzolan.

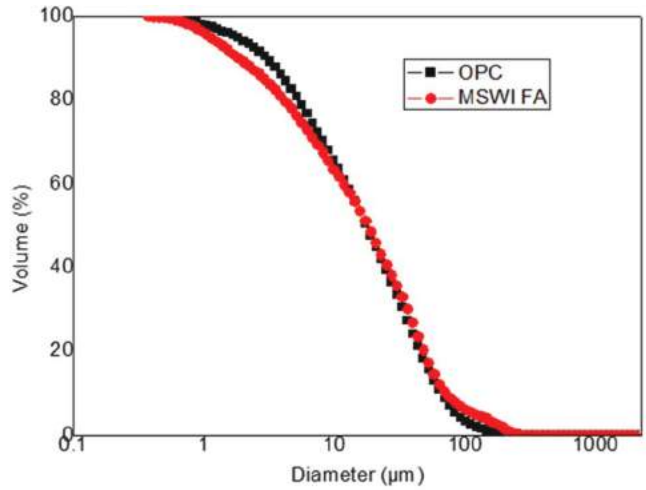

Fig. 1—Particle size distribution of OPC and MSWI fly ash. (Note: 1 mm = 0.039 in.)

Table 1—Chemical composition and physical properties of portland cement, MSWI fly ash, and silica fume

Chemical composition	OPC	MSWI FA	Silica fume
CaO, %	64.95	45.0	1.05
SiO_2, %	21.92	1.89	89.5
Al_2O_3, %	4.32	0.784	0.32
Fe_2O_3, %	3.78	0.601	0.38
MgO, %	2.16	0.552	0.1
SO_3, %	2.08	8.67	0.1
Alkalis (Na_2O + 0.658 K_2O), %	0.68	18.3	—
Loss on ignition, %	1.00	1.9	2.3
Insoluble residue, %	0.68	1.06	1.0
Physical properties			
Specific gravity	3.09	2.25	2.01
Blaine fineness, cm^2/g	3527	—	—

Note: — indicates not measured items; 1 cm^2/g = 4.39 $in.^2/oz$.