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EVALUATION OF WASTE PERLITE FINES IN THE PRODUCTION OF CONSTRUCTION MATERIALS

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The use of supplementary cementitious materials (SCM) is a well established practice worldwide in the manufacture of Portland cement (PC)-based construction materials. While utilisation of industrial by-products has been successful, the potential of mining wastes is yet to receive adequate attention in the context of construction materials. In an expanded form perlite, which is a naturally occurring, hydrated volcanic siliceous glass, is an ideal material as a lightweight aggregate for use in a wide range of construction materials including concrete. The mining and processing of the grades of perlite required for the production of lightweight aggregate results in the creation of a fine grained waste which currently has no economic value. This paper reports preliminary data on the utilisation of waste perlite fines as a SCM in calcium silicate-based construction material and discusses the potential of this mining waste to reduce the environmental impact of the production of conventional cement-based construction materials.

Keywords: *mining waste, perlite, portland cement, pozzolan*

Introduction

Portland cement (PC) based building products, such as concrete, consume vast quantities of both natural resources and energy, and constitute a large proportion of the materials used in the construction industry. The manufacture of PC is one of the largest single contributors to the greenhouse effect accounting for between 5 and 10% of global anthropogenic carbon dioxide (CO_2) emissions [1]. The production of PC liberates one tonne of CO_2 for each tonne of PC manufactured [2]. A reduction in PC consumption will, therefore, significantly reduce energy consumption and CO_2 emission. In this context, the use of industrial waste products to blend with PC helps not only to reduce energy consumption but also to conserve dwindling natural resources and to solve problems encountered in disposal of the waste. Supplementary cementing materials (SCM) such as fly ash, silica fume, blast furnace slag and alkali activated slag are utilised worldwide to partially replace PC [3]. Recent research has demonstrated that clay brick fines, another industrial waste product and a source of both alumina and silica, can be utilised as partial replacement of PC in the manufacture of PC based construction materials [4–6]. While wastes from industrial by-products have received attention from researchers and practitioners in their utilisation in PC based construction materials, the potential of mining by-products, which are essentially naturally occurring raw materials, has not been investigated as intensively in this field. The proposed project investigates the use of one such waste material, perlite fines.

Perlite is a generic term for naturally occurring, hydrated volcanic siliceous glass. A characteristic which separates perlite from other naturally occurring volcanic glasses is its ability to expand upon heating. These properties make expanded perlite ideal as a lightmass aggregate for use in a wide range of construction materials including concrete. Expanded perlite increases concrete's insulating qualities and fire resistance [7]. Perlite is mined all over the world including Australia because of high demand for expanded perlite in construction, horticultural and industrial applications [8]. The mining and processing of the grades of perlite required for the production of this lightmass aggregate material, however, results in the production of perlite fines which currently have no economic value and are stockpiled as waste at the mine site. A recent publication has highlighted the potential of fine perlite in suppressing the deleterious alkali silica reaction in cement systems [9]. Little has been reported in the literature on the use of fine perlite and its pozzolanic activity. In Australia, a large perlite deposit in the Nychum district, near the town of Chillagoe in far north Queensland, approximately 200 km west of Cairns, has been developed by King Eagle

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Resources Pty Ltd. (KER). The deposit has an in situ resource potential exceeding 100 million tonnes of high quality perlite. The current mining operations at Nychum include crushing of the excavated perlite followed by screening prior to transportation from the quarry for further processing and marketing. Approximately 30% of the crushed perlite is less than 0.5 mm, which is regarded as waste and is currently stockpiled at the mine site in the form of waste dumps as no alternative use has yet been found.

The subject of this paper is the evaluation of waste perlite fines as a supplementary material in the production of Portland cement-based construction materials. In this preliminary study, the effects of perlite fines as partial replacement of PC have been evaluated by comparing mortar samples made with equivalent proportion of two of the widely accepted pozzolanic materials, namely fly ash and silica fume. Differential thermal analysis (DTA), thermogravimetry (TG) and compressive strength determinations along with X-ray diffraction (XRD) were employed to characterise the mortar samples.

