Computers and Concrete, *Vol. 21, No. 3 (2018) 311-319*
DOI: https://doi.org/10.12989/cac.2018.21.3.311

Study on the engineering and electricity properties of cement mortar added with waste LCD glass and piezoelectric powders

Shu-Chuan Chang[1], Chien-Chih Wang[2] and Her-Yung Wang*[1]

[1]Department of Civil Engineering, National Kaohsiung University of Applied Sciences, Kaohsiung, 807, Taiwan, R.O.C.
[2]Department of Civil Engineering and Geomatics, Cheng Shiu University, Kaohsiung, 833, Taiwan, R.O.C.

(Received January 12, 2016, Revised December 27, 2017, Accepted January 4, 2018)

Abstract. This study used a volumetric method for design. The control group used waste Liquid Crystal Displayplay (LCD) glass powder to replace cement (0%, 10%, 20%, 30%), and the PZT group used Pd-Zr-Ti piezoelectric (PZT) powder to replace 5% of the fine aggregate to make cement mortar. The engineering and the mechanical and electricity properties were tested; flow, compressive strength, ultrasonic pulse velocity (UPV), water absorption and resistivity (SSD and OD electricity at 50 V and 100 V) were determined; and the correlations were determined by linear regression. The compressive strength of the control group (29.5-31.8 MPa) was higher than that of the PZT group (25.1-29 MPa) by 2.8-4.4 MPa at the curing age of 28 days. A 20% waste LCD glass powder replacement (31.8 MPa) can fill up finer pores and accelerate hydration. The control group had a higher 50 V-SSD resistivity (1870-3244 Ω.cm), and the PZT group had a lower resistivity (1419-3013 Ω.cm), meaning that the resistivity increases with the replacement of waste LCD glass powder. This is because the waste LCD glass powder contains 62% SiO_2, which is a low dielectric material that is an insulator. Therefore, the resistivity increases with the SiO_2 content.

Keywords: waste LCD glass powder; Pd-Zr-Ti piezoelectric (PZT); Engineering and electricity properties; cement mortar; linear regression

1. Introduction

Taiwan is located at a plate junction with frequent earthquakes and copious rain during the typhoon season, and it is a place where many natural disasters often happen. Therefore, strengthening the disaster prevention of buildings has been an urgent issue. With the continuous change and improvement of science and technology, piezoelectric composite materials have become a gradually developing trend, and piezoelectric composite materials have been slowly migrated from mechanical, electrical and electronic engineering to civil engineering. In addition to remedying the functional deficiencies in the original substrate, the piezoelectric effect of piezoelectric materials can be used in the design of a controller or sensor, greatly increasing the functionality of civil engineering materials. Thereby, the concrete material commonly used in civil engineering would not only be characterized by good compression resistance but also by imbuing the concrete with many intelligent functions, such as self-monitoring, self-healing and mechanical sensing. If used properly, the damage caused by catastrophic events can be reduced, and numerous business opportunities can be created (Chaipanich 2007, Jaitanong *et al.* 2008, Li *et al.* 2009, Li *et al.* 2008, Li, Gong and Zhang 2009, Sun *et al.* 2007, Xu *et al.* 2006).

In recent years, with the advancement of optoelectronics, software and hardware technologies, crystal and their related industries, LCD glass products have proliferated. The throughput of Taiwan's TFT-LCD panels makes up 25% of global market, but the manufacturing process produces waste materials that are difficult to treat (Cheng 2004). Among the many types of solid waste, glass has been popularly studied as a substitute for coarse and fine aggregates and even cement (Du and Tan 2013).The densities of glass and concrete are approximately 2400 kg/m^3 and 2500 kg/m^3, respectively, and the compressive strength of glass is higher than that of concrete by 30-80 MPa, approximately 880-930 MPa. The heat transfer coefficient of glass is 3 W/m.K. Waste glass concrete has a higher elastic modulus than concrete (40 GPa) and a lower price (Wang *et al.* 2009, Hwang 2001, Huang 2009). Glass powder is a material that is amorphous and has a high silica content, which is the primary requirement for a pozzolanic material. Hydration and strength development in glass powder modified cement pastes and mechanical and durability properties of concrete containing glass powder have been reported in earlier studies (Schwarz and Neithalath 2008, Schwarz *et al.* 2008, Shayan and Xu 2006, Vijayakumar *et al.* 2013). The use of waste glass particles as fine aggregates would reduce the flowability and density of the mortar, but increase its air content. Except for drying shrinkage, the mechanical properties were compromised due to micro-cracking in the glass sand and a resulting weakened bond with the cement paste. However, the durability was enhanced, especially in terms of the resistance to chloride ion penetration (Matos and Coutinho 2012, Tan and Du 2013, Wang 2009).

