Utilization of asphalt waste Dust and fly ash for sustainable mortar

Jiratchaya Ayawanna [1], *Namthip* Kingnoi[2], *Pimchanok* Sertsoongnern[1], and *Salisa* Chaiyaput[2]

[1]School of Ceramic Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand
[2]School of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand

Abstract. This study presents a utilization of asphalt waste dust (AD) as a filler material to replace sand in a mortar. Moreover, fly ash (FA) is utilized as an additive of pozzolanic material. The compressive strength and microstructures were investigated to propose the suitable ratio of AD and FA for sustainable mortar. All samples were fixed with a mixing ratio of ordinary Portland cement (CM): sand (Si) at 1: 2.75. The Si was replaced by AD content at 0, 50, 60, 70, 80, 90, and 100% by weight (%wt) of Si, respectively. Furthermore, the FA was added to the suitable mixing conditions of CM, AD, and Si, which is called the suitable mortar containing AD, at 0, 10, 20, 30, and 40 %wt. The results from the compressive strength test were evaluated and compared under the different curing times for 3, 7, and 28 days in saturated limewater. The microstructures of testing samples were analyzed using different characterization techniques including X-ray diffraction (XRD) and scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (SEM-EDS). From the results, the mortar containing AD showed higher compressive strength than those without AD. After the addition of FA and AD, the compressive strength was more increased rather than using AD without FA. Sand can be replaced with AD as filler aggregates to reduce voids in the mortar. Additionally, FA can be used as a pozzolanic additive in mortars. Therefore, those two waste materials (AD and FA) are alternative materials suitable for use in the development of compressive strength in mortar.

1 Introduction

Mortar is a wide bonding material used in building construction to bond bricks and many other masonry materials into structures. Mortar is a homogenous mixture of cementitious materials, fine aggregates, and water. Fine aggregate is one of the main components in mortar production and has a significant influence on mortar strength. Sand is commonly used as fine aggregate to increase the volume of the mortar and increase the strength of masonry [1].

Asphalt waste dust is by-product waste material from asphalt concrete production. In the manufacturing process, the residual waste dust occurs from the incineration of stone at 150 – 170 °C before being mixed with asphalt concrete. Currently, a large amount of asphalt waste dust is disposed of in landfills, which require a large area and are costly to eliminate this abandoned waste dust. Asphalt waste dust contains a high content of calcium oxide (CaO) similar to the composition of limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). From XRD results, it was determined that calcium carbonate in the form of calcite phase is a stable phase at room temperature. This means that asphalt waste dust is an inert material [2]. Meanwhile, fly ash is a by-product containing a high content of silicon dioxide (SiO_2) and aluminium oxide (Al_2O_3) from coal-fired thermal power plants, and it is widely used as a substitute for cement as an additive of pozzolanic materials [3]. The micro-spherical shape of the fly ash particles can boost the pozzolanic activity, which is related structural density and stability of mortar. The fly ash (class C) has calcium (Ca) content higher than 20%, which shows cementitious properties similar to ordinary Portland cement [4-5].

Therefore, the two waste materials have interesting compositions: asphalt waste dust from the production of asphalt concrete and fly ash from coal-fired thermal power plants. The use of asphalt waste dust and fly ash for mortars was investigated.

2 Materials

2.1 Materials

The main raw materials used for this study were asphalt waste dust, fly ash, ordinary Portland cement, and sand. The asphalt waste dust (AD) was obtained from the asphalt concrete plant at Saraburi, Thailand (Fig. 1a). Fly ash (FA) was taken from the Mae Moh power plant with high calcium fly ash, which was classified as class C (Fig. 1b). According to standard ASTM C618-22 [6], fly ash (class C) contains more than 20% of calcium oxide (CaO). Ordinary Portland cement (type I) was used (Fig. 1c). According to ASTM C136/C 136M-19 [7], C33/C 33M-18. [8] standard, sand with a fineness modulus of 2.18 was utilized and categorized as fine sand (Fig. 1d).

