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Technical Note

Effects of chrome oxide and limestone filler on the wear characteristics of paste and concretes made with white Portland cement

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Abstract

This paper is concerned with the wear characteristics of limestone filler blended white Portland cement paste and concretes with and without chrome oxide. The results indicate that the wear loss in limestone filler blended white Portland cement paste is very high, usually higher than 38 (cm^3/50 cm^2). The wear losses of limestone filler blended white Portland cement concretes range from 21.79 to 27.98 (cm^3/50 cm^2). However, replacement of the limestone filler in the blend by chrome oxide causes a significant decrease in wear loss. This sample has a value of wear loss of 14.83 cm^3/50 cm^2, which is 6.96 cm^3/50 cm^2 less than the value found for white Portland cement concrete without chrome oxide. The apparent correlation between wear loss and flexural strength of white Portland cement concrete observed in this study appears significant.

Keywords: Chrome oxide; Limestone filler; Flexural strength; Wear loss; Paste and concrete

1. Introduction

"Wear of concrete results from the loss of surface quality. Loss of surface quality can be caused by friction during service [1,2] or by several types of surface degredation due to erosion and cavitation [3–8]. Some measures can be taken to decrease the wear loss of concrete. For example, the shrinkage-compensating cement can be used in the production of concrete. This type of concretes displayed a marked decrease in wear loss. This effect is ascribed to the absence of fine cracks which encourage the progress of wear [9–14]. The hardening of concrete surface may also be benefical. In this treatment, a thin layer of hard, transparent inorganic materials such as silicates is applied to the surface of concrete. The compability of their properties of stiffness, brittleness and thermal coefficient of expansion with those of concrete make them most useful for this purpose [15]. This treatment has also been succesfully used in many applications. In the case of solid polymers, such coatings are limited to small areas by the mechanics of application[16]. Some general conclusions as to the wear properties of solid polymers can be found in [17–22]. A decrease in wear loss of concrete can be obtained by the use of selected aggregates [23–27]. The presence of an admixture within a Portland cement paste or concrete often has a profound effect on the wear properties [28–38]." For example, the introduction of a significant proportion of silica fume in Portland cement concrete causes an increase in wear resistance [37]. This effect is attributed primarily to the formation of more C–S–H within the concrete and the decrease in $Ca(OH)_2$ content [38]. These chemical changes caused by silica fume are also of extreme importance, especially for paving applications. However, the mechanical properties of concrete pavements may vary significantly with the percentage of individual material components. These composites generally contain limestone filler and the pigment (chrome oxide). Limestone filler is incorporated in concrete to provide a filled, quite durable and strong paving material. The chrome oxide is a special component originally added for obtaining the desired colour [39–42]. The change in strength resulting from these added admixtures can

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seriously affect the wear characteristics of concrete. Therefore, the wear characteristics should be determined in order to assess properly the feasibility of using an admixture in a given concrete. This information can be obtained, with varying degrees of accuracy, by several experimental approaches [43–45]. This study seeks to relate the strength and wear characteristics to the inherent chemical and physical properties of the components, both the white Portland cement and the chrome oxide. In addition, the relation which is developed to interpret the physical and mechanical behaviour is discussed.

2. Materials and method

Böhme test [43] was used for assessing the wear resistance of paste and concretes. "This test which is also defined in TS 699 consists of measuring the wear loss of the sample sliding on a hard metal surface with carborundum powder". The machine is operated by using a load of 30 kg and a sliding speed of 20 rpm. The wear loses are calculated after at least 440 traversals over the same track. White Portland cement was used in the production of paste and concrete samples. All the blends contained limestone filler. Limestone filler was added in amounts ranging between 18% and 73% by weight of blend. The chemical compositions of white Portland cement and limestone filler are given in Table 1. The composition of concrete is modified with chrome oxide to obtain the desired colour. This treatment allows the use of this particular concrete in specific paving applications. Chrome oxide requires an optimum dosage. Generally, an amount of about 2% is sufficient, this value being far lower than that required for decorative building elements. The properties of chrome oxide is given in Table 2. The aggregate system in the concrete relies on the mixing of three crushed limestone. The mix proportions and particle size distributions of crushed limestones are given in Table 3. The compositions of the paste and concretes containing these components are given in Table 4. The paste and concretes were placed into steel moulds with dimensions $7.1 \times 7.1 \times 7.1\ cm^3$ and then subjected to a load of 4 ton by a flat-ended metal plate of $50.41\ cm^2$ cross-sectional area. The pressed samples in this manner were demoulded and cured in a lime-saturated water at 20 ± 2 °C for 28 days. After curing, they were stored in a laboratory condition of 20 ± 2 °C and 65% R H for 1 day and tested at the end of this period. In addition, flexion test was made on the blended white Portland cement paste and concretes. Dimensions of the sample used in the study of flexion behavior of paste and concretes are $4 \times 4 \times 16\ cm^3$. The production and curing conditions mentioned above were also applied to these samples.

