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Evaluation of Pfa concrete for pavement construction and repair

H.I. ElSayad and A.A. Shaat** explore how the use of Pfa as a partial cement replacement can cut costs and improve concrete properties.*

Abstract

Today, highway authorities face the increasingly difficult task of managing an ageing infrastructure. This task is further complicated by the decline in revenues and the substantial increase in traffic flow, speeds and axle weights. The use of pulverised fuel ash (Pfa) as a partial cement replacement in concrete improves the properties of fresh concrete. Pfa's ef- f[illegible] on the absorption, abrasion resistance and some durability aspects of concrete would be favourable. Pfa, being a by-product of burning coal at electricity generating power stations, is cheaper than cement. The cost of new roads and the maintenance of existing ones would, therefore, be reduced if Pfa is used in the mixes. There has been concern, however, about the interaction of Pfa with air-entrainment. The effect of Pfa inclusion on the air-entraining agent (AEA) requirement, quality of void system and freeze-thaw durability of concrete was investigated. The most commonly used Pfa and AEA in the UK were tested. It was found that Pfa concrete requires 2 to 4 times as much AEA as the OPC counterpart for air contents below 5%. For higher air levels and concrete strengths of approximately 30 to 40 N/mm^2, the AEA requirement for Pfa concretes can be more than 8 fold that for OPC ones. Provided that both types of concrete have similar air contents and strength, the air void system and freeze-thaw durability of Pfa and OPC concrete is almost identical.

Introduction

Concrete slabs in a road pavement provide both the main structural strength and the wearing course for the traffic. Specifications for highway works tend to be stringent to ensure that th[illegible]ngth of concrete is adequate. In the UK, the grade of concrete required by the Department of Transport Specification for Highway Works is C40. It is also essential that road concrete is able to withstand the wear and tear of both daily use and environmental conditions. The use of pulverised fuel ash (Pfa) in road type structures would be desirable for many reasons. Due to the low cost of Pfa compared to OPC, some reduction in the cost of produced concrete can be attained when Pfa is used. It has been estimated that a saving of £3.5 per m^3 of concrete can be made if 30% of the cement is replaced by Pfa[1]. Pfa inclusion reduces the water absorption of concrete[2,3]. This is achieved by allowing a reduction in the water content of the mix[4] and blocking the capillaries normally capable of supporting flow[5]. This effect may also be influenced by the increase in the cohesion of fresh concrete and hence the reduction in bleeding and segregation[6]. In addition the use of Pfa is known to dramatically improve the resistance of concrete to chloride ions ingress[7] and sulphate attack[4]. Pfa concrete also possesses excellent mechanical properties. For example, Pfa concrete would continue gaining strength beyond 28 days because of the pozzolanic reaction[6]. Consequently, abrasion resistance of Pfa concrete was found to be greater than that for the OPC counterpart[8].

The cost of repair for deteriorated bridge decks over a period of 20 years is US$60 to 70 billion. It can be argued that because of the effect of Pfa inclusion on the properties of concrete, maintenance cost may be reduced. However, there has been concern about the effect of Pfa on air-entrained concrete[10]. As early as 1949, Larson[11] reported that the substitution of a portion of air-entraining Portland cement with Pfa reduced the air content of concrete. The effect of Pfa on the air void system was studied by Larson[12], Pistilli[13] and Clendenning and Durie[14] with no conclusive results. The freeze-thaw durability of air-entrained Pfa concrete was investigated by Washa and Withey[15], Yamazaki[16], Carrasquillo[17], and Gebler and Klieger[18]. No conclusion can be drawn from these investigations because of variations in the materials used with Pfa, mix proportions and test techniques.

In this investigation, the effect of the most commonly used Pfa in the UK on the dosage requirement of a vinsol resin AEA was studied. Mixes were produced to have air levels of 5.5, 4.5, 3.5, 2.5 and natural or non air-entrained concrete. The design strengths were 15, 20, 30, 40 and 50 N/mm^2 giving 23 combinations in total.