Experimental

Raw materials

The following raw materials were used:

General purpose (GP) portland cement having the typical composition of 20% SiO_2, 64.2% CaO, 4.5% Al_2O_3, 3.7% Fe_2O_3 and 3% SO_3, was used in the preparation of mortar mixes. Fine washed sand 2 and 52% passing the standard 600 and 300 micron sieves was used in the mortar mixes. An equal amount of superplasticiser (Glenium 51) to produce workable mortar mixes necessary for hand compaction was used.

Perlite fines, with a chemical composition as listed in Table 1, was supplied by the King Eagle Resources Pty Ltd.

Table 1 Chemical composition of waste perlite fines

	Mass/%		Mass/%
SiO_2	70.30	CrO_3	<0.01
Al_2O_3	13.32	TiO_2	0.09
Fe_2O_3	1.28	MnO	0.02
CaO	1.24	P_2O_5	0.04
MgO	0.13	SrO	0.02
Na_2O	4.36	BaO	0.06
K_2O	2.06	LOI	7.90

Mixing of mortar

The sand to cementitious materials ratio and water to cementitious materials ratio by mass for all mortar mixes were kept constant at 2.75 and 0.40, respectively. A high-range water-reducing admixture was used to achieve sufficient consistency required for uniform mixing. A control mix with GP cement alone along with three other mortar mixes, containing 10% by mass replacement of PC with perlite fines, fly ash and silica fume were produced in a Hobart mixer. Table 2 summarises the compositions of the four mortar mixes investigated in this study.

Casting, curing and testing of mortar cubes

For each mortar mix, a total of twelve 50 mm mortar cubes were cast in steel moulds. The fresh mortar was placed in the moulds in layers and compacted with a standard tamping rod to achieve full compaction of the cubes. The cubes were removed from the moulds after 24 h; three cubes were tested for their 1-day compressive strength. A set of three cubes were placed in a hot water bath at 55°C for two days to accelerate the strength development and tested at the age of 3 days. The remaining cubes were placed in water at room temperature of 20°C until testing at the ages of 7 and 28 days. At each testing age, three cubes were tested and the mean cube strength is reported in Table 3.

Table 2 Composition and density of mortar mixes

Material	Control	10% perlite	10% fly ash	10% silica fume
Cement type GP/g	1000	900	900	900
Fine sand/g	2750	2750	2750	2750
Perlite/fly ash/silica fume	0	100	100	100
Water/g	430	430	430	430
Water/binder ratio	0.43	0.43	0.43	0.43
Superplaticiser/g	50	50	50	50
Flow	130	130	125	160
Density/kg m^{-3}	2170	2190	2160	2120

Table 3 Compressive strength (MPa) of mortar mixes

Age/day (temperature/°C)	Control 100% cement	10% perlite	10% fly ash	10% silica fume
1 (20)	2.67	0.87	0.84	0.97
3 (2 days at 55°C)	39.1	33.5	32.1	38.2
7 (20)	31.5	26.1	26.1	29.4
28 (20)	32.9	30.5	26.5	38.5

Methods

A TA Instrument SDT 2960 simultaneous DTA-TGA analyser was used for thermal characterisation of selected samples which were cured for 1, 3 and 7 days. The mass range of powdered specimens ranged between 20 and 25 mg. Each specimen was evenly packed into an open Pt–Rh crucible and analysed at a heating rate of 10°C min^{-1} under flowing air at 20 mL min^{-1} from 25 to 1000°C. The DTA and TG curves were evaluated using the TA Instruments analysis software with two-point rotations carried out for all curves.

X-ray diffraction (XRD) analysis was carried out to detect crystalline phases present in the specimens, which were taken from the same samples used for thermal analysis. A Siemens D5000 X-ray powder diffractometer with symmetrical Bragg-Brentano geometry and a CuK_α radiation (λ=1.540981 Å) with a power of 40 kV and 30 mA were used for XRD analysis. XRD patterns of powered specimens were collected for 2θ values from 5 to 65° at intervals of 0.02° and 2 s per step. Specimens were spun during the analysis. ICDD-JCPDS Powder Diffraction File was used for qualitative phase identification.

