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ORIGINAL ARTICLE

Simulation of the behavior of pressurized underwater concrete

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Abstract Under-Water Concrete (UWC) contains Anti-Washout Admixtures (AWA) (0.0%, 0.2%, 0.3%, 0.4% and 0.5%) by weight of cement with cement contents (400, 450, 500 and 550 kg/m^3). All concrete mix contains silica fume and high-range water reducing (15% and 4%) respectively by weight of cement. The fine to steel slag coarse aggregate was 1:1. The concrete mix was tested for slump, slump flow, compressive strength and washout resistance using two test methods based on different principles. The first method is the plunge test CRDC61 which is widely used in North America, and the second method is the pressurized air tube which has been manufactured for this research and developed to simulate the effect of water pressure on washout resistance of underwater mix. The results of compressive strength test were compared to concrete cast underwater with that cast in air. Test results indicated that the use of an AWA facilitates the production of UWC mix with the added benefit of lower washout resistance. New technique of simulating pressurized UWC is reliable for detecting UWC properties. Adding AWA (0.3–0.5%) by weight of cement makes all mix acceptable according to Japanese Society of Civil Engineers.

1. Introduction

Underwater concrete is one special type of high performance concrete used in the past, present, and in the foreseeable future as long as there is need to construct bridges, with foundations in soil with high water levels, and almost all off- and on-shore structures. The term high performance concrete refers to concrete that performs particularly well in at least three key performance indicators: strength, workability, and service life. [1]. Successful casting of UWC can be achieved if sufficient attention is paid to the concrete mix design and placement techniques. Reduction in quality of the hardened concrete is mainly due to the washing out of cement and fine particles as well as segregation of coarse aggregates upon casting in water. Agitation of wet concrete by the action of surrounding water also causes washout of constituent elements [2]. Anti-washout UWC is by nature used essentially in aquatic environment and is increasingly finding most of its applications in marine environment rather than freshwater or river [3]. The anti-washout admixtures can

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be made from various organic and inorganic materials. The two materials most commonly marketed as AWA are cellulose and gum. They act primarily by increasing the viscosity and the water retention of the cement paste [4]. Normally, underwater repairs pose a challenge to the contractor for various reasons, including the need to minimize washout of cement and fines during concrete placement. Dewatering is a solution, but it is costly. The cost of dewatering averages more than 40% of the total repair costs for hydraulic structures. An alternative to dewatering is placing concrete underwater, using a mix proportion containing higher amounts of cement, pozzolans such as silica fume, or AWA. Several projects have used this technology with great success [5]. The bond strength for the underwater repair concrete placed on the horizontal substrates with surfaces prepared using three various methods. Significant differences were found depending on the method of preparation of the concrete substrate surface. The best bond strength to the substrate, regardless of the applied pressure, was obtained for the substrates with sand-blasted surface. The bond strength to the horizontal sand-blasted surfaces was more than twice higher as compared to the repair concrete placed on the surfaces treated by low-pressure washing and much higher than in the case of the hammered surfaces. For the low-pressure washing hammering, a favorable effect of hydrostatic pressure on the bond strength of the repair concrete to the substrate was observed. However, for the sand-blasted surfaces, no distinct impact of hydrostatic pressure on the bond strength was found [6]. Concrete used for casting marine and offshore structures is generally referred to as UWC. The UWC develops lower in situ performance than other concrete cast and consolidated above water. Typical in situ residual compressive strengths reported in the literature were in the order of 80–90% for UWC cast using the tremie/hydrovalve technique [7]. The increase in demand for the ingredients of concrete is met by partial replacement of materials by the waste materials, which is obtained by means of various industries. Slag is a byproduct of metal smelting and hundreds of tons of it are produced every year all over the world in the process of refining metals and making alloys. Like other industrial byproducts, slag actually has many uses, and rarely goes to waste. It appears in concrete, aggregate road materials, as ballast, and is sometimes used as a component of phosphate fertilizer. In appearance, slag looks like a loose collection of aggregate with lumps of varying sizes [8]. The used electric arc furnace steel slag (EAFSS) in concrete aggregate helps in enhancing the cohesion between the aggregate particles and the surrounded cement mortar as well as the higher hardness of (EAFSS) due to the surface texture and shape [9].

The main objective of this paper was to provide guidelines for evaluating the efficiency of anti-washout admixtures for using in underwater concrete mix containing steel slag as the coarse aggregate. The paper aimed to highlight the effect of anti-washout admixtures, overhead pressures and cement contents on the workability, washout resistance, compressive strength loss, and the washout mass loss.

2. Experimental program

2.1. Materials

The materials that were involved in the experimental work were selected from local sources in Egypt. Ordinary Portland cement (CEM I 42.5N) was used. It is produced according to the Egyptian standards 4756/1-2007. The chemical compositions of cement are presented in Table 1. A silica fume was locally produced in Egypt containing more than 96% amorphous silicon dioxide (SiO_2). Its specific gravity and bulk density 2.15 and 0.345 are t/m^3 respectively. A high performance super plasticizer admixture of aqueous solution of modified polycarboxylate basis (Viscocrete-5930) was used to increase workability and viscosity (strong self-compacting behavior) of the concrete mix. Viscocrete-5930 complies with ASTM-C-494 types G, and BS EN 934 part 2: 2001. The dosage of the admixture was adjusted to minimize the water/cement ratio. Anti-washout admixtures consist of a powder-based welan gum developed specifically for using with underwater concrete construction and being as benefits for production of thixotropic mix with cohesive nature. A clean tap drinking water was used in all mix. Fine aggregate used was locally available in natural siliceous sand with a fineness modulus of 2.36 and specific gravity of 2.63. Steel slag coarse aggregate used local electric arc furnace steel slag that was obtained from Ezz steel industry factory in Suez. The EAFSS is a by-product during melting of steel scrap from the impurities and fluxing agents, which forms the liquid slag floating over the liquid crude iron or steel in electrical arc furnaces. Its specific gravity was 3.5, water absorption was 1.02% and bulk density was 1.92 t/m^3.

Table 1 Chemical properties of used cement, silica fume and steel slag coarse aggregate.

Cement		Silica fume		Steel slag coarse aggregate	
Chemical composition	Results by wt. (%)	Chemical composition	Results by wt. (%)	Chemical composition	Results by wt. (%)
SiO_2	21.0	SiO_2	96.00	SiO_2	13.10
Fe_2O_3	3.00	Fe_2O_3	1.45	Fe_2O_3	36.80
Al_2O_3	6.10	Al_2O_3	1.10	Al_2O_3	5.510
CaO	61.5	CaO	1.20	CaO	33.0
MgO	3.8	MgO	0.18	MgO	5.030
SO_3	2.5	K_2O	1.20	MnO	4.180
Na_2O	0.4	Na_2O	0.45	Cr_2O_3	0.775
K_2O	0.3	SO_3	0.25		
		H_2O	0.85		