2.2 Materials characterization

The chemical composition of asphalt waste dust, fly ash, and ordinary Portland cement used in this study was

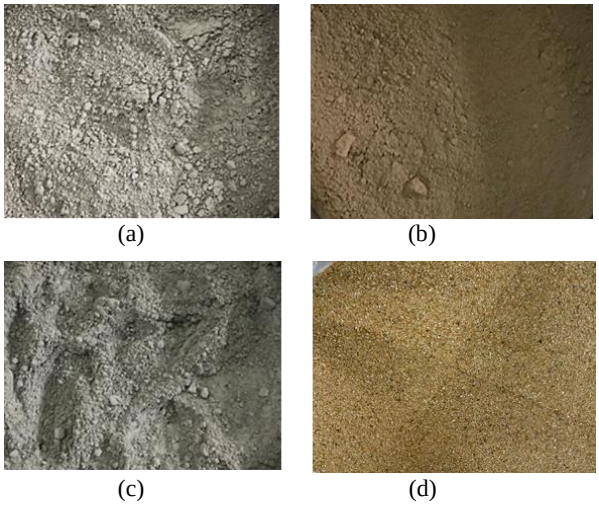

Fig. 1. Materials (a) asphalt waste dust (b) fly ash (c) ordinary Portland cement (d) sand.

characterized by Energy Dispersive X-ray Fluorescence (ED-XRF; Horiba XGT-5200). The phase composition was investigated using an X-ray diffractometer (XRD; Bruker D2 PHASER) with Cu-Kα radiation over the 2θ range of 10°-60°. Meanwhile, the particle size distribution analysis was examined using (PSD; Laser scattering particle size distribution analyzer LA-950V2).

3 Mix proportions and test methods

Tables 1 and 2 show all the testing conditions or the condition of mortar mixture samples. All testing conditions were prepared in a weight ratio of 1: 2.75 (ordinary Portland cement: Sand) following the standard ASTM C109/C109M [9].

Table 1. Mix proportion of asphalt waste dust as sand replacement in mortar.

Sample ID.	Mix proportion ratio		
	CM	AD	Si
AD0	1 (26.67%wt)	-	2.750 (73.33%wt)
AD50	1 (26.67%wt)	1.375 (36.67%wt)	1.375 (36.67%wt)
AD60	1 (26.67%wt)	1.650 (44.00%wt)	1.100 (29.33%wt)
AD70	1 (26.67%wt)	1.925 (51.33%wt)	0.825 (22.00%wt)
AD80	1 (26.67%wt)	2.200 (58.67%wt)	0.550 (14.67%wt)
AD100	1 (26.67%wt)	2.750 (73.33%wt)	-

Noted: ordinary Portland cement (CM), Asphalt waste dust (AD) and Sand (Si)

Table 2. The fly ash content as an additive of pozzolanic material in a mortar containing asphalt waste dust (AD).

Sample ID.	Mix proportion ratios			Fly ash (FA) (wt%)
	CM	AD	Si	
AD50-FA0	1	1.375	1.375	0
AD50-FA10	1	1.375	1.375	10
AD50-FA20	1	1.375	1.375	20
AD50-FA30	1	1.375	1.375	30
AD50-FA40	1	1.375	1.375	40

Noted: ordinary Portland cement (CM), Asphalt waste dust (AD), Sand (Si) and Fly ash (FA).

For the compressive strength test, the testing samples were prepared as a cube (50 x 50 x 50 mm). The testing samples were cured for 3, 7, and 28 days in saturated-lime water before testing by using a compressive strength test machine with a capacity of 100 kN and a 1 mm/min loading rate.

After the compressive strength test, the XRD analysis was performed by an X-ray diffractometer (Bruker D2 PHASER). The microstructure of the testing samples was examined by scanning electron microscopy (SEM; JEOL JSM6010 LV) accompanied by an elemental analysis by Energy dispersive spectroscopy (EDS).

