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Compressive strength performance of low- and high-strength concrete soaked in mineral oil

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ABSTRACT

This study focused on the impact of used engine oil on the compressive strength of concrete. The compressive strengths of concrete cubes soaked in used mineral oil for 6 months were compared with those of oil-free concrete cubes. Five different concrete mixes were adopted to investigate the negative impact of mineral oil on low- and high-strength concrete. Furthermore, this paper describes an investigation into the effect of oil absorption on concrete frame foundations used for large machines at Assiut cement factory, CEMEX, in Egypt. It is concluded that the evaluation of the aggressive effect of mineral oil on concrete by experimentally comparing the strengths of oil-free concrete and oiled concrete at the same age is the most optimal and most reliable of the existing methods. The aggressiveness of oil is very clearly observed for low- and high-strength concrete, and the reductions in compressive strength were observed to be 17% and 11.8%, respectively. Additionally, based on this field study, the degree of oil absorption in concrete is an important determinant of compressive strength.

1. Introduction

Concrete is a mixture of cement, water, fine aggregate and coarse aggregate, which hardens to a stone-like mass. Concrete is used more than any man-made material on earth. Mechanical strength is often regarded as the most important property of concrete. Concrete suffers from one major drawback compared with other materials such as steel and timber: its strength cannot be measured prior to it being poured. Factors affecting the compressive strength of concrete are water/cement ratio, mix ratio, degree of compaction, type of cement, aggregate grade, design constituent, mixing method, placement, curing method and the presence of contaminates.

Reinforced-concrete (RC) elements used in underground structures, garage buildings and industrial constructions, are subjected to contamination by different materials, i.e., water, chemical and oil products. Oil products affect tank walls, foundations and other structures that support machines, and storage floors; therefore, the range of the problem is wide, and the subject should be considered of great technical importance, especially in industrial construction. Oil leakage from machines above foundations is considered to be the prime factor in the deterioration of RC elements supporting machines [1,2]. A comparison of the influence of various oil products on the compressive strength of concrete shows that there are large differences in their effects [3,4].

The leakage of oil into the cement of older structures has been reported to result in concrete with greater resistance to freezing and thawing [6]. Accordingly, adding used engine oil to fresh concrete mix could be similar to adding an air-entraining chemical admixture, thus enhancing some durability properties of concrete while serving as a technique for disposing of oil waste. Hamad et al. [7] studied the effect of adding used engine oil, as an air-entraining agent, to concrete on the properties of fresh and hardened concrete. The main conclusion of this study is that used engine oil improves the fluidity of a concrete mix and reduces the properties of hardened concrete. Moreover, the 28- and 90-day compressive strengths of concretes featuring used engine oil as an air-entraining agent depend on the water/cement ratio.

Generally, raw materials used for concrete production should be free from oil contamination. However, Ayininuola [8] studied the impact of contaminated sand with 2%, 5% and 10% both diesel oil and cut bitumen, separately, on the compressive strength of concrete. Upon comparing concrete samples with controlled concrete cubes, it was concluded that the presence of diesel oil and bitumen in any proportion in sand results in concrete with lower compressive strength. This study clearly revealed that diesel oil and bitumen act as compressive strength inhibitors in concrete production. Additionally, Ajagbe et al. [9] studied the effect of aggregate contaminated with crude oil and concluded that an aggregate containing more than 5% crude oil contamination reduces the compressive strength of concrete by more than 50%.

In recent years, deterioration has been observed in concrete structures subjected to oil. The degree of this deterioration

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depends on the quality and density (impermeability) of the concrete [3,10,11]. The oiling of structural elements is a problem observed in industrial construction. Heavily oiled concrete floors display considerable damage, which often compromises a building's integrity. After a few years, the significant enlargement of cracks due to oil can be observed [2]. Błaszczyński [10] and Biczok [12] presented an example of an oiled, reinforced concrete floor in which significant cracking and deflection occurred. During repair work, the concrete was easily separated from reinforcement bars. The author also noticed in the frame foundations of an industrial building (Assiut cement company, CEMEX) considerable damage as a result of the reduction in the structure's dynamic stiffness due to oil. The behavior of oiled frame foundations is analyzed later in this paper.

Pukhov [11] concluded that mineral oil is aggressive with respect to its effect on concrete and that the compressive strength of oil-impregnated concrete was 20–63% lower than that of oil-free concrete. On the other hand, some authors presented contradictory results regarding oiled concrete. The effects of oil products on concrete are classified as either non-harmful or only mildly harmful [3,13,14]. Gerbiec [13] presented contradictory results regarding oiled concrete in his research and concluded that the relatively long-term oiled samples (approximately 5.5 years) did not show a decrease in compression or tensile strength below the samples' initial values. Similar results were obtained by Ejeh and Uche [3]. Nevertheless, there is evidence that serious damage can be caused [5,10,15].

2. Research significance

The current study was performed to experimentally investigate the impact of oiled concrete soaked in used oil for 6 months. In addition, a field study was carried out on three frame foundations with different degrees of oil saturation at CEMEX. The evaluation of the aggressiveness of oil was determined based on the performance of oiled concrete and that of oil-free concrete of the same age. Many factors were taken into consideration in this study, such as permeability, water/cement ratio, admixtures, and concrete strength.