Results and discussion

DTA curves of 7 day cured mortar samples of various mixes and those of 1, 3 and 7 days cured mortar samples containing only perlite fines are presented in Figs 1 and 2, respectively. The principal endotherms observed are ascribed to:

200 to 300°C	decomposition of calcium silicate hydrates (C–S–H)
400 to 500°C	calcium hydroxide (CH)
550 to 600°C	$\alpha \rightarrow \beta$ crystalline inversion of unreacted quartz sand
650 to 750°C	decarbonation of calcium carbonate

It may be noted that in Fig. 2, the endotherms due to decompositions of C–S–H and CH are not detected in the 1 day cured perlite mortar. Additionally, the decomposition endotherm due to C–S–H is more intense for the 7 days cured sample compared with the 3 days cured sample. These observations indicate that:

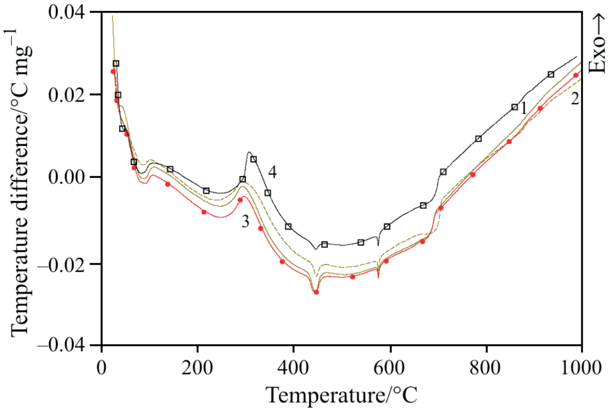

Fig. 1 DTA curves of 7 days cured mortar mixes; 1 – mortar no perlite 7 days, 2 – mortar with perlite 7 days, 3 – mortar with fly ash 7 days, 4 – mortar with silica fumes 7 days

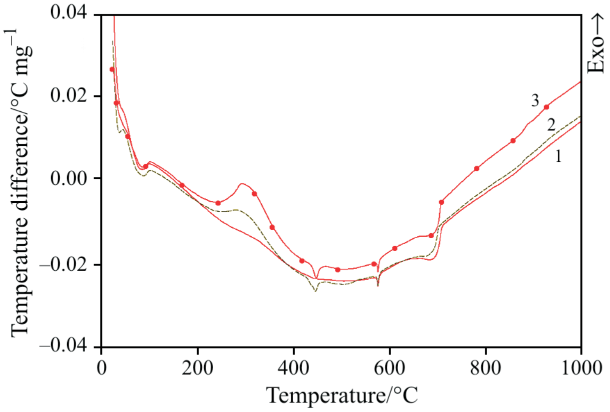

Fig. 2 DTA curves of 1, 3 and 7 days cured perlite mortars; 1 – mortar with perlite 1 day, 2 – mortar with perlite 3 days, 3 – mortar with perlite 7 days

- the hydration reaction of the GPC with water was insignificant in the presence of perlite after 24 h, which is supported by the absence of significant amount of CH in the sample and
- with continued curing the amount of C–S–H increased between 3 and 7 days.

XRD analysis confirmed the above observations made from thermal analysis. Although C–S–H could not be detected in XRD due to its amorphous nature, the intensity of the main portlandite (CH) peak at 2.73 Å was found to increase between 3 and 7 days. XRD analysis of all mortar samples also confirmed the presence of calcium carbonate in all mortar samples.

It is evident from Fig. 1 that all four mixes have similar characteristics after 7 days of curing; in other words, the perlite mortar is comparable with the fly ash mortar and silica fume mortar with regard to formation of critical phases. A small difference is observed between the samples in the decomposition behaviour of the calcium carbonate peak where the mortar samples with silica fume and perlite appear to show the decarbonation at a slightly higher temperature compared with the other two mortars.

Furthermore, the TG curves of the four mortar specimens after 7 days of curing as shown in Fig. 3 indicate that the percentage mass loss due to the decomposition of calcium carbonate was the highest in the perlite mortar specimen compared with the other three mortar specimens. XRD analysis of these samples confirms the presence of a greater amount of calcium carbonate in the 7 days cured perlite mortar specimen compared with the rest. As mentioned above, a more intense endotherm attributable to the decomposition of C–S–H was found for the 7 days cured perlite mortar sample. Thus a larger proportion of CH was also generated in the 7 days cured sample. It follows that a greater proportion of CH produced after 7 days was carbonating for the perlite mortar sample than for the other mortars. In other words, perlite's reactivity in the early stages for up to 7 days may be slow and improves considerably with age as evidenced by the 28 days strength of the perlite mortar samples (Fig. 4).