4 Results and discussion

4.1 Particle size distribution

Table 3 shows the particle size distribution (PSD) of asphalt waste dust, fly ash, and ordinary Portland cement. The average particle size D (V,0.5) of asphalt waste dust is smaller than those of fly ash and cement, respectively. These small particle sizes of asphalt waste dust were acting as a good filler material.

Table 3. Particle size distribution of asphalt waste dust, fly ash, and ordinary Portland cement.

Raw Materials	D (V,0.5) / μm	SD
Asphalt waste dust	6.892	0.055
Fly ash	9.858	0.222
Ordinary Portland cement	11.325	0.552

Table 4. Chemical composition of asphalt waste dust, fly ash, and ordinary Portland cement.

Raw materials	Oxides, wt%						
	CaO	SiO_2	Fe_2O_3	Al_2O_3	SO_3	MgO	C
Asphalt waste dust	81.80	1.69	0.48	0.97	-	2.39	4.41
Fly ash	28.97	26.68	18.12	14.68	6.62	2.65	2.28
Ordinary Portland cement	68.22	15.89	3.29	3.64	3.39	1.16	4.41

4.2 Chemical and Phase compositions

The chemical composition of asphalt waste dust, fly ash, and ordinary Portland cement from the XRF analytical analyzer is shown in Table 4. The major chemical composition in asphalt waste dust is calcium oxide (CaO), which is an environmentally-friendly component greater than 80% by weight [10]. The result is consistent with the XRD analysis (Fig. 2a). Fig. 2a showed that the main phase of asphalt waste dust includes calcium carbonate ($CaCO_3$) as a major phase and dolomite $CaMg(CO_3)_2$ as a minor phase. Moreover, the highest intensity peak at 2θ degrees was around 29.5°, which represented a calcite structure. The calcite phase is a rhombohedral crystal, which is the thermodynamically stable phase of calcium carbonate at room temperature [11]. This means that the asphalt waste dust is an inert material and is also used as filler material in mortar mixed with fly ash.

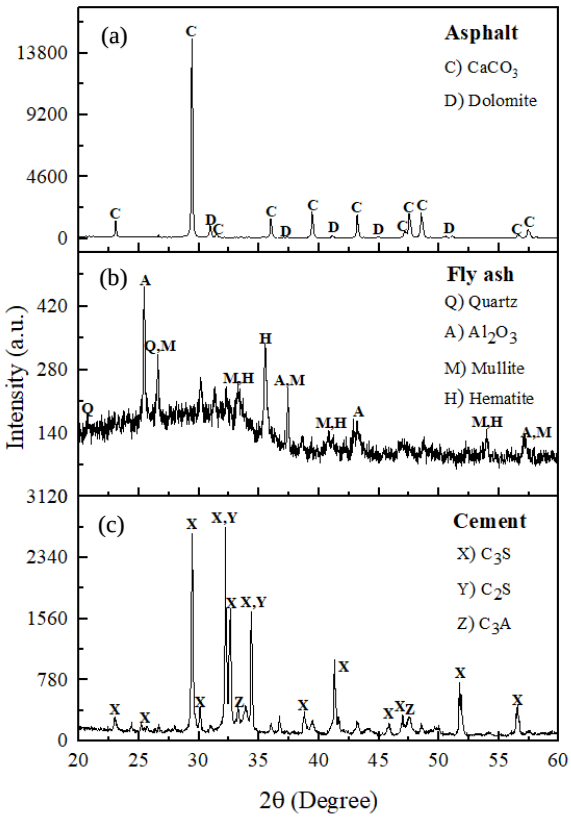

Fig. 2. XRD patterns of (a) asphalt waste dust (b) fly ash (c) ordinary Portland cement.

