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FULL LENGTH ARTICLE

Upgrading offshore pipelines concrete coated by silica fume additive against aggressive mechanical laying and environmental impact

M.I. Abdou, Hesham Abuseda *

Production Department, Egyptian Petroleum Research Institute, Naser City, 11727 Cairo, Egypt

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Abstract Studies have been carried out to investigate the possibility of utilizing a broad range of micro-silica partial additions with cement in the production of concrete coating. This study investigated the strength properties and permeability of micro-silica concrete to achieve resistance toward concrete cracking and damage during laying. The chemical composition of micro-silica (silica fume) was determined, and has been conducted on concrete mixes with additions of 3 up to 25% by weight of cement in concrete. Properties of hardened concrete such as compressive strength, flexural strength, and permeability have been assessed and analyzed. Cubic specimens and beams were produced and cured in a curing tank for 7 and 28 days. Testing results have shown that additions of silica fume to cement between 5% and 7%, which acts as a filler and cementations material, developed high flexural and compressive strength with reduction of permeability.

1. Introduction

Concrete is the most important engineering material and the addition of some other materials may change the properties of concrete. Micro-silica or condensed silica fume is a byproduct from the reduction of high purity quartz with coal in electric arc furnaces during the manufacture of silicon and ferrosilicon alloys. The silica fume has a high content of amorphous SiO_2 and is composed of extremely fine, spherical particles that are used as an additive for improving concrete performance, it is approximately a hundred times finer than cement. Micro-silica is also collected as a byproduct in the production of silica and other silicon alloys such as ferrochrome, ferromanganese and ferrovanadium. Offshore oil and gas pipelines require special care to protect them from aggressive saline seawater in which these pipelines are submerged. Therefore, special protective anticorrosion coating is applied to the pipe. In addition to the anticorrosion coating, the submarine pipes should have an outer reinforced concrete coating layer compatible with the anticorrosion coating. The external concrete coating layer protects the offshore pipelines from mechanical damage and stabilizes it on the sea bed. The concrete cladding possesses the advantage of low cost, low thermal and electrical conductivity, good resistance to corrosion and low energy content. Offshore petroleum development involves

* Corresponding author.
E-mail address: heshamabuseda@yahoo.com (H. Abuseda).
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an aggressive environment due to deep salt water, severity of prevailing climatic conditions imposed by high winds, strong seas and low temperatures in winter [1]. The offshore pipelines play an important role in offshore oil and gas production and transportation. The hostile environments and the currents on the sea floor call for coatings of sufficient weight to provide stability and of specific composition to prevent corrosion [2,3]. These characteristics are provided by two layers of coating, anticorrosion coating and concrete coating. The concrete coatings to sub-marine pipelines are required to resist unique loads and are of unusual mix proportions. This gives rise to two problems when monitoring the quality of the coating. There is a risk of using inappropriate quality assurance techniques, or misinterpreting their results [4].

The offshore pipelines are exposed to a hostile submarine environment and that the risks may cause very serious and expensive incidents. The concrete coating should be flexible, although the concrete of all construction material is the most rigid. Ordinary concrete usually cracks and does not bend. This irreversible cracking, however, must not threaten the integrity of the coating itself. The cement should be sulphate resisting Portland cement suitable for undersea use in preparation of the concrete [5]. The cement should have a tricalcium alluminate content of not more than 3.5% and low alkali content less than 0.6% in order to attenuate the reactions of certain types of aggregates in marine environments [6,7]. The cement should be of good quality and stored in a manner which provides satisfactory protection from the elements. The concrete aggregates are made up of natural mineral material. Aggregates should be clean and free of any chemical compounds, organic materials or solids which may impair the strength and durability of the concrete [8]. The aggregate should make a ringing (not dull) sound when grasped in the hand, and not leave any trace of dirt on the hands (shall not be made from chalky or decomposed stone) [9]. Heavy aggregate should consist of crushed iron of high density and hardness to give the required compressive strength and density for the concrete mix [10,11]. Heavy aggregate should be clean and free from all deleterious materials and stored in a suitable manner to avoid contamination from soil or other foreign matters [12]. The aggregate grain size ranges between fine and course depending on the technique of application of the concrete coating [9,13]. With the increase in trend toward the wider use of concrete there is a growing demand of concrete with higher compressive strength and flexibility. The main target of this study is focused on the effect of micro-silica addition on the improvement of permeability and mechanical properties of offshore petroleum pipelines.

2. Experimental work

Several tests have been carried out in this research to determine the effect of micro-silica on permeability and mechanical properties of concrete, such as compressive and flexural strength, the micro-silica to be utilized as an addition material for high performance concrete coating of marine petroleum pipelines.

2.1. Chemical analysis for micro-silica

Micro-silica is a byproduct in the reduction of high purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Micro-silica consists of fine particles, with particles approximately one hundredth the average grain size of cements because of its extreme fineness and high silica content. This test was designed to measure the chemical composition of micro-silica and results given in Table 1 with silica indicate that the material is mainly composed of approximately 94.10% SiO_2.

Table 1 Chemical analysis of silica fume (micro-silica).

Element	%
SiO_2	94.10
Al_2O_3	0.47
CaO	0.92
Fe_2O_3	0.25
MgO	1.18
Na_2O	0.40
K_2O	1.22
SO_3	0.26
L.O.I	0.90

2.2. Mechanical analysis for aggregates

This test was designed to determine the particle size distribution (sieve analysis test) for the heavy aggregates suitable as constituents for concrete coating applied by impingement machine. The aggregate size grading should be varied from 9.50 mm down to 0.15 mm. It is quite significant that the platy and flat shaped grains be avoided or eliminated. The semi cubic, equidimensional shape is always preferable in concrete mix operations. The results show that the grading complies with coating specifications of Petroleum Companies [13,14]. Table 2 shows the particle size of the aggregates used and their particle size distraction are graphically represented in Fig. 1.

2.3. Concrete mix design

The preparation of concrete depending on the mixing ratio of aggregates, cement with various micro silica levels and water. The mixing ratio was encountered after various trials to achieve the best mixing design with best results as shown in Table 3. Thorough mixing is required to ensure maximum dispersion of micro silica within the concrete.

2.4. Saturation test

The cubic samples are weighted after drying to the nearest gram to obtain a constant weight. The sample is immersed in

Table 2 Mechanical analysis for the heavy aggregates.

Sieve size (mm)	Average results	Percent passing standard
9.50	100	100
5.75	97	95–100
2.36	91	80–100
1.18	66	50–85
0.60	43	25–60
0.30	19	5–30
0.15	4	0–10