Table 2
Properties of chrome oxide

Cr_2O_3 (%)	98
Residue (45 μm) (%)	0.73
pH value	5–8
Water soluble matter (%)	0.89
Oil absorption	17–32 g/100 g
Moisture (%)	0.65

3. Results and discussion

The data given in Table 5 for white Portland cement paste and concretes are listed in the order of decreasing values of wear loss. This is also the order of decreasing limestone filler content. White Portland cement paste is rich in limestone filler. The wear loss of this paste is of the order of $38.78\ cm^3/50\ cm^2$. This low wear resistance limits the use of this paste to applications where the load and sliding velocity are low. However, it is possible to greatly reduce the wear loss by reinforcing the composition with crushed limestone, without a substantial change in strength. Indeed, a parallel and regular decrease in wear loss is observed with progressive replacement of limestone filler by crushed limestone in white Portland cement concrete. For example, wear loss changes from 38.78 to $21.79\ cm^3/50\ cm^2$ when the limestone filler content varies from 73% to 20%. However, an important contribution to wear resistance is afforded by chrome oxide. The presence of 2% chrome oxide in white Portland cement concrete tends to decelerate the removal of surface material and lower the wear loss. This conclusion is reached when the values of wear loss of 21.79, 25.9 and $27.98\ cm^3/50\ cm^2$ obtained for white Portland cement concretes are compared with that of $14.83\ cm^3/50\ cm^2$ for white Portland cement concrete with chrome oxide. This effect observed may be directly related to the incorporation of Cr throughout the concrete structure as it affects wear [46–55].

Studies of the effect of compressive strength on the wear characteristics of Portland cement concrete have shown that the depth of wear decreases with increasing compressive strength [38,56]. Ghafoori et al. [38], and others [57–59] have found an essentially linear relationship between these variables. The results of this investigation indicate that the wear loss is very much dependent on the flexural strength of white Portland cement concrete. It is possible to derive a relationship between wear loss and flexural

Table 1
Chemical compositions of white Portland cement and limestone filler (wt%)

	SiO_2	CaO	Fe_2O_3	Al_2O_3	MgO	Na_2O	K_2O	SO_3	LOI
White Portland cement	19.4	67.1	0.36	5.3	0.4	0.52	1.35	2.1	3.4
Limestone filler	1.07	53.21	0.10	0.12	0.21	0.08	0.35	0.23	43.73

Table 3
Mix proportions and particle size distributions of aggregates

Aggregate type	Sieve size (mm)								Mix proportion (%)
	31.5	16	8	4	2	1	0.5	0.25	
	Percentage passing								
Crushed limestone	100	60	1						40
Crushed limestone	100	100	58	8	2				24
Crushed limestone	100	100	100	88	58	38	24	14	36

Table 4
Compositions of paste and concretes (wt%)

Mix no.	White cement	Water	Limestone filler	Crushed limestone	Chrome oxide
1	18	9	73		
2	18	9	25	48	
3	18	9	23	50	
4	18	9	20	53	
5	18	9	18	53	2

Table 5
Wear losses and flexural strengths of paste and concretes

Mix no.	Flexural strength (MPa)	Wear loss ($cm^3/50\,cm^2$)
1	5.03	38.78
2	5.75	27.98
3	6.98	25.9
4	7.24	21.79
5	8.28	14.83

strength. The analysis of available data in Table 5 results in the following quadratic equation:

$$y = a \cdot x^2 + b \cdot x + c \tag{1}$$

where y is the wear loss ($cm^3/50\,cm^2$); x is the flexural strength of white Portland cement concrete (MPa); and a, b and c are constants of the material. The three constants could be determined by choosing three wear loss-strength values on the table, writing Eq. (1) using these values, and then solving the three resulting equations simultaneously. The proposed equation with its statistical relevance is also shown in Fig. 1. The result of R^2 indicates that there is a high degree of correlation between these variables.

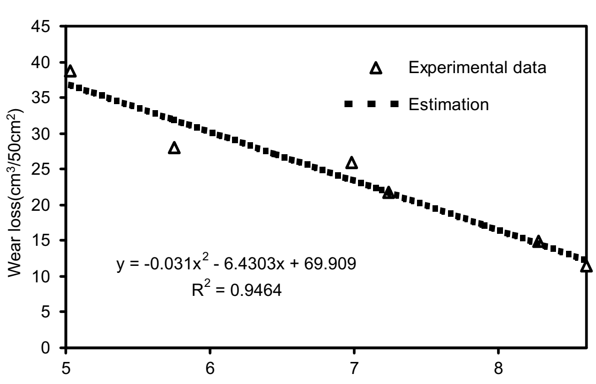

Fig. 1. Correlation between wear loss and flexural strength of white Portland cement concrete.

Eq. (1) has also been used by Ghafoori et al. [56] and others [60–63] for describing the compressive strength dependence of wear loss of concrete. The equation shows excellent agreement with the data on high strength concrete over a wide range of compressive strength.

4. Conclusions

1. A high limestone filler content offers some potential for increasing the susceptibility of white Portland cement paste and concretes to wear. However, replacement of the limestone filler in the mixture by crushed limestone or chrome oxide results in a concrete with a lower wear loss.
2. It is found that for white Portland cement concretes, wear loss can be estimated with somewhat better accuracy if the flexural strength of the sample is taken into consideration.

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