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A study of the engineering properties of waste LCD glass applied to controlled low strength materials concrete

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ABSTRACT

The Taiwan production of TFT-LCD front-panels comprises a global share of 39.2%, the highest production rate in the world. Inevitably, a large amount of waste is produced in the fabrication process. The objective of this research is to recycle waste LCD glasses in the production of controlled low strength material (CLSM), which has been used extensively for pipeline refill and pavement foundations world-wide. The glass replaces sand in ratios of 0%, 10%, 20% and 30% in order to produce CLSM specimens with high silicon contents. The specimens are then tested for their compressive strength, supersonic strength, electrical resistivity, and permeability ratio.

Results show a slump range up to 200 mm and a slump flow range up to 410 mm. For the general type CLSM, the setting time for the 10% glass–sand replacement is the shortest while that for the 30% replacement is the longest. After a 28-day aging, the compressive strength is 2.87–2.40 MPa. The ultrasonic pulse velocity is between 1267–3200 m/s and is found to be faster for the early strong type. The electrical resistivity after 28 days for the general type is 6.7–8.2 kΩ-cm and doubles for the early strong type. The permeability ratio is 1.03–2.02% for the normal and 0.35–0.75% for the early strong type. It was observed that adding waste LCD glass into CLSM meets engineering property requirements including high fluidity, low strength, high permeability, and low electrical resistivity, ushering in a creative application of waste glass.

1. Introduction

According to the American Concrete Institute (ACI), controlled low strength materials (CLSM) are a new type of material capable of replacing excellent class materials [1]. Their compressive strengths range between 345 and 8400 kPa [2]. Also known as 'flowable fill', these materials are used mainly for filling cavities in civil engineering projects where the application of granular fill is either impossible or difficult [1]. CLSM mixtures have superior shear strength, cohesion intercept, and angle of shearing resistance values compared to conventional soil materials after seven days, making them ideal candidate materials for backfill applications [3]. The type of CLSM to be used needs to be selected according to technical and economic considerations for specific applications [4]. The production technology involved is similar to that of concrete, but its low mechanical requirements compared with concrete enable the use of industrial by-products such as cement kiln dust, asphalt dust, coal fly ash, coal bottom ash, and quarry waste for its production [5].

As the world's leading manufacturer, Taiwan's TFT-LCD panel production accounts for approximately 39.2% of the total world output. Inevitably, a large amount of waste in the form of by-products is produced during the manufacturing process. For example, waste LCD glass amounts to a staggering 1000 tons every year. In response to such a trend in science and technology, the development of the most suitable resource recycling technologies for the sustainable use of resources is currently a major concern [6]. In 2005, the Taiwan TFT-LCD manufacturing industry produced a total of more than 130,000 tons of waste, of which 70% was subsequently recycled [7].

While rapid industrial development and increases in the standard of living have led to an increase in the amount of waste glass produced, little of it has been reused or recycled, thus posing a serious threat to natural resources and the ecosystem [8]. The term 'glass' comprises several chemical varieties, including binary alkali-silicate glass, boro-silicate glass, and ternary soda-lime silicate glass [9]. Glass is unstable in the alkaline environment of concrete and could cause a deleterious alkali–silica reaction (ASR) [13]. However, such a problem can be overcome by grinding it into fine glass powder (GLP) for incorporation into concrete as a pozzolanic material. Laboratory experiments have shown that fine GLP can suppress the alkali reactivity that is present in coarser glass particles, as well as that of natural reactive aggregates. GLP undergoes beneficial pozzolanic reactions in the concrete and can replace up to 30% of cement in some concrete mixes with satisfactory

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Table 1
Cement, fly ash and glass–sand chemical properties (%).

Items	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	TiO_2	P_2O_5
Cement	20.74	4.65	3.10	62.85	3.43	2.36	–	–	–	–
Fly ash	48.27	38.23	4.58	2.84	–	–	1.16	0.21	1.42	–
LCD glass	62.48	16.67	9.41	2.70	0.2	–	0.2	0.64	0.01	0.01

strength development [10]. Although fine GLP has been utilized as a pozzolanic material as early as the 1970s, its use has become more widespread only in recent years, mainly because of the continual accumulation of waste glass and its consequential environmental problems [10–13].

Using waste glass to replace aggregates in concrete mixing offers a number of advantages due to its impermeability, enhanced flow properties, and higher strength at elevated temperatures when used in low replacement proportions [14].

