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Effect of initial moisture of wet fly ash on the workability and compressive strength of mortar and concrete

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HIGHLIGHTS

- Initial moisture contents of wet fly ashes affect the double mixing process.
- Wet fly ashes lead to higher workability in mortar and concrete.
- Wet fly ashes can improve the microhardness values in ITZ.
- Effect of initial moisture contents of wet fly ashes is more significant on fine aggregate.

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ABSTRACT

This study aims to investigate the influence of initial moisture of wet fly ashes on properties of fresh and hardened mortar and concrete. In this study, wet fly ashes are used as a pozzolanic material in concrete with three levels of initial moisture content. The pre-existence of water in the wet fly ashes, equal to the initial moisture content, is considered as the first water in a double mixing method. Correspondingly, the effect of the initial moisture of wet fly ashes is evaluated by using the double mixing method. The studied properties in a fresh state include water requirement, flow of mortar, and slump of concrete. The strength activity index of mortar and compressive strength of hardened concrete are also studied in details. In order to clarify the effect of the initial moisture of wet fly ashes on the above-mentioned properties, microhardness is also examined to consolidate with the experimental results. Test results show that the properties of mortar and concrete are enhanced by using wet fly ashes, as compared to those using dry fly ash. Through microhardness observation, it is also revealed that the Vickers hardness values in the ITZ of the mixtures with wet fly ashes are higher than the values outside the ITZ. This effect is more obvious in the ITZ near the fine aggregate particles than in the ITZ near the coarse aggregate particles.

1. Introduction

In general, fly ash is widely used in various applications, such as used as a raw material in the cement industry, a cement replacement material in concrete, and a filling material. However, the utilization rate of fly ash is not 100% due to the occasional mismatching between the demand and supply of the fly ash. Therefore, some of the dry fly ash has to be dumped near the power plant. In Thailand, the excess of demand, especially for low CaO fly ash, is water-sprayed to have moisture content about 15–20%, before being dumped without the effective use near power plants. The process of the water spray on the dumped dry fly ash is to prevent the spreading of the dry fly ash into the air. This wet fly ash is planned to be used during the high demand period. This large stock of wet fly ash is needed to be more properly managed. If the effective utilization of disposed ash can be achieved, the environment will be improved and the value of the dumped fly ash will also increase. There are two types of fly ash, class F with low CaO content and class C with high CaO content, following ASTM C618 [1]. It is commonly known that unlike the low CaO fly ash, high CaO fly ash has some cementitious properties in addition to the pozzolanic reaction, so it can get hardened in the presence of water while wet low CaO fly ash just tends to agglomerate. The hardened high CaO fly ash requires drying and grinding processes before it can be used in concrete [2]. These processes are not cost effective and the hardened fly ash has already lost some pozzolanic properties. Therefore, the use of wet, high CaO fly ash

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in concrete is difficult in practice [3,4], but the use of wet, low CaO fly ash is still possible. However, information on the utilization of wet fly ash in concrete is still insufficient.

The ITZ is a zone near the aggregate surface, which has different physical properties from that of the matrix paste far from the aggregate surface [5–8]. It is established in experimental research that the ITZ microstructure receives some influences from the mixing process of concrete. Some previous researches have investigated the effects of aggregate characteristics, such as aggregate size and structure of aggregate on ITZ properties [9,10]. The properties of the ITZ around porous aggregates are found to be enhanced in concrete containing porous aggregates, as reported by Kinaanath et al. [11]. They verified that the hardness values near bottom ash particles, obtained from the microhardness test, were higher than those near normal sand particles because of the formation of a hard shell around the bottom ash particles. In addition to bottom ash, recycled aggregates (RAs) are of interest for concrete applications [12,13]. Poon et al. [14] showed that the mechanical properties of RA concrete (RAC) can be improved by modifying the surface properties and the pore structure of the RAs. Thus, the ITZ microstructure in concrete with RAs is an important factor in governing strength development of the RAC. Additionally, the moisture state of aggregate affects the properties of concrete [12,15,16,17]. Poon et al. [16] investigated the influence of moisture states of natural and recycle aggregate on the slump and compressive strength of concrete. The moisture states of the aggregates were controlled at air-dried (AD), oven-dried (OD), and saturated surface-dried (SSD) states prior to use. The test results showed that the initial slump of concrete was dependent on the initial free water contents, and the slump loss values of concrete were related to the moisture content states of the aggregates.

