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Characterization of the abrasion resistance and the acoustic wave attenuation of the engineered cementitious composites for runway pavement

Chao Wu [a,*], Yang Pan [a], Tamon Ueda [b]

[a] School of Transportation Science and Engineering, Beihang University, 37 Xueyuan Road, Beijing 100191, China
[b] Division of Engineering and Policy for Sustainable Environment, Faculty of Engineering, Hokkaido University, Kita 13 Jo Nishi 8 Chome Kita-ku, Sapporo 060-8628, Japan

HIGHLIGHTS

- The abrasion resistance and the acoustic wave attenuation of ECC were characterized through experimental tests.
- The compressive and tensile strengths of ECC can be affected by the fiber volume ratio.
- The abrasion resistance of ECC is mainly dependent on the compressive and tensile strengths.
- The acoustic wave attenuation of ECC is linearly related to its void ratio.

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ABSTRACT

Concrete runway pavement is subjected to a critical issue of brittle cracking, which is hazardous for the safety operation of the airport. Engineered cementitious composite (ECC) is a promising pavement material due to its ductility with a strain capacity up to 5%, as well as its desirable micro-cracking and self-healing properties. However, the abrasion resistance and acoustic wave attenuation of ECC, which are important behaviors for a pavement, have not been quantified yet. This paper presents an experimental program to investigate the abrasion resistance and the acoustic wave attenuation of ECC. The experimental results showed that the abrasion resistance of ECC (with 3% fiber volume ratio) could be comparable with the ordinary concrete of the same compressive strength. It was also found that, the acoustic wave attenuation of ECC was positively related with its fiber volume ratio and much higher than that of the ordinary concrete with the same compressive strength. It was interesting to find that the acoustic wave attenuation of ECC was independent of the wave frequency (ranging from 200 Hz to 2000 Hz) of the acoustic signal. The underlying mechanisms for the abrasion resistance and acoustic wave attenuation of ECC were discussed with the measurement of its void ratio, compressive and tensile properties.

1. Introduction

Many international airports have adopted concrete runway pavement due to its high strength and stiffness with low surface deformation [1–3]. However, the concrete pavement has an inherent drawback of brittle cracking, which is hard to repair and limits the service life of the pavement [2,4,5]. The debris from the cracking may also damage the engine of the airplane which raises a critical issue for the safety operation of the airport. Recently, engineered cementitious composite (ECC) has been proposed as the road pavement by many researchers [6–9]. ECC was developed based on the micro fracture mechanics with a strain capacity in the range of 3–7% [10], comparing to 0.1% for ordinary concrete. This ductility of ECC is achieved by micro-cracking (with micro-crack width less than 60 μm [10]) in the strain hardening stage [11]. Considering these advantages, ECC is a promising alternative to the conventional concrete pavement. This can be demonstrated by a pioneer project using ECC as a link slab of a bridge located in southeast Michigan, US [12].

However, before more pavement applications of ECC, many other important properties have to be characterized such as the abrasion resistance [13,14], acoustic wave attenuation [15,16] and etc. This is to ensure that ECC is qualified in every aspect to be used as a pavement material. Unfortunately, the abrasion resistance of ECC has scarcely been reported in the literature [8,17],

* Corresponding author.
E-mail address: wuchao@buaa.edu.cn (C. Wu).

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although this property of the other fiber reinforced concrete has been widely researched. For ordinary concrete, many factors could affect the abrasion resistance, such as the environmental conditions, the cement to sand ratio, the use of special cement or supplementary cementitious materials, etc. [13,14,18–24] As for the polyester fiber reinforced concrete, its abrasion resistance increased when more polyester fibers (0.03–0.14% volume ratio) were added in the mixture [25–27]. However, the above findings on the abrasion resistance of the concrete or fiber reinforced concrete materials may not be directly applicable to the ECC. This is because ECC has different mixture and microstructure. For example, ECC has no coarse aggregate in the mixture, and it uses silica sand with a maximum grain size of 250 μm which is much finer than the sand in the concrete [7,28–31]. In addition, the volume ratio of Poly-Vinyl Alcohol (PVA) fibers in ECC is around 2%, which is about 20 times higher than the fiber volume ratio of the fiber reinforced concrete [25–27]. Therefore, the abrasion resistance of ECC needs to be investigated to be used as the pavement material.