3. Materials and method

3.1. Materials

The materials used to develop the concrete mixes in this study were ordinary Portland cement, fine aggregate (FA), coarse aggregate (CA), water, superplasticizer, and an air-entraining agent. Natural sand was used as a fine aggregate, and natural gravel with a maximum particle size of 40 mm was used as a coarse aggregate to produce a normal-strength concrete mix, Meanwhile, basalt gravel with a maximum particle size of 20 mm was used as a coarse aggregate to produce a high-strength concrete mix. Concrete cubes were contaminated by a used industrial mineral oil, gear oil with an ISO VG 220 base oil viscosity, with kinematic viscosity at a temperature of 40 °C (217.4 mm^2/s). The used oil was obtained from machines at the Assiut cement company in Egypt-CEMEX.

3.2. Preparation of test specimens

A total of four primary mixes were prepared in five groups to illustrate the performance of concrete soaked in oil for 6 months. The target 28-day compressive strength of these mixes was 17.5, 25 and 70 MPa. A superplasticizer complying with ASTM C-494 Type A, F was used for high-strength concrete, and an air-entraining agent was used to produce an impermeable concrete mix. Details regarding the concrete types and their mixing proportions are shown in Table 1.

Materials were mixed together in a small rotary mixer to produce homogenous fresh concrete. Steel molds measuring $150 \times 150 \times 150\ mm^3$ were coated with oil and placed on flat steel plates. Fresh concrete was poured into the waiting molds in three equal layers. Using a tamping rod, each layer was tamped 25 times to remove trapped air. The top surface of the concrete was trowel smoothed and leveled with the top of the mold. After 24 h, the cubes were removed from the molds and completely immersed in water for 28 days.

The experimental program featured 42 cubes divided into five groups. Group I, C17.5, has an expected 28-day compressive strength equal to 17.5 MPa and represents low-strength, high-porous concrete. Group II, C25, has an expected 28-day compressive strength equal to 25 MPa and is most commonly used for industrial RC structures in Egypt. Group III, C25-A, features an air-entraining agent to reduce the permeability of the concrete. Group IV, C25-B, represents concrete protected by a surface coating. Three layers of bitumen were painted on the surface of the Group IV cubes before they were immersed in an oil tank. Group V, C70, represents high-strength, low-porosity concrete.

3.3. Experimental procedures

The procedure adopted to study the compressive strength of oiled concrete is as follows:

(1) After a curing period, 30 concrete cubes were heated to approximately 100 °C and weighed. After 100 days of aging, 15 cubes were immersed in a tank filled with the used gear oil, except Group IV, C25-B, which was coated with three layers of bitumen. After drying, it was also immersed in the same oil tank. The other 15 cubes were kept in a laboratory environment.
(2) Concrete compressive strengths were determined experimentally after 28 and 280 days of concrete cube production. On day 28, twelve cubes were crushed to determine the 28-day compressive strengths of the cubes. Only three specimens were used to represent C25 and C25-B because they contained the same mix. No bitumen was added to the cubes until day 28.
(3) Two days before the test, cubes were removed from the oil tank and wiped with a dry cloth to remove oil from the surfaces; they were then weighed. On day 280, thirty cubes were crushed: 15 oil-free cubes and 15 oiled concrete cubes, which were soaked in oil for 6 months, as shown in Fig. 1. Each cube was placed perpendicular to the cast face in contact with the platform of the testing machine. A load was applied in increments of 5 kN per second until failure. The deformations of the cubes until failure were measured using a dial gauge placed on the moveable head of the machine, as shown in Fig. 1.

4. Experimental results

4.1. Compressive strength

The compressive strengths of the cubes are shown in Table 2. The table shows that the strength of oiled concrete at 280 days of age is slightly higher than that at 28 days of age. The average strength percentage ratio, based on the 28-day strengths, is equal to 1.05, which means that oil has no negative effect on the compressive strength of concrete soaked in oil for 6 months. This finding is consistent with that cited in the literature [11,15]. A greater increase in percentage is observed for C25-B in Table 2. The possible reason for this greater increase may be due to the change in test conditions: cubes crushed at 28 days of age had no bitumen on their surfaces unlike the cubes crushed at 280 days of age. The presence of bitumen may lead to greater bonding and increased friction between the cubes and the head of the machine. On the other hand, the minimal reduction in strength, based on the 280-day compressive strength of oil-free concrete, was observed for C25-B, which was subjected to the same experimental conditions. Therefore, it can be concluded that coating a concrete surface with bitumen is a reasonable method to protect concrete from the oil effect.

The results also show that the oil-free compressive strength of cubes of the same age increased significantly. Sound concrete is expected to have a compressive strength that increases with age if cured under normal conditions. The percent variation of the oiled concrete strength based on the strength of oil-free concrete of the same age is listed in Table 2. The table shows that the strength of oil-free concrete is higher than that of oiled concrete of the same age. The variation in compressive strength is mainly due to the effects of oil, i.e., oil has an aggressive effect on the compressive strength of concrete.

The average compressive strength of the oil-free and oiled concrete samples listed in Table 2 are also shown in Fig. 2. Moreover, Fig. 3 shows the percent variation of the compressive strength of oiled concrete based on both the 28-day and 280-day compressive