Materials used and specimen preparation

The properties of materials used in this investigation are shown in Table 1. The vinsol resin AEA complied with BS 5075 : Part 2 : 1982. The mix proportions are shown in Table 2. The air content of the fresh concrete was determined using a pressure air meter as suggested by BS 1881 : Part 106 : 1983.

Four prisms (80 x 80 x 300 mm) were prepared from each mix. The specimens, still in their moulds, were cured for 24 hours under wet hessian. The demoulded prisms were then transferred to water curing at 20°C for a further 27 days. At this point two prisms underwent freeze-thaw cycles in accordance with ASTM C666-84. The other two, however, were sliced to expose the central longitudinal plain. They were then prepared for microscopic examination to determine the air void parameters as described in ASTM C457-82.

Table 1. Properties of material used

Property and material	Percentage (%)	
Compound composition of OPC		
C_3S	42.67	
C_2S	30.62	
C_3A	7.01	
C_4AF	10.55	
Physical properties of Pfa		
Loss on igniation	3.6	
Fineness	7.0	
Water reduction	90	
Pozzolanic activity index	101	
Compliance with BS 3892	Part 1	
Properties of aggregates		
	Coarse	**Fine**
Specific gravity	2.63	2.69
Water absorption	1.1	1.2
BS sieve size (mm)		
5.00		100
2.36		100
1.18		70
0.6		57
0.3		37
0.15		9

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Effect of Pfa on AEA dosage requirements

The AEA needed to produce the various air levels in Pfa concrete is plotted, as a ratio of that for OPC counterpart, in Figure 1. It can be seen that the ratio of AEA dosages varies with both the air level and concrete grade. For most air content/grade combinations, Pfa concrete required 2 to 4 times as much AEA as the OPC. However, to produce concrete with 5.5% air this ratio was increased to 6.6 and 8.3 for grades 30 and 40, respectively.

BS 8110 : 1985 requires concrete with maximum size of aggregate of 20 mm (e.g. the concrete used in this investigation) to have an air content of at least 5% if it is at a risk of being damaged by frost. ACI Committee 201, however, states that the concrete with similar properties should have air contents of 6 and 5% for severe and moderate exposure, respectively. It is interesting to find that the effect of Pfa on air-entrained concrete is most pronounced in the range of grades commonly used in practice combined with the air contents quoted in the specifications. This is perhaps the reason for this effect becoming widely known. However, as this behaviour was observed with the single Pfa/AEA combination employed in this study, more research is needed before conclusions can be generalised.

Effect of Pfa on air void system quality

The number of voids per mm is plotted against the air content of the fresh OPC and Pfa concrete in Figure 2. It can be seen that the number of voids for both types of concrete increase with the air content. The data points for OPC and Pfa concrete are very close and sometimes overlap. Therefore at a given air content both types of concrete would possess similar numbers of voids.

The specific surface of the air voids is shown in Figure 3. It is clear that regardless of the air content the specific surface is between 10 and 16 mm^{-1} for both types of concrete. Therefore the sizes of air voids in OPC and Pfa concrete are similar. It would seem that the introduction of Pfa has little or no effect on the air void system of air-entrained concrete provided that enough AEA is added to produce similar air contents in both types of concrete. This supports the arguments of Larson[12].

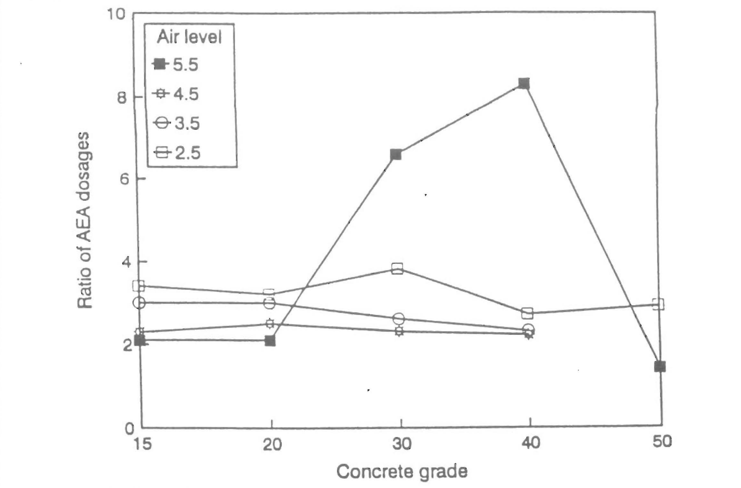

Figure 1. Ratio of AEA dosage used in Pfa concrete to that for OPC concrete.

