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Study of thin film transition liquid crystal display (TFT-LCD) optical waste glass applied in early-high-strength controlled low strength materials

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Abstract. The present study verifies compressive strength, ultrasonic pulse velocity, electrical resistance, permeable ratio, and shrinkage from waste glass controlled low strength materials (WGCLSM) and early-high-strength WGCSLM specimens, by replacing the sand with waste glass percentages of 0%, 10%, 20%, and 30%. This study reveals that increasing amounts of waste LCD glass incorporated into concrete increases WGCLSM fluidity and reduces the setting time, resulting in good working properties. By increasing the glass to sand replacement ratio, the compressive strength decreases to achieve low-strength effects. Furthermore, the electrical resistance also rises as a result of increasing the glass to sand replacement ratio. Early-high-strength WGCSLM aged 28 days has twice the electrical resistance compared to general WGCSLM. Early-high-strength WGCSLM aged 7 days has a higher ultrasonic pulse velocity similar to WGCSLM aged 28 days. The variation of length with age of different compositions is all within the tolerance range of 0.025%. This study demonstrates that the proper composition ratio of waste LCD glass to sand in early-high-strength WGCSLM can be determined by using different amounts of glass-sand. A mechanism for LCD optical waste glass usage can be established to achieve industrial waste minimization, resource recycling, and economic security.

Keywords: waste LCD glass; controlled low strength materials (CLSM); compressive strength.

1. Introduction

The TFT-LCD manufacturing industry is the largest fraction of the photo-electronics industry in Taiwan (Hou 2003). Lack of proper treatment and handling of industrial waste threatens the environment and causes slow ecological and potentially irreversible damage. Due to industrialization and rapidly increasing living standards, the amount of waste glass produced in Taiwan has skyrocketed in recent years. Most of the produced waste glass has not been treated properly for reuse, and the pollution from these materials is a serious risk to the environment (Park, Lee, *et al.* 2004). Taiwan produces nearly 5 million tons of waste each year, of which 10% is glass materials (Su and Chen 2002). The utilization of many industrial byproducts in the construction industry is now well-developed and improves sustainability in two ways: materials, that would otherwise be thrown away, be potentially damaging the environment and occupy scarce land resources are reused, and the damage to the environment associated with sand digging is minimized (Mohamad 2006). The primary chemical components of TFT-LCD waste glass include silicon dioxide, SiO_2; sodium

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oxide, Na_2O; and a small amount of indium-tin oxide, ITO. The use of ITO to coat liquid crystal displays increases the transparency and conductivity by reducing the charging of the substrate surface. Unfortunately, such waste glass is not suitable for disposal methods like land-fill dumping, incineration, and composting. Moreover, the ideal treatment for waste glass is complete recycling to reduce energy consumption and prevent air and water pollution (Lin 2007).

Work investigating the use of finely ground glass as a pozzolanic material began in the 1970s; however, most work in this area is recent, and has been encouraged by the impending environmental issues associated with the continual accumulation of waste glass (Ahmad and Aimin 2004; Jin, Meyer, *et al.* 2000; Shao, Lefort, *et al.* 2000; Shi, Wu, *et al.* 2004). Waste glass offers a number of advantages for its use as an aggregate replacement in concrete due to its impermeability, enhanced flow properties, and its higher strength at elevated temperatures. Concrete slump increases with higher percentages of aggregate replacements that contain fine waste glass, coarse waste glass. In general, concrete made with 10% aggregates replaced with fine waste glass, coarse waste glass, and fine and coarse waste glass have better properties in the fresh and hardened states at ambient and high temperatures compared to those with larger replacement percentages (Mohamad 2006).

According to the American Concrete Institute (ACI), controlled low strength materials (CLSM) are a new type of material able to replace excellent class materials (Shi, *et al.* 2004). CLSM compressive strength needs to be within the range of 345 and 8400 kPa (ACI 229R-94). CLSM, also known as “flowable fill” is used as a replacement for compacted soil in construction where the application of the latter is difficult or impossible. The low mechanical requirements (compared with structural concrete) enable the use of industrial by-products for the production of CLSM. Cement kiln dust, asphalt dust, coal fly ash, coal bottom ash, and quarry waste are tested for the possibility of producing CLSM with large proportions of these wastes (Amnon and Konstantin 2004).