Traditional piezoelectric materials can be approximately

∗Corresponding author, Professor
E-mail: wangho@cc.kuas.edu.tw

ISSN: 1598-8198 (Print), 1598-818X (Online)

divided into three types: piezoelectric ceramics, piezoelectric polymers and piezoelectric composite materials (Dong and Li 2005, Jou 2003). Common piezoelectric materials include lead zirconate titanate (PZT), quartz, $BaTiO_3$, PLZT with an electro-optic effect and PVF_2. PZT is a piezoelectric ceramic with a good pyroelectric effect and piezoelectric effect, and it has been applied to civil engineering. Traditional piezoelectric intelligent materials have progressed considerably in the mechanical and medical domains; piezoelectric intelligent materials have been used in civil engineering and building construction of late. Because of the reaction behaviors of mechanics, deflection or thermal expansion of traditional piezoelectric materials in machines or alloys is not identical to those inside concrete; traditional piezoelectric materials (e.g., piezoelectric ceramic or piezoelectric polymer) are used as sensors in bridges, slopes and RC buildings, but the compatibility of these traditional piezoelectric sensors and cement-based structures is lower than that of cement-based piezoelectric composite material. Therefore, the piezoelectric sensors for metals are not always applicable to civil engineering and building construction. Cement-based piezoelectric composite materials were developed to use the piezoelectric material more effectively (Dong *et al.* 2011, Dong *et al.* 2014, Xing *et al.* 2009, Zhao *et al.* 2015).

The resistivity of the specimen can be measured by the bipolar probe method, where the voltage is measured at one end, a direct current is applied to the other end, and the resistivity of the specimen is calculated. The bipolar probe measurement method uses two probes to measure the resistivity of the specimen. The current input and voltage output of the bipolar principle use the same electrode; the current path can be straight line or arc, according to the electrode geometry. It is difficult to obtain the measured region size to work out the accurate resistivity using this method; if parallel plates are used as the measuring probe, the current path is a parallel flow, and so the resistivity of the specimen can be measured by putting parallel plates at either side of the specimen (Chiou 2010, Hou *et al.* 2010, Hu 2011).

In the present studies, the proportion of the piezoelectric material (PZT) to the cement-based piezoelectric composite material exceeds 50%, and it shall be polarized and electrified to generate a piezoelectric effect. The piezoelectric material has a high unit price, and the PZT contains lead, so it shall not be used in large quantities for concern of harming human health. To sum up, this study discusses mixing waste glass powder and piezoelectric material with cement mortar to control the cost and economy based on the characteristics of the piezoelectric material (PZT). 5% piezoelectric material (PZT) is added without changing the process, polarization treatment and electrification test, and the engineering and the mechanical and electricity properties are analyzed to build a database for engineering and academia to refer to. The effect of the recycled material and piezoelectric material on the durability and electricity properties of the cement mortar without changing the basic engineering properties of the cement mortar is discussed preliminarily (Kuo *et al.* 2013). A reference database is compiled for engineers and academicians to use with a hope that the use of recycled materials and PZT results in an economic benefit, by monitoring building safety, and contributes to the development of nondestructive inspection techniques for monitoring the health of buildings (Wang *et al.* 2015, Wang *et al.* 2016).

2. Experimental plan

2.1 Experimental materials

1. Cement: Type I Portland cement produced by Taiwan Cement Corporation was used; its properties conformed to the Type I Portland cement specified in ASTM C150. All the cement was sealed with waterproof plastic on the day it was bought, and it was separated from the ground to prevent moisture permeation.
2. Mixing water: Conforms to ASTM C94 concrete mixing water.
3. Fine aggregate: The aggregate originated from the Ligang District and conformed to ASTM C33.
4. Glass powder: TFT-LCD waste LCD glass sand was ground into 6000 cm^2/g.
5. PZT: S-44 type PZT powder was bought from the Sunnytec Electronics Co., Ltd., and its density was 7.7 cm^3/g.

2.2 Experimental design and variables

As shown in Table 3, this study uses a standard mix design of cement mortar according to ASTM C109, with the cement-water-sand ratio fixed at 1: 0.64: 2.75. The volumetric method is used for design. The control group uses glass powder to replace cement (0%, 10%, 20%, 30%), and the PZT group uses PZT piezoelectric powder to replace 5% of the fine aggregate.