Meanwhile, fly ash, which is classified as class C, has four major components of 28.97% of calcium oxide (CaO), 26.68% of silicon dioxide (SiO_2), 18.12% of hematite (Fe_2O_3), and 14.68% of alumina oxide (Al_2O_3) as shown in Table 4. Figure 2b shows the XRD patterns of fly ash. Mostly quartz (SiO_2) and mullite ($3Al_2O_3.2SiO_2$) were observed as major phases. Moreover, the presence of crystalline and amorphous phases was found in fly ash (class C). The hump peak is an indication of amorphous characteristics, which present between 25 – 35°. Therefore, the fly ash with amorphous component is a positive effect on pozzolanic reaction [12].

The chemical composition of ordinary Portland cement is composed of 68.22% of CaO as a major chemical composition followed by 15.89% of SiO_2 as a minor chemical composition. The other trace oxides belong to Fe_2O_3, Al_2O_3, sulphur trioxide (SO_3), magnesium oxide (MgO), and carbon (C) as shown in Table 4. The consistent with XRD analysis in Figure 2c, the tricalcium silicate ($3CaO.SiO_2$; C_3S), dicalcium silicate ($2CaO.SiO_2$; C_2S), and tricalcium aluminate ($3CaO.Al_2O_3$; C_3A) were major phases in ordinary Portland cement. As C_3S is the main contributor to strength of cured mortar in early phases and involves the hydration reaction for precipitation of calcium silicate hydrate (CSH) and calcium hydroxide ($Ca(OH)_2$).

4.3 Compressive strength

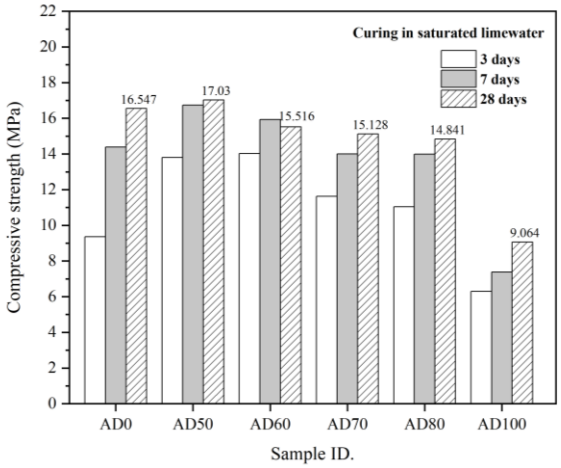

Fig. 3. Compressive strength of mortar containing asphalt waste dust (AD) at different mix ratios with curing in saturated limewater for 3,7 and 28 days.

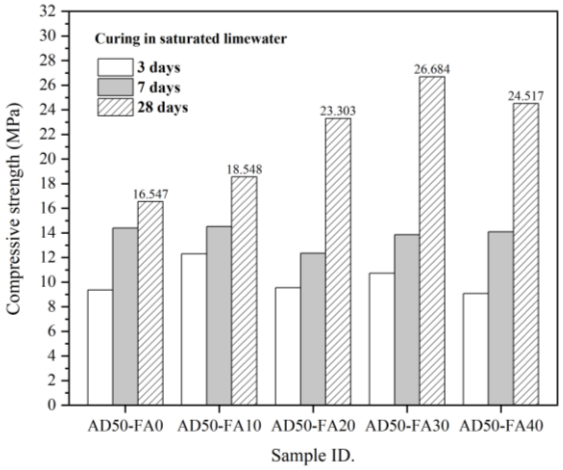

Fig. 4. Compressive strength of mortar containing 50% of asphalt waste dust at different fly ash content curing in saturated limewater for 3, 7, and 28 days.

The compressive strength and curing time of mortar at different asphalt waste dust mix ratios are shown in Fig. 3. The mortar without asphalt waste dust (AD0) has a lower compressive strength than mortar containing asphalt waste dust (AD50) for all curing days. After the addition of asphalt waste dust, the compressive strength was increased, especially for 7 days. The AD50 compressive strength was found to be 17.03 MPa at 28 curing days, which has a maximum compressive strength. This could be explained by the filler effect of fine particles of asphalt dust on the compressive strength of mortar, which was investigated by Wu et al. [13].