Typical CLSM contains coal-combustion fly ash (FA), cement, water, and fine or coarse aggregates (Gabr and Bowders 2000; Taha, Alnuaimi, *et al.* 2007). CLSM mixtures aged 7 days have superior shear strength properties compared to compacted soils. Shear strength, cohesion intercept, and angle of shearing resistance values of CLSM mixtures exceed conventional soil-based materials with similar properties. These parameters demonstrate that CLSM mixtures are suitable materials for backfill applications (S. Turkel 2006 and 2007).

2. Experimental plan

2.1. Experimental materials and mixture

The materials for concrete mixing included normal-weight aggregates, cement, fly ash, slag, superplasticizer and water. They were obtained locally from Taiwan and all met the specified requirements listed in CNS61, CNS3036, CNS12549, ASTM C494 TYPE-D, CNS13961 and CNS1240. Particulate waste glass-sand, able to pass through a No. 8 sieve, came from Chi-Mei Industrial Corp. in Taiwan, as shown in Fig. 1. Gradations of coarse and fine aggregates to waste glass are as shown in Table 1 and Fig. 2. Waste LCD glass is ground into 2500 cm^2/g by ball milling. The chemical properties of the cement, fly ash, and glass-sand are as shown in Table 2, and the physical properties of the aggregates and the glass-sand are as shown in Table 2. The quick setting agent, polyethylene glycol alkyl amide, was provided by Standard Resources International Company, with properties that adhere to the type-E chemical mixture specifications stipulated in

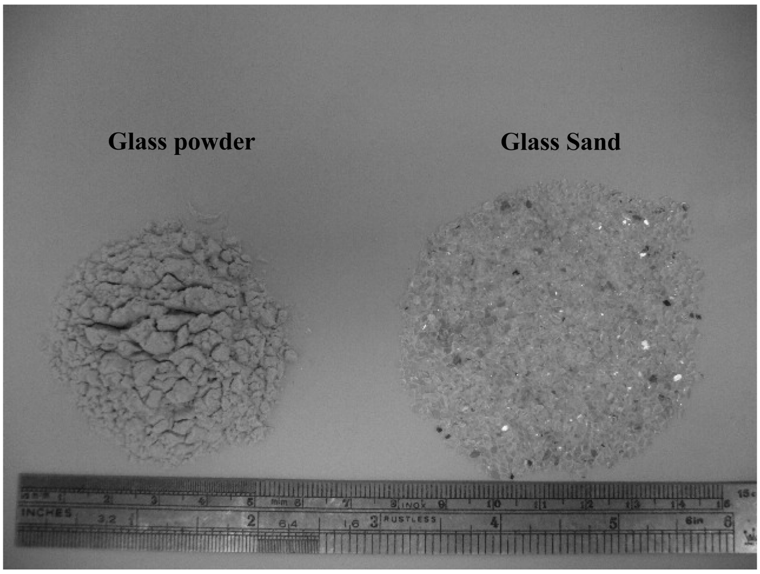


Fig. 1 Glass powder and glass sand of LCD

Table 1 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	25	12.5	9.5	4.75	plate
Coarse aggregate (%)	100	100	100	99.8	89.5	64.2	10.3	0

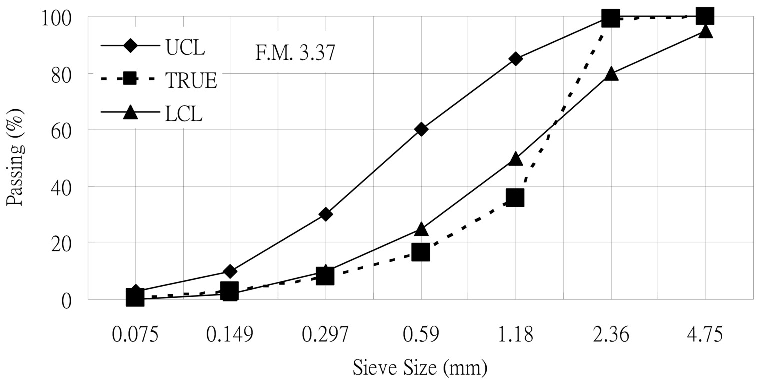


Fig. 2 Glass sand composition curve

Chinese National Standards (CNS). The present study used two specimens: a general WGCLSM using 10% fly ash and 10% glass powder, and an early-high-strength WGCLSM using a quick-setting agent. Mixture proportions are shown in Table 4.