Table 1 The chemical properties of the materials (unit:%)

Items	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	LOI	SO_3
Cement	20.22	4.96	2.83	64.51	2.33	2.4	2.46
Glass powder	62.48	16.67	9.41	2.7	-	-	-
PZT	-	-	-	-	-	-	-
Items	Alkalis	K_2O	Na_2O	TiO_2	P_2O_5	$PbZrO_3$	$PbTiO_3$
Cement	0.48	-	-	-	-	-	-
Glass powder	-	0.2	0.64	0.01	0.01	-	-
PZT	-	-	-	-	-	55	45

Table 2 The physical properties of the materials

Items	Cement	Glass powder	Fine Aggregate	PZT
Specific gravity	3.15	2.54	2.65	7.7
Water absorption (%)	-	-	2.3	-
F.M	-	-	3.1	-
Fineness (cm^2/g)	3500	6000	-	-

Table 3 Unit weight of mix design (unit:kg/m^3)

NO.	Cement	Glass	PZT	Sand	Water
G0	543	-			
G10	462	44	-	1494	
G20	408	88			
G30	353	131			348
PZT-G0	543	-			
PZT-G10	462	44	217	1420	
PZT-G20	408	88			
PZT-G30	353	131			

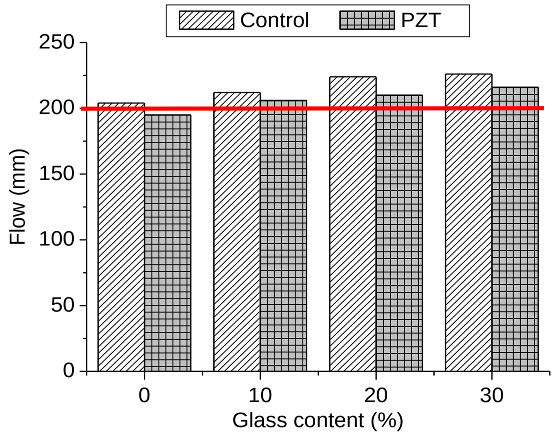

Fig. 1 Flow of cement mortar added with Waste LCD glass powder and PZT

2.3 Experimental Methods

The flow (ASTM C109) of fresh mixture was tested. A 5 cm×5 cm×5 cm cement mortar specimen was made and solidified. The form was removed after 24 hours, and the specimen was cured in saturated limewater. The compressive strength (ASTM C109), water absorption (ASTM C642-90) and UPV (ASTM C597) were tested at the age of 1, 7, 28 and 56 days. The electric property was tested in the SSD and OD states. Resistivity was measured under the applied voltage of 50 V and 100 V and a fixed current of 0.01A, at the ages of 1, 7, 28 and 56 days. The engineering-electricity relationship was evaluated by linear regression.

SSD: Remove the specimen from the curing tank; wipe the surface of the water, so that it was within the saturated surface dry.

OD: specimen in the oven at 100℃ environment for 24 hours, so that no internal moisture was dried state.

2.4 Treatment of specimen for electric properties test

The cured square specimen was put aside until the saturated surface was dry. The specimen surface was planeside by impermeable sand paper of three finenesses to make the surface smooth. Conductive silver paste was spread on two smooth sides of the specimen and allowed to dry. An appropriate length of conductive copper foil tape was cut out according to the length of the specimen, and a 0.5 cm-1.0 cm bulge was maintained in the center of the conductive copper foil tape to hold the electrode in the electric property test. Conductive copper foil tape was affixed to the specimen with both sides covered with conductive silver paste, and the conductive silver paste and conductive copper foil tape were completely covered with insulating tape to avoid electrical leakage.

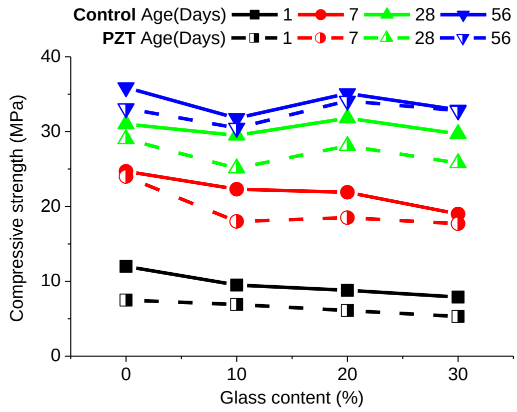

Fig. 2 Compressive strength of cement mortar added with Waste LCD glass powder and PZT

3. Results and analysis

3.1 Flow value

Fig. 1 shows when the water-cement ratio was 0.64, the flow value of the control group 0% was 200 mm and conformed to the standard flow value range specified in ASTM C109. Due to the repellency of the waste LCD glass powder, the flow of the cement mortar increases due to the replacement. The flow is 204-226 mm when the replacement is 0%-30%. When the replacement of waste LCD glass powder is 30%, the flow is increased by 22 mm compared with the control group 0%. When the waste LCD glass powder replacement with the PZT group is 0%-30%, the standard flow is 195-216 mm. When the piezoelectric material is added, the flow is lower (10 mm) than in the control group. This may be because a part of the fine aggregate is replaced by piezoelectric material, so that the piezoelectric material cannot effectively be combined with the cement and fine aggregate.