The acoustic wave attenuation is another important property of the pavement because it is related to the noise reduction when the tyres are running on the pavement surface. The pavement is expected to absorb as much noise as possible to limit the interference to the passengers [16] and surrounding environment. However, there has been little research on the characterization of the acoustic wave attenuation of ECC in the literature. This is probably due to the lack of suitable international testing standard to characterize and compare the acoustic wave attenuation among different pavement materials. ISO 11819-1:1997 describes several methods for the measurement of the pavement noise, such as Statistical pass-by method [32], Close-proximity method [33], Reference tyres [34] and SPB method using backing board [35]. However, these methods require building a 100-meter long road with the vehicle running on the pavement and at the same time measure the noise with on-board complicated acoustic facilities [32–35]. Therefore, it is necessary to develop a testing method which is suitable and convenient to be conducted in the laboratory scale to compare and select among different pavement materials. It has been reported that the acoustic frequency generated between the tyres and the pavement ranges between 200 Hz and 2000 Hz [15], i.e. 600 Hz for low-speed road, and 1000 Hz for the high-speed road [15]. Considering these acoustic behaviors, the routine ultrasonic testing method in the structural health monitoring can be resorted to characterize the acoustic wave attenuation of the pavement materials [36–38]. The details and setup of this method will be introduced in the experimental program of this paper.

This paper presents an experimental program to characterize the abrasion resistance and the acoustic wave attenuation of ECC. Specimens of ECC with a fiber volume ratio from 1% to 5% were prepared and tested. For comparison purpose, ECC matrix specimens without fibers and the ordinary concrete specimens with the same compressive strength as the ECC specimens with a fiber volume ratio of 2% were also tested. The abrasion tests were conducted and the index of abrasion resistance of ECC and concrete were calculated. A new method for the characterization of the acoustic wave attenuation of ECC and concrete was developed. Finally, the abrasion resistance and acoustic wave attenuation of ECC were discussed considering the compressive and tensile properties as well as the void ratio of the material. This paper contributes to the understanding on the abrasion resistance and acoustic wave attenuation of ECC for pavement applications.

2. Experimental program

2.1. Materials and mix proportions

ECC specimens with various fiber volume ratios were prepared. The mix proportions of the ECC specimens are presented in Table 1. The name of specimens was denoted using the form of "E-N", where "E" refers to ECC and "N" means the percentage of the fiber volume ratio. The mixture of E-2 was intentionally designed to generate strain hardening and microcracking behaviors according to the micro fracture mechanics [39–41]. While other ECC specimens had the same mix except changing PVA volume ratios.

The raw materials in the mixture of ECC include ordinary Portland cement (P.O 42.5), fly ash, fine aggregate (F-75 silica sand), water, olycarboxylate-based high range water reducing admixture (HRWRA) and the Poly-Vinyl Alcohol (PVA) fibers. Ordinary Portland cement was provided by BBMG Cement Trading Co., LTD, and the chemical properties provided by the manufacturer are listed in Table 2. The fly ash was from Lingshou Country, Lanxiang Mineral Processing Plant with the chemical compositions shown in Table 3. The F-75 silica sand from Huiyan Mineral Processing Plant has a maximum grain size of 250 μm and an average grain size of 110 μm.

Table 1
The mixture of the ECC specimens.

No.	Water (W) (kg/m^3)	Cement (C) (kg/m^3)	Fly ash (FA) (kg/m^3)	Silica sand (kg/m^3)	PVA fiber		HRWRA kg/m^3	W/(C + FA) Ratio	FA/C Ratio
					By weight (kg/m^3)	By volume (%)			
E-0	457	306	969	510	0	0	0.5	0.39	4.7
E-1	453	303	960	505	13	1	1.6	0.39	4.7
E-2	449	300	950	500	26	2	3.3	0.39	4.7
E-3	444	297	940	495	39	3	5.0	0.39	4.7
E-4	440	294	931	490	52	4	6.7	0.39	4.7
E-5	435	291	921	485	65	5	8.3	0.39	4.7

Table 2
The chemical properties of the ordinary Portland cements (P.O 42.5 and P.O 32.5).

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	C_3S	C_2S	C_3A	C_4AF
P.O 42.5	22.09	5.13	3.79	66.33	1.96	55.62	23.37	6.96	12.39
P.O 32.5	20.33	5.31	4.13	67.21	1.91	57.27	18.31	8.05	12.41

Table 3
The chemical composition of the fly ash.

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss on ignition
The fly ash	50.8	28.1	6.2	3.7	1.2	0.8	1.2	0.6	7.9