Table 2 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	LCI
cement	20.74	4.65	3.10	62.85	3.43	2.36	–	–	–	2.11
Fly Ash	48.27	38.23	4.58	2.84	–	–	1.16	0.21	1.42	5.38
LCD glass	6.04	1.62	0.91	0.27	0.02	–	0.13	0.06	–	–

2.2. Experimental method

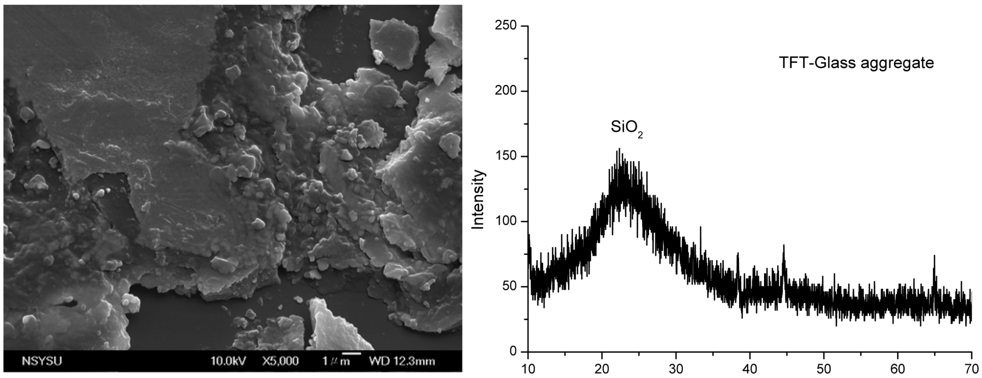
A twin shaft paddle mixer was used to make 10 cm×20 cm cylindrical concrete specimens and long type specimens 10 cm×10 cm×28 cm. Specimens were aged 1, 3, 7, 28, and 56 days. The fresh property experiment followed the ASTM C134 specifications. Bleeding experiments were conducted according to ASTM C232 at intervals of 0, 10, 20, 30, 40, 70, 100, and 130 minutes. Specimens were manufactured according to the standard operational procedures in ASTM C192 and compressive strength was measured according to ASTM C39-96. Ultrasonic pulse velocity experiments were conducted according to ASTM C597 and the electrical resistance was measured according to ASTM C876. The permeability ratio experiments referred to CNS 3763. Aging of 28 days and conduction length variation experiments were conducted according to ASTM C827.

Finally, the microstructures of the specimens were observed by optical microscopy (OM) and scanning electron microscopy (SEM).

3. Results and discussion

3.1. Waste LCD glass physical and chemical properties

The waste LCD glass-sand has a unit weight of 1.68 kg/L, a density of 2.42, a water absorption rate of 0.45%, and the fineness modulus of 3.37. The glass powder is composed of 6.04% SiO_2, 1.62% Al_2O_3, 0.91% FeO_3, 0.261% CaO, 0.13% K_2O, 0.06% Na_2O, 0.02% MgO, and trace amounts of TiO_2, P_2O_6, and MnO, and has the fineness of 2500 cm^2/g. The SEM picture and X-ray



(1) SEM (2) X-ray

Fig. 3 The SEM picture and X-ray diffraction graphs for LCD glass sand

Table 3 Aggregate and glass sand physical properties

Items	Dmax (mm)	density (g/cm^3)	Unit weight (kg/m^3)	Water absorption (%)	F.M.
Coarse aggregate	125	2.65	1530	–	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 4 Mixture proportions of WGCLSM

