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Mechanical Performance of Concrete with Waste from Oil Industry

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In this paper, the mechanical properties of concrete with an added residue of the petrochemical industry (at levels of 10, 20, 30%), called catalytic cracking catalyst residue (FCC), are evaluated. The mechanical properties evaluated include compressive strength, modulus of elasticity, flexural strength, and ultrasonic pulse velocity. Two reference materials, portland cement concrete without addition and added with 20% of metakaolin (MK), were used. These tests were performed up to 360 days of curing age. Based on the results obtained, correlations were established between the different properties evaluated. The best mechanical performance was obtained with 10% FCC as a cement replacement.

Keywords: catalyst spent; mechanical strengths; metakaolin; ultrasonic pulse velocity.

INTRODUCTION

The partial replacement of clinker in portland cement by supplementary materials (such as fly ash, steel slag, natural pozzolans, and thermally activated clays) has given rise to a type of cement called "blended cement." These cements are considered more environmentally friendly than ordinary portland cement (OPC) as their manufacture is less energy-intensive, and they emit fewer greenhouse gases into the atmosphere (it is said to be approximately 17% less than in the production of OPC). Besides this, there is a reduction in the consumption of natural resources.[1,2] The blended cements included in the ASTM C595 standard can be of the binary or ternary type, and it is considered that the addition rate depends on the availability and quality of the by-products, the existing standards, and the market itself.

The catalyst spent in the process of catalytic cracking (FCC) is a residue of the oil industry. According to Marafi and Stanislaus,[3] the total amount generated worldwide is between 300 and 340 × 10^6 lb/year (150,000 and 170,000 tonnes/year). In the last few years, it has been studied and demonstrated that this waste can be used as a pozzolanic material in the construction industry for the production of concrete. It should be noted, however, that most studies have focused on evaluating its effect on pastes and mortars.[4-13] Payá et al.[7] analyzed the effect of incorporating FCC on the mechanical strength (bending and compression) of portland cement mortars at ages up to 28 days; the authors conclude that by reducing the average particle size to approximately 2 μm and increasing the curing temperature to 104°F (40°C), an appreciable increase in strength is achieved, and reported an optimum cement replacement percentage between 15 and 20%.

Su et al.[12] evaluated the properties of two types of spent FCC catalyst, Ecat and EPcat, whose chemical composition of SiO_2/Al_2O_3 is in a ratio of 1.25 and 1.36, respectively; researchers recommend using up to 15% FCC as cement replacement, indicating that there is an excessive demand for water in the mixture. In another study, Su et al.[13] proposed the use of FCC as a substitute for fine aggregate in portland cement mortars and conclude that it is possible to incorporate up to 10% without affecting the final properties of the mortar. Borrachero et al.,[14] however, suggest dosing the FCC as an addition to cement and not as a replacement. Based on a study of the first 48 hours of curing for mortar test specimens with added FCC, and with an addition of 10%, they report strengths of up to double those of the reference mortar.

Reports on the application in concretes, are relatively scarce. Pacewska et al.[15] evaluated concrete with 18.73 lb/ft^3 (300 kg/m^3) of cement added with FCC (10 and 20%) and reported increases in the compressive strength and density and lower water absorption compared to the reference concrete; the strengths of concrete added cured to 28 days are in the range of 7975 to 9425 psi (55 to 65 N/mm^2). Moreover, Neves et al.[16] evaluated the durability of concrete with FCC and concludes that the addition of 15% improves performance in the presence of chlorides, but that the material is more susceptible to attack by carbonation. However, it should be noted that concretes in this case have a cement content of 471.9 lb/yd^3 (280 kg/m^3). These results coincide with those obtained by Torres Castellanos et al.,[17] who in a previous study demonstrated the excellent performance of concrete with FCC in the presence of sulfates.[18]

In this article, some mechanical properties of concrete (10, 20, and 30%) with FCC are evaluated and discussed. The mechanical properties evaluated include compressive strength, modulus of elasticity, flexural strength, and ultrasonic pulse velocity (UPV). The results obtained are compared with the corresponding mixtures added with metakaolin (MK), a pozzolan recognized worldwide whose chemical characteristics are very similar to FCC.

RESEARCH SIGNIFICANCE

FCC as a supplementary cementitious material has been studied lately due to its pozzolanic characteristics. Most of the studies developed were carried out in pastes and mortars, but the studies on concrete mixtures are very scarce. The aim of this study is to investigate the mechanical properties of

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FCC blended concretes and compare with the corresponding properties of a concrete with MK. The results obtained show that the performance of concrete added with FCC is comparable to that of concrete made with well-known pozzolans.