Figure 4 shows the compressive strength plots of all four mixes over a period of 28 days. It is noteworthy from this figure that after 28 days the perlite mortar's performance matches that of the control sample and is better than that of the fly ash mortar. After 7 days the strength of the perlite mortar was equal to that of the fly ash mortar but marginally less than that of the control mortar. The strength characteristics of the perlite mortar sample over the 28 days period indicate a continuing hydration reaction with increasing development of the strength contributing C–S–H phase. This conclusion is in accord with the trend observed above from the thermal data that the amount of C–S–H increased between 3 and 7 days of curing.

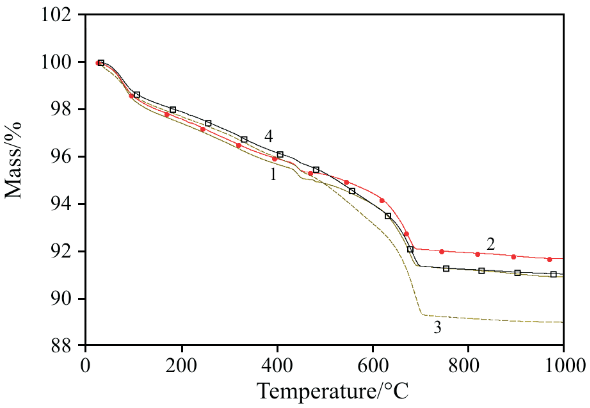

Fig. 3 TG curves of 7 days cured mortar mixes; 1 – mortar no perlite 7 days, 2 – mortar with fly ash 7 days, 3 – mortar with perlite 7 days, 4 – mortar with silica fumes 7 days

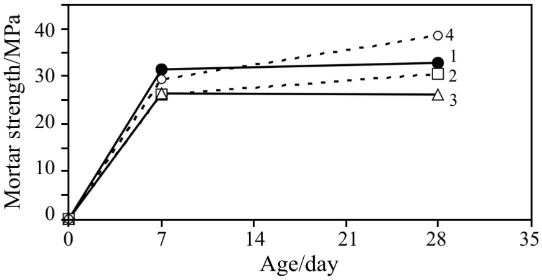

Fig. 4 Strength development of mortar mixes; 1 – control, 2 – perlite, 3 – fly ash, 4 – silica fume

External aluminosilicate sources such as metakaolin and fired clay brick waste have been shown to have strong influence on the properties of blended PC based products [5]. Perlite is a natural source of aluminosilicate and perlite fines are, therefore, potentially capable of improving the properties of cement based construction materials. Bektas *et al.* [9] demonstrated that perlite powder in both natural and expanded forms is capable of suppressing expansion due to alkali–silica reaction in concrete. This property of perlite is attributed to its pozzolanicity which may be due to its ability to consume calcium hydroxide formed during chemical reaction of PC with water and/or to the binding of alkalis onto perlite. The authors also commented that the expanded form of perlite powder was more effective in suppressing the alkali–silica reaction in concretes than the natural perlite powder. In another recent study, Yu *et al.* [10] also demonstrated the pozzolanic effect of natural perlite in a finely ground form.

Future investigation on the long term strength development of samples incorporating perlite and their microstructural and thermal characterisation will be needed to ascertain the full benefit of perlite addition in PC based construction materials. The preliminary results reported in this paper clearly indicate that waste perlite fines have good potential to be used as a supplementary cementitious material in blended PC based construction materials.

Conclusions

Perlite is a natural source of aluminosilicate and is potentially capable of improving the properties of cement based construction materials. The preliminary investigation with mortar samples containing waste perlite fines from an Australian perlite deposit indicates that the waste has good potential to partially replace PC. Its reactivity appears comparable with both fly ash and silica fume, which are well established supplementary cementitious materials accepted by the construction industry worldwide. Our results show test mortar samples using perlite fines give superior unconfined compressive strength to those containing fly ash after 28 days of curing and were comparable with the control sample containing GP cement only. Thermal analysis provided valuable insights into the reactivity of perlite fines in a Portland cement environment. Further study is underway on the long term strength development of GP cement blends containing perlite fines, the results of which will be reported in future publications.

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