Type	No.	Binding Materials (kg/m^3)			Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)			Water (kg/m^3)
		Cement	Glass powder (10%)	Fly ash		Substa-tions (%)	Glass sand	sand	
Generally-strength	N11GS0	100	10	10	480	0	0	1080	195
	N11GS1	100	10	10	480	10	108	972	195
	N11GS2	100	10	10	480	20	216	864	195
	N11GS3	100	10	10	480	30	324	756	195
Early-high-strength	E11GS0	100	E Type chemical Admixtures 4 (kg/m^3)		480	0	0	1080	195
	E11GS1	100			480	10	108	972	195
	E11GS2	100			480	20	216	864	195
	E11GS3	100			480	30	324	756	195

diffraction analysis, as shown in Fig. 3.

The heavy metal contents of the waste LCD glass are Hg 6.06 mg/kg, Pb 0.17 mg/kg, Cr 5.56 mg/kg, all of which are within the legal allowance range. The TCLP experimental results are far lower compared to the standard values. Therefore, the waste glass is a general waste that can be safely be used in concrete.

3.2. Fresh property

3.2.1. Workability

Table 5 shows the slump and slump flow of the early-high-strength WGCLSM are slightly lower than those of the general WGCLSM. The slumps (200 mm above) of both types of WGCLSM increase with increasing amounts of waste LCD glass replacements, while the higher glass-sand replacements lead to a larger slump flow, indicating the potential for high fluidity effects.

3.2.2. Unit weight

Table 5 shows the unit weight of the aggregate unit includes the aggregate volume, the pores inside the aggregate, and the gaps between aggregates. The unit weight of the concrete tested in the present study is between 2173 kg/m^3 to 2211 kg/m^3, with the early-high-strength WGCLSM being higher than the general WGCLSM.

3.2.3. Air content

Table 5 shows that the air content of the early-high-strength WGCLSM is two to three times

Table 5 Property of fresh WGCLSM

N.O.	Slump	Slump Flow	Unit Weight	Air Content	Initial setting time
	mm	mm	kg/m^3	%	min
N11GS0	200	280	2186	0.7	372
N11GS1	200	320	2179	0.8	422
N11GS2	210	420	2177	0.7	453
N11GS3	210	450	2173	0.6	463
E11GS0	190	290	2211	1.4	288
E11GS1	200	300	2207	1.9	322
E11GS2	200	370	2202	1.7	325
E11GS3	210	380	2195	1.6	333

higher than the general WGCLSM due to bubbling effects produced by chemical reactions of the quick setting agent. They are change with increasing glass-sand content.

3.2.4. Initial setting time

Table 5 shows that the setting time is longer with increasing concentration of waste LCD glass-sand replacement. The initial setting time of the early-high-strength WGCLSM is shortened by 70 to 84 mins compared to the general WGCLSM.

3.2.5. Bleeding

Fig. 4 shows the early-high-strength WGCLSM has a rapid growth of bleeding due to the water repulsion effects of the quick setting agent. The bleeding peaks at 30% of the replacement amount. The bleeding amount is higher for the early-high-strength WGCLSM compared to the general WGCLSM for all composition ratios.

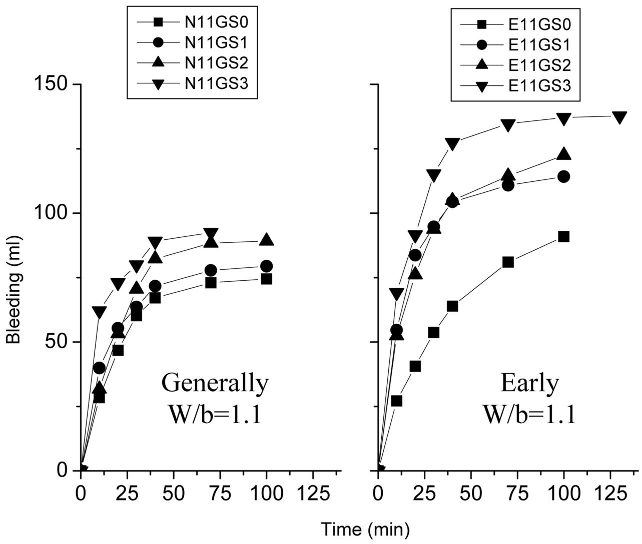


Fig. 4 Accumulated bleeding amount of different glass sand replacement amount of general type and the early-high-strength type WGCLSM