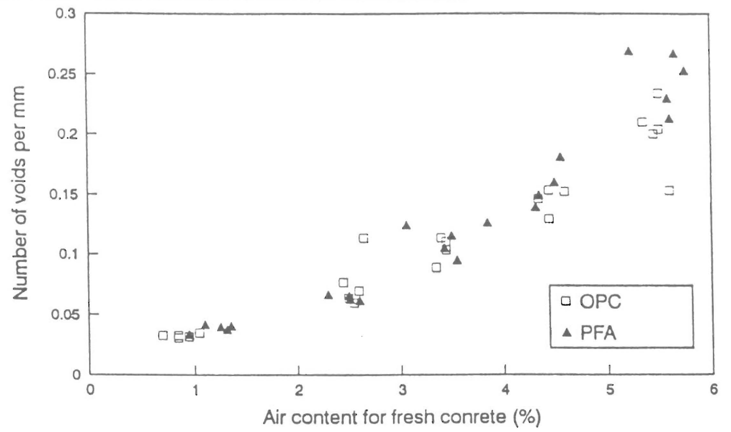

Figure 2. The number of voids per mm as a function of the air content.

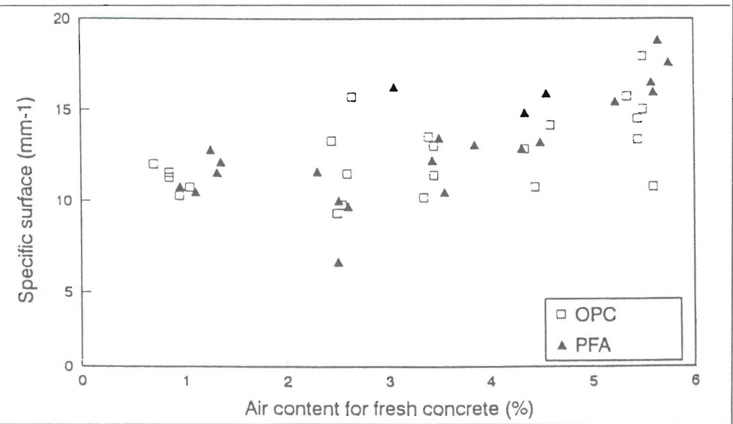

Figure 3. The specific surface of the air voids as a function of the air content.

Effect of Pfa on concrete freeze-thaw durability

The durability factors for the different mixes employed in this investigation, obtained in accordance with ASTM C666-84, are shown in Figure 4. It can be seen that the durability factors for both types of concrete are very similar. Concretes with 4.5 or 5.5% air did not show any sign of distress after 300 freeze-thaw cycles. Non air-entrained concrete deteriorated very quickly and always exhibited low durability regardless of the grade.

Pfa concrete of grade 15 exhibited a lower durability factor than its OPC counterpart. It can be seen from Table 2 that the 28 day strengths of this grade were not comparable. This may explain the poor performance of the Pfa concrete of this grade.

The durability factors of concretes with 2.5% air were dependant on the grade. The relationship for this air level was magnified in Figure 5. Adequate durability factors were obtained only when the grades were equal to or more than C40. It should be noted that the behaviour of Pfa and OPC concrete is identical.

In general it can be seen that the freeze-thaw durability of Pfa concrete is comparable to that of OPC concrete of similar air content and grade. Therefore, the use of Pfa in concrete would reduce the cost of repair or maintenance without sacrificing any of the mechanical and durability properties.