However, the compressive strength of mortar containing asphalt waste dust increased at the early age of 3 and 7 days but not much increased at the later age of 28 days.

Furthermore, the compressive strength of mortar containing asphalt waste dust with different fly ash (FA) content is shown in Fig. 4. The compressive strength increases with the increase of fly ash content. Moreover, the addition of fly ash content, which is pozzolanic material, reacted with calcium hydroxide to produce additional cementitious compounds. The pozzolanic reaction of fly ash in mortar resulted in a significant enhancement of the long-term compressive strength, particularly after 28 days.

The AD50-FA30 condition exhibits the highest compressive strength after 28 days. It has been found that the presence of fly ash (class C) tends to decrease the compressive strength in the early stages, specifically at 3 and 7 days. However, it has a positive effect on long-term strength, particularly at 28 days [14].

4.4 Phase composition

According to Fig. 5, the XRD results show the formation of quartz (SiO_2) as a major phase and calcium carbonate ($CaCO_3$) as a minor phase. Moreover, other phases including calcium hydroxide ($Ca(OH)_2$), dolomite ($CaMg(CO_3)_2$), and gypsum ($CaSO_4.2H_2O$) were observed in the trace phase composition.

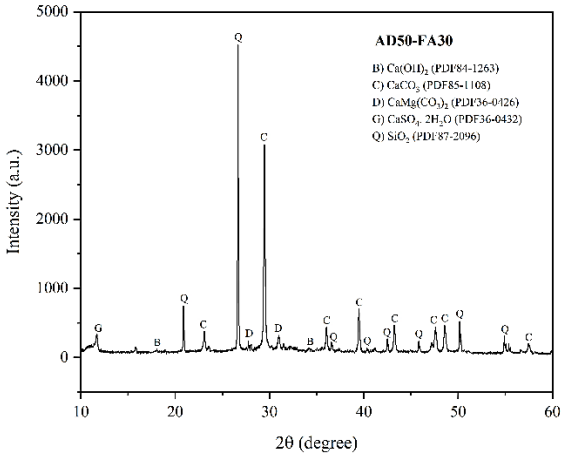

Fig. 5. XRD pattern of mortar containing 50% of asphalt waste dust and 30% of fly ash (class C) curing in saturated limewater for 28 days.

4.5 Microstructures

According to Fig. 6, the SEM image showed the spherical shape-like fly ash (FA) in the mortar containing asphalt waste dust and fly ash. As evidenced by the microstructure, high packing density leads to the extremely compressive strength of mortar containing 50% of asphalt waste dust and 30% of fly ash (class C).

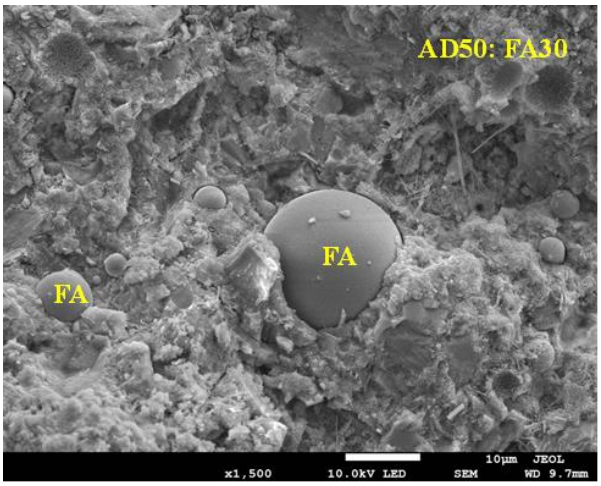

Fig. 6. SEM image of mortar containing 50% of asphalt waste dust and 30% of fly ash (class C) curing in saturated limewater for 28 days.