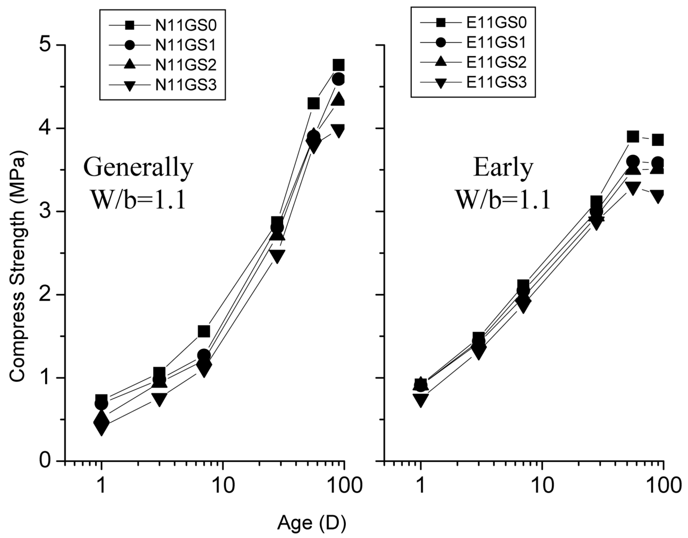


Fig. 5 Compressive strength of different glass sand replacement amount of general type and the early-high-strength type WGCLSM

3.3. Compressive strength

Fig. 5 shows that the compressive strength gradually reduces with increasing amounts of waste LCD glass-sand replacement. It verifies the statement of lker Bekir Topcu (lker and Mehmet 2004), that compressive strength decreases with increasing amounts of optical waste glass in the concrete, since optical waste glass and cement do not effectively adhere. When the water to binder ratio is the

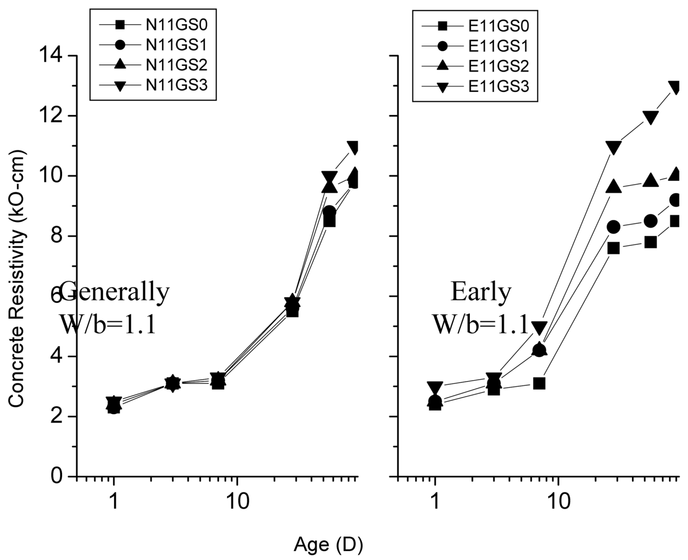


Fig. 6 Electrical resistance of different glass sand replacement amount of general type and the early-high-strength type WGCLSM

same, the WGCLSM using the quick setting agent has a higher initial strength, while the compressive strengths of all the groups are within the range of low strength.

3.4. Electrical Resistance

Fewer concrete pores represent a higher density and longer electrical conduction route, leading to a comparatively higher concrete electrical resistance (Wang and Zeng 2006). As shown in Fig. 6, the electrical resistance of concrete aged 28 days increases with increasing amounts of waste glass-sand. With increased concrete age, the internal organization of the concrete with waste glass-sand becomes denser, and the early-high-strength WGCLSM has nearly twice the electrical resistance, compared to the general WGCLSM.