3.2 Compressive strength

Fig. 2 shows that the compressive strength increases with age. The strength of control group decreases as the replacement of the waste LCD glass powder increases at the curing ages of 1 day and 7 days. The control group has the maximum strength (31.8 MPa) when the replacement of the waste LCD glass powder is 20% at the age of 28 days (increased by 72.3%), followed by replacements of 0%, 30% and 10% in turn. Because the 6000 cm^2/g glass powder is able to fill the finer pores, the hydration is accelerated. When the replacement of waste LCD glass powder is 30% for the control group, as the amount of replaced cement content is large, the reaction time is longer, and the partial

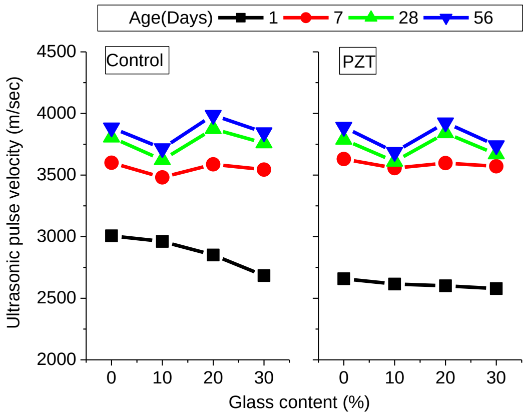

Fig. 3 UPV of cement mortar added with Waste LCD glass powder and PZT

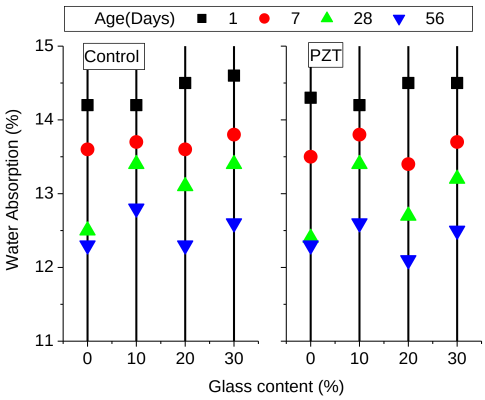

Fig. 4 Water absorption of cement mortar added with Waste LCD glass powder and PZT

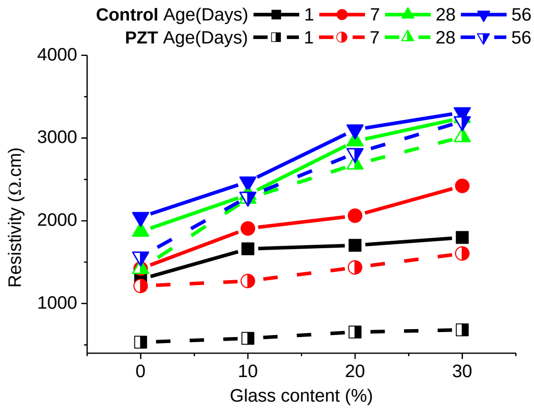

Fig. 5 The 50V-SSD resistivity of cement mortar added with Waste LCD glass powder and PZT

waste LCD glass powder has not yet undergone a pozzolanic reaction. The overall trend of the compressive strength of the PZT group is similar to that of the control group; only the compressive strength is slightly lower than in the control group. The compressive strength is at its maximum when the replacement waste LCD glass powder is 20% at late ages (28U and 56 days).

3.3 Ultrasonic pulse velocity (UPV)

Fig. 3 shows the UPV of the control group 20% replacements of the waste LCD glass powder at the age of 28 days was 3875 m/s, beyond the control group 0% (3806 m/s). Age of 56 days also showed the same growth trend. This may be because the 20% content of waste LCD glass powder at the age of 28 days, the pozzolanic reaction is enough to fill up the finer pores. The UPV of the control group with 30% replacement with waste LCD glass powder is 3759 m/s lower than the control group 0% (3806 m/s). Possible reasons for the pozzolanic reaction of cement hydration and waste LCD glass powder, the larger the amount of cement due to the substitution of the reason, some of the waste LCD glass powder has not yet undergone a pozzolanic reaction, it will be present in other forms of internal cement mortar. The waste LCD glass powder was a quartz material, when the media as ultrasound, with different crystal structure and atomic arrangement, UPV will change. Especially when a large amount of substitution, the impact is relatively large. The maximum UPV when the replacement of the waste LCD glass powder is 20% at the age of 28 days and 56 days, followed by replacements of 0%, 30% and 10% in turn. The overall UPV trend of the PZT group was the same as the control group. The UPV of the PZT group was lower than the control group because PZT replaces 5% of the fine aggregate, and the overall compactness of specimen was reduced.

3.4 Water absorption

Fig. 4 shows that the water absorption of the cement mortar with piezoelectric material and waste LCD glass