5 Conclusion

In this study, asphalt waste dust and fly ash were used in the mortar in order to study the possibility of using those two waste materials to improve the compressive strength of the mortar. The findings are as follows:

1. Asphalt waste dust is utilized as a filler material. Asphalt waste dust is an inert material that does not react with cement. Nevertheless, it can enhance the strength of mortar by filling in the gaps between cement, sand, and fly ash particles.
2. The utilization of asphalt waste dust results in enhanced compressive strength during the early age, whereas the addition of fly ash (class C) leads to improved compressive strength at 28 days.

The authors would like to acknowledge Suranaree University of Technology (SUT), and Thailand Science Research and Innovation (TSRI). King Mongkut's Institute of Technology Ladkrabang and KMITL Smart Material Center (KSMC) are also highly appreciated.

References

1. I.B. Muhit, M.T. Raihan, M.D. Nuruzzama, Determination of mortar strength using stone dust as a partially replaced material for cement and sand. Adv. Concr. Constr. **2**, 249-259 (2014). https://doi.org/10.12989/acc.2014.2.4.249.
2. K. Suito, J. Namba, T. Horikawa, Y. Taniguchi, N. sakurai, M. Kobayashi, A. Onodera, O. Shimomura, T. Kikegawa, Phase relations of $CaCO_3$ at high pressure and high temperature. Am. Mineral. **86**, 997-1002 (2001). https://doi.org/10.2138/am-2001-8-906.
3. A. Dwivedi, M.K. Jain, Fly ash – waste management and overview: a review. Recent Res. Sci. Tech. **6**(1): 30-35 (2014).
4. I.M.T. Tatarchuk, N. Paliychuk, I. Heviuk, A. Horpynko, O. Yarem, I. Mykytyn, Effect of surface-modified fly ash on compressive strength of cement mortar. Mater. Today. **35**(4), 534-537 (2021). https://doi.org/10.1016/j.matpr.2019.10.016.
5. S. Shirkhanloo, M. Najafi, V. Kaushal, M. Rajabi, A comparative study on the effect of class C and class F fly ashes on geotechnical properties of high-plasticity clay. Civil Eng. **2**, 1009–1018 (2021). https://doi.org/10.3390/ civileng2040054.
6. ASTM C618-22. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. ASTM International, West Conshohocken, PA (2022).
7. ASTM C136/C 136M-19. Standard test method for sieve analysis of fine and coarse aggregates. ASTM International, West Conshohocken, PA (2020).
8. ASTM C33/C 33M-18. Standard specification for concrete aggregates. ASTM International, West Conshohocken, PA (2019).
9. ASTM C109/C 109M-20. Standard test method for compressive strength of hydraulic cement mortars (using 2-in. or [50-mm] cube specimens). ASTM International, West Conshohocken, PA (2020).
10. S. Chaiyaput, N. Arwaedo, N. Kingnoi, T.N. Nguyen, J. Ayawanna, Effect of curing conditions on the strength of soil cement. Case Stud. Constr. Mater. 16, e01082 (2022). https://doi.org/10.1016/j.cscm.2022.e01082.
11. S. Chaiyaput, P. Sertsoongnern, J. Ayawanna, Utilization of waste dust from asphalt concrete manufacturing as a sustainable subbase course material in pavement structures. Sustainability. **14**, 9804 (2022). https://doi.org/ 10.3390/su14169804.
12. Y.K. Cho, S.H. Jung, Y.C. Choi, Effects of chemical composition of fly ash on compressive strength of fly ash cement mortar, Constr. Build. Mater. **204**(20), 255-264 (2019). https://doi.org/10.1016/j.conbuildmat.2019.01.208.
13. C.H. Wu, C.H. Huang, Y.C. Kan, T. Yen, Effects of fineness and dosage of fly ash on the fracture properties and strength of concrete. Appl. Sci. **9**(11), 2266 (2019). https://doi.org/10.3390/app9112266.
14. C.H. Huang, S.K. Lin, C.S. Chang, H.J. Chen, Mix proportions and mechanical properties of concrete containing very high-volume of Class F fly ash, Constr. Build. Mater. **46**, 71-78 (2013). https://doi.org/10.1016/j.conbuildmat.2013.04.016.