3.5. Ultrasonic pulse velocity

Fig. 7 shows that the cement-water setting reaction accelerates due to the addition of the quick setting agent in the early-high-strength WGCLSM. Hence, early-high-strength WGCLSM aged 7 days has an ultrasonic pulse velocity higher than the general WGCLSM. Early-high-strength WGCLSM aged 28 days has almost the same ultrasonic pulse velocity as the general WGCLSM.

3.6. Permeability ratios

Fig. 8 shows that the permeability ratio of the general WGCLSM is higher than the early-high-strength WGCLSM, since the quick setting agent removes redundant water in the initial setting period, leading to fewer pores. Increasing the glass-sand replacement concentration decreases the permeable ratio, possibly due to the glass-sand particles filling the aggregate gaps.

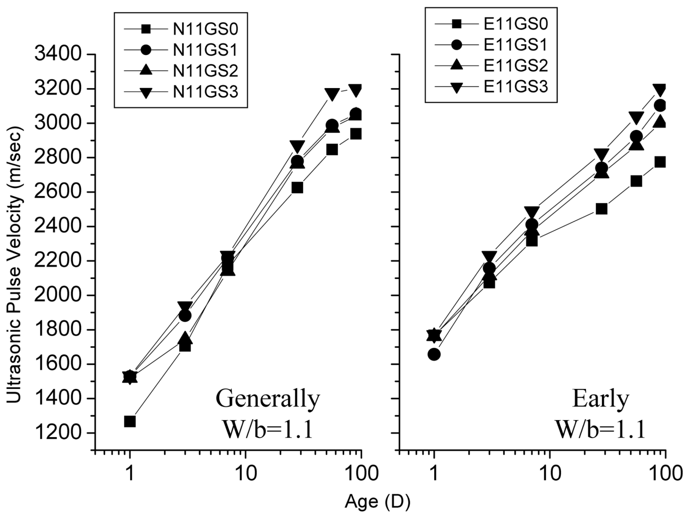


Fig. 7 Ultrasonic curve of different glass sand replacement amount of general type and the early-high-strength type WGCLSM

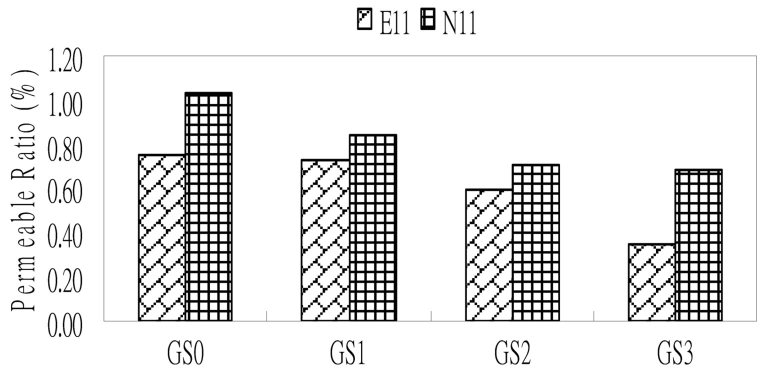


Fig. 8 Permeable ratio of different glass sand replacement amount of general type and the early-high-strength type WGCLSM

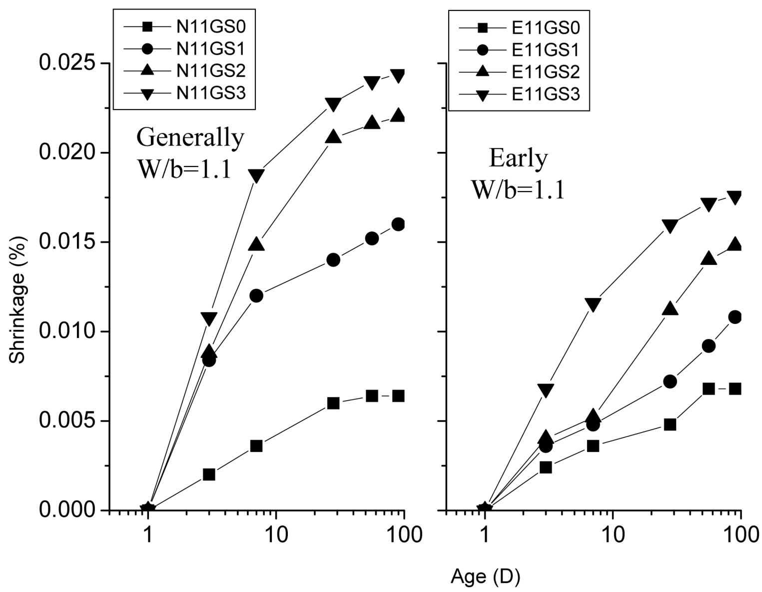


Fig. 9 Length variation of different glass sand replacement amount of general type and the early-high-strength type WGCLSM