In this study, the feasibility of using waste LCD glass to produce controlled low strength concrete (CLSC) is explored. Recycling of waste LCD glass into CLSM for mixing concrete offers not only an economical substitute for aggregates but also an ecological alternative to the management of waste LCD glass, thus contributing to the pursuit of sustainable development.

Table 2
Aggregate and glass–sand physical properties.

Items	Dmax (mm)	Density	Unit weight (kg/m^3)	Water absorption (%)	FM
Coarse aggregate	125	2.65	1530	1.07	5.00
Fine aggregate	23.6	2.63	1760	1.5	2.73
LCD glass	11.8	2.42	1680	0.45	3.37

Table 3
Glass–sand and coarse/fine aggregate composition sieve analysis.

Mesh (mm)	4.75	2.36	1.18	0.59	0.297	0.149	0.075	Plate
LCD glass–sand (%)	100	99.9	35.6	16.4	8.0	2.7	0.7	0
Fine aggregate (%)	99.5	84.0	65.7	45.8	23.5	8.4	3.1	0
Mesh (mm)	75	37.5	25	19.5	12.5	9.5	4.75	Plate
Coarse aggregate (%)	100	100	100	99.8	89.5	64.2	10.3	0

2. Experimental plan

2.1. Experimental materials and mixture

The cement, fly ash, and aggregate used in this study are local materials in compliance with specifications in ASTM C150, ASTM C618, and ASTM C33, respectively. Particulate waste glass–sand, able to pass through a No. 8 sift, was provided by Chi Mei Optoelectronics. Waste LCD glass has the fineness of 2500 cm^2/g. The chemical properties of the cement, fly ash, and glass–sand are shown in Table 1. The physical properties of aggregates and glass–sand are shown in Table 2, while the sieve analysis is presented in Table 3. The quick-setting agent, polyethylene glycol alkyl amide, was provided by Standard Resources International Company, and its properties adhere to the type-E chemical mixture specifications stipulated in CNS. The present study used two specimens: a general CLSM concrete using 10% fly ash and 10% glass powder and an early-high-strength CLSM concrete using a quick-setting agent. Mixture proportions are shown in Table 4.

2.2. Experimental method

A twin shaft paddle mixer was used to make 10 cm × 20 cm cylindrical concrete specimens. Specimens were aged 1, 3, 7, 28 and 56 days. The fresh property experiment followed ASTM C134 specifications. Specimens were manufactured according to the standard operational procedure in ASTM C192 and compressive strength was measured according to ASTM C39-96. Ultrasonic pulse velocity experiments were conducted according to ASTM C597 and a four-stage resistivity meter (Swiss Proceq Company) was used to measure the electrical resistivity of the specimens. Finally, the permeability ratio experiments complied with CNS 3763.

3. Results and analysis

3.1. Properties of fresh concrete

As shown in Table 5, the slumps at W/B (water to binder) ratios of 1.1, 1.3 and 1.5 were 200–210 mm, 220–230 mm, and 230–250 mm, respectively. The slump of CLSM for the early-high-strength specimen with a W/B ratio of 1.1 was 190–210 mm. The slumps for the various W/B ratios were within the standard range.

Table 4
Mixture proportions of CLSM.

W/B	NO.	Binding Materials (kg/m^3)			Coarse aggregate	Fine aggregate (kg/m^3)			Water (kg/m^3)
		Cement	Glass powder 10%	Fly ash		Substitution (%)	Glass–sand	Sand	
1.1	N11GS0	100	10	10	480	0	0	1080	195.4
	N11GS1	100	10	10	480	10	108	972	195.4
	N11GS2	100	10	10	480	20	216	864	195.4
	N11GS3	100	10	10	480	30	324	756	195.4
1.3	N13GS0	100	10	10	480	0	0	1080	230.9
	N13GS1	100	10	10	480	10	108	972	230.9
	N13GS2	100	10	10	480	20	216	864	230.9
	N13GS3	100	10	10	480	30	324	756	230.9
1.5	N15GS0	100	10	10	480	0	0	1080	266.4
	N15GS1	100	10	10	480	10	108	972	266.4
	N15GS2	100	10	10	480	20	216	864	266.4
	N15GS3	100	10	10	480	30	324	756	266.4
Early-high-strength (1.1)	E11GS0	100	E Type chemical admixtures 4 (kg/m^3)		480	0	0	1080	195.4
	E11GS1	100			480	10	108	972	195.4
	E11GS2	100			480	20	216	864	195.4
	E11GS3	100			480	30	324	756	195.4