EXPERIMENTAL PROCEDURE

Materials

In this study, OPC and two types of cement additions are used: FCC from a Colombian petroleum company, and MK produced by a Colombian company. Table 1 shows the chemical and physical characteristics of the cement, FCC, and MK. It can be seen that FCC is composed almost entirely of silica and alumina—43.97% and 45.48%, respectively—and has an average particle size of 18 μm. This material, used in previous studies, has been demonstrated to be a pozzolan which has an activity index higher than the 75% limit required by ASTM C618,[19] as can be seen in Table 1; it should be noted that this exceeds the value reported by the addition of MK used in this investigation.

Previous studies using analytical techniques such as X-ray diffraction, infrared spectroscopy, and scanning electron microscopy have found that FCC is partially amorphous; among its crystalline components, there is a faujasite-type zeolite, kaolinite and quartz.[10,11,17,18] In contrast, the MK used in this research is predominantly of amorphous character, with traces of quartz as the only crystalline phase.[20]

Alluvial aggregates with the following characteristics were used in the production of concrete: coarse aggregate with a nominal maximum size of 0.5 in. (12.7 mm), nominal density of 166.6 lb/ft^3 (2668 kg/m^3), unitary weight of 96.3 lb/ft^3 (1542 kg/m^3), and absorption of 3.0%. The characteristics of fine aggregate are a nominal density of 167.2 lb/ft^3 (2679 kg/m^3), nominal weight of 104.1 lb/ft^3 (1667 kg/m^3), absorption of 2.1%, and fineness modulus of 2.84. In Fig. 1, the grading curve for the two types of aggregate can be seen.

Table 1—Chemical and physical characteristics of FCC, MK, and cement used

Characteristics	Cement	MK	FCC
Chemical composition, %			
SiO_2	19.43	53.38	43.97
Al_2O_3	4.00	43.18	45.48
Fe_2O_3	3.61	1.29	—
CaO	64.46	0.05	0.43
MgO	1.52	0.35	—
K_2O	0.39	1.11	0.15
TiO_2	0.34	0.59	0.69
Loss on ignition	2.58	0.52	2.19
Physical characteristics			
Density, lb/ft^3 (kg/m^3)	0.2 (3.13)	2.50 (40.05)	2.63 (42.13)
Pozzolanic activity index	—	92.9	97.4
Average particle size, μm	16.07	7.53	18.00

Note: "—" indicates items not measured.

Preparation of concrete mixtures

A total of five mixtures were made, including a control sample (OPC) and four added mixtures in the following percentages: FCC (10, 20, and 30%) and MK (20%). In Table 2, proportions of the components in each of the mixtures are shown. As can be seen, that the water-cementitious materials ratio (*w/cm*) remained constant (0.5). This value was selected according to the durability requirements expressed in the Colombian Earthquake Resistant Building Code[21] (NSR-10), item C.4.2. To ensure workability in the different mixtures, and due to the high fineness of the additions used, the incorporation of a high-range water-reducing admixture was required. It is noteworthy that the demand for water in the mixture is directly related to the proportion of addition. The percentage of additive, the settling properties, and air content of each of the mixtures thereof is included in Table 2. The samples were cured by immersing them in water saturated with $Ca(OH)_2$ at room temperature until the test age.

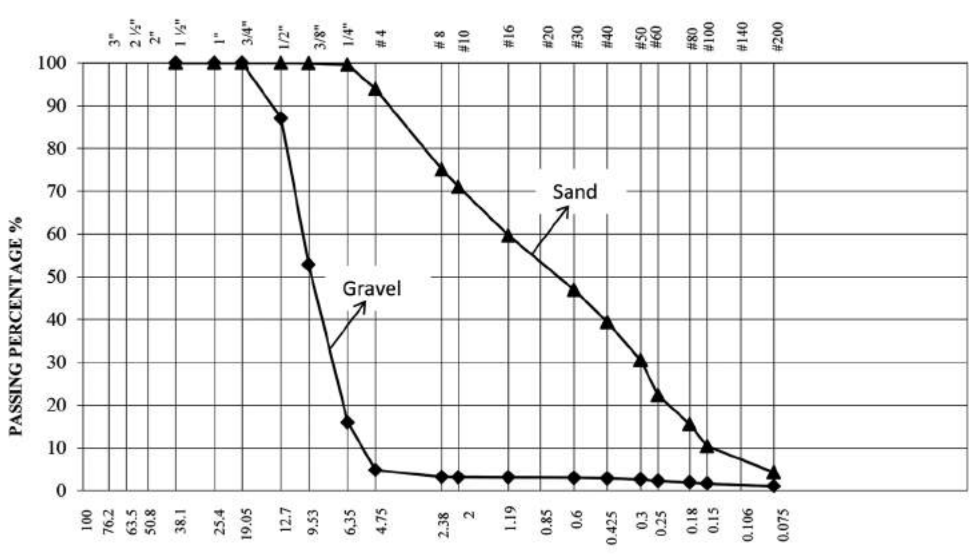

Fig. 1—Grading curve for coarse and fine aggregate. (Note: 1 mm = 0.039 in.)