3.7. Shrinkage

Fig. 9 shows the WGCLSM with higher glass-sand content and the general WGCLSM have a larger length variation, and the shrinkage is stable within 0.02%. The shrinkage experimental results of different replacement amounts agree with the findings of Ahmad Shayan (Ahmad and Aimin 2004). The concrete length variation is lower than 0.075%, as stipulated in the Australian Standard AS 3600.

3.8. Interfacial microstructures

The OM result indicates that the LCD glass sand can densely integrate with the cement paste, as

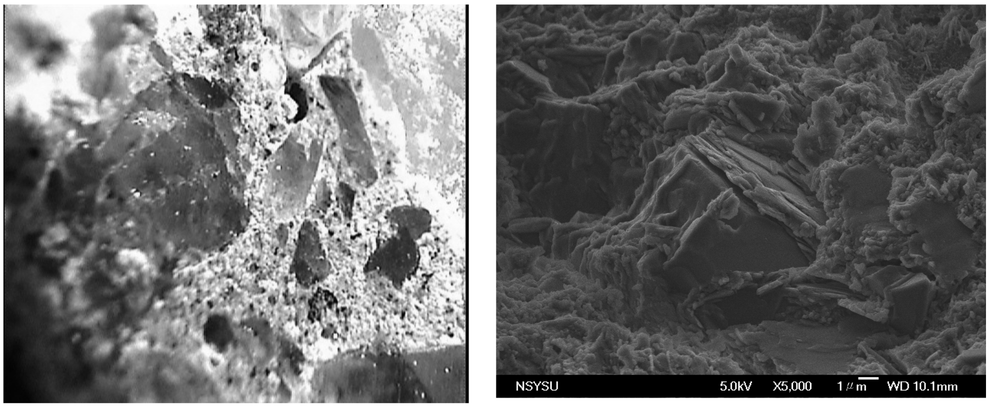


Fig. 10 The OM and SEM picture for WGCLSM

shown in Fig. 10. Displays the SEM picture for waste glass controlled low strength materials (WGCLSM) cured at 28 days. The dense C-S-H gel hydrate was produced in the glass sand concrete and connected into a continuous matrix, which generated a denser concrete structure.

4. Conclusion

1. Increasing the concentration of waste LCD glass replacement can achieve high fluidity and good workability. The early-high-strength WGCLSM has a slightly lower slump and slump flow.
2. The WGCLSM using the quick setting agent has a higher bleeding amount and air content, since more glass-sand replacement enhances superficial bleeding. The WGCLSM using the quick setting agent has 2 to 3 times the higher air content, which delays the setting with increased content of glass-sand.
3. Compressive strength gradually decreases along with increasing concentration of waste LCD glass-sand replacement in WGCLSM. The concrete with a concentration of 10% waste LCD glass replacement is superior to other concretes. In all cases, low strength effects of 3 MPa are achieved and the early-high-strength WGCLSM has a higher compressive strength.
4. Electrical resistance increases with increasing glass-sand replacement. Early-high-strength WGCSLM has twice the electrical resistance of the general WGCSLM. Early-high-strength WGCLSM aged fewer than 7 days has a higher ultrasonic pulse velocity and becomes comparable to WGCLSM aged 28 days.
5. Early-high-strength WGCLSM has a lower permeability ratio than WGCSLM, which decreases with increasing concentration of glass-sand. Volume variation in concretes with different compositions is all within the tolerance range of 0.02%. General WGCLSM has a higher permeability ratio than early-high-strength WGCLSM.

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