BS 8110 : 1985 requires the concrete to be air entrained if it has a grade lower than C50. ACI Committee 201 permits the reduction of the air contents, for concrete with maximum size of aggregates of 20 mm and strength greater than 37.8 N/mm^2, to 5 and 4% for severe and moderate exposures, respectively. It is clear from Figures 4 and 5 that the recommendations of BS 8110 and ACI Committee 201 are conservative. No alterations of these specifications seem to be needed for Pfa concrete.

Table 2. Mix propotions and compressive strength for the test concretes

Grade	Mix designation	Cementitious material content kg/m³		Water content kg/m³	Sand content kg/m³	Coarse aggregate content kg/m³		Stength N/mm²
		OPC	Pfa			10 mm	20 mm	
15	O15	213	-	166	777	380	765	17.5
	P15	167	73	150	775	395	790	15.1
20	O20	223	-	166	778	380	765	19.6
	P20	172	73	150	756	395	790	20.4
30	O30	281	-	166	739	380	750	31.6
	P30	226	84	150	642	410	825	30.9
40	O40	325	-	166	697	370	750	41.3
	P40	265	90	150	557	425	855	40.7
50	O50	380	-	166	657	375	750	51.9
	P40	313	107	150	450	435	875	50.8

Conclusions

- It would be advantageous to use Pfa in roads, bridge decks and airport slabs made of concrete since Pfa has a beneficial effect on the absorption and mechanical properties of concrete and its resistance to ingress of aggressive elements.
- The increase in AEA dosage for Pfa concrete depends on the desired air level and grade.
- The inclusion of Pfa in concrete has no effect on the air void parameters.
- The freeze-thaw durability of Pfa concrete is similar to that for the OPC counterpart provided that both types of concrete have identical air level and grade.
- The current specifications for air content requirement are conservative.

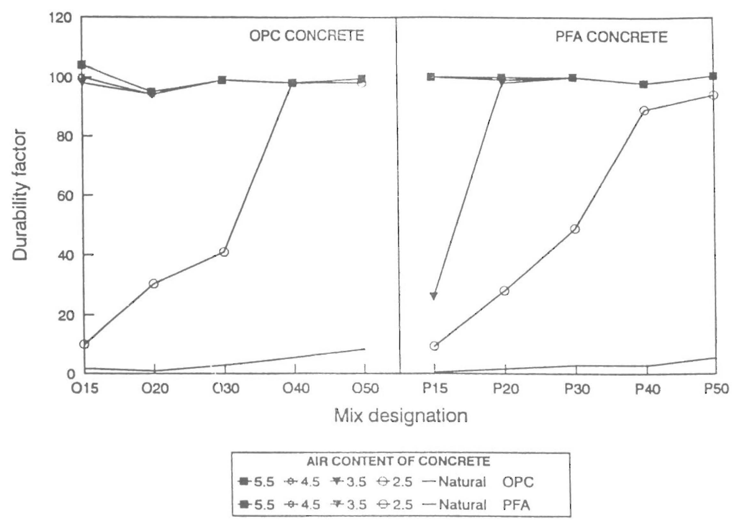

Figure 4. Durability factors for POC and Pfa concrete with diffrent air levels.

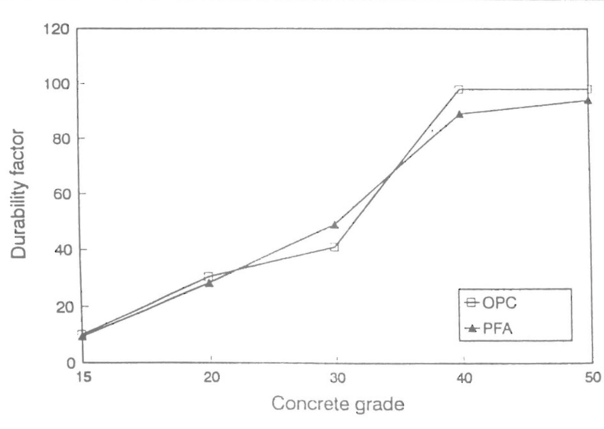

Figure 5. Durability factors for concrete with 2.5% air level.

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Enquiry no: 42