The mixing process is a major factor to influence the properties of ITZ, especially in RAC [9,18,19]. The double mixing method (DM) has been applied to improve the ITZ near RA particles. By using the DM, the premixing process can fill up some pores and cracks of RAs. RA particles are coated with a paste with lower water to binder ratio than the rest of paste matrix. Hence, the ITZ is more compact. Moreover, Deyu et al. [14] applied a triple mixing method (TM) in RAC containing pozzolanic materials, such as fly ash, slag, and silica fume. The surface of RAs was coated with pozzolanic materials by TM, and thus, properties of the ITZ were further enhanced. It was revealed that the strength and durability of the RAC were further enhanced.

The effect of the moisture content of fly ash on properties of concrete has not been observed. The objective of the present study is to describe the influence of the initial moisture content of fly ash, low CaO content in particular, on concrete properties. This experimental program was prepared to study the properties of fresh and hardened mortar and concrete with dry fly ash, as well as wet fly ashes with different initial moisture contents. The examined properties of fresh mortar are water requirement and flow, while slump is measured for studying the properties of fresh concrete. Furthermore, the micro-hardness test is also conducted to clarify the influence of the initial moisture contents of wet fly ashes on the tested hardened concrete properties. The double mixing process was also carried out to explain the effect of moisture content of the wet fly ashes on the obtained properties. The essential point of this study is not on the double mixing but on verifying that the use of dumped wet fly ash is possible without having problems on concrete properties. The test on double mixing was conducted just for explaining the reasons of enhanced properties especially workability due to the pre-existence of water in the wet fly ash. This study also considers the effect of aggregate size on the microhardness of the ITZ in concrete. It is believed that this article provides useful information for applications of wet fly ashes in concrete production.

2. Experimental program

2.1. Materials

A locally produced cement, equivalent to ASTM Type I Portland cement, was used in this study. A low CaO fly ash was collected from a Power Plant in Rayong province, Thailand. All pairs of tested dry fly ash and wet fly ash samples were collected from the same lot of production. The actual moisture content of the dumped

Table 1
Mineral compositions of dry fly ash and wet fly ashes by X-ray diffraction analysis.

Mineral compositions (%)	Dry fly ash	Wet fly ashes		
	FA	FA-25	FA-45	FA-65
Amorphous	68.04	68.2	67.44	69.56
Quartz	15.47	15.27	16.56	15.61
Mullite	12.53	12.93	13.34	12.83
Hematite	0.32	0.32	0.32	0.37
Magnetite	1.04	1.12	1.16	1.08
Diaoyudaoite	2.61	2.17	1.27	0.57

Table 2
Chemical composition of ordinary Portland cement Type I, dry fly ash, and wet fly ashes.

Chemical compositions (%)	OPC	Dry fly ash	Wet fly ashes		
		FA	FA-25	FA-45	FA-65
SiO_2	19.70	61.09	61.39	61.26	61.30
Al_2O_3	5.19	20.35	19.99	20.11	20.06
Fe_2O_3	3.34	5.20	5.32	5.19	5.14
CaO	64.80	2.32	1.75	1.83	1.90
MgO	1.20	1.35	1.36	1.35	1.37
SO_3	2.54	0.28	0.28	0.21	0.25
Na_2O	0.16	0.79	1.16	1.33	1.03
K_2O	0.44	1.36	1.32	1.40	1.41
TiO_2	0.25	0.98	1.01	0.93	0.99
P_2O_5	0.11	0.23	0.30	0.32	0.30
SrO	–	0.09	0.08	0.08	0.08
ZrO_2	–	0.07	0.07	0.06	0.07
Free CaO	0.87	0.03	0.02	0.02	0.04
LOI	2.10	5.68	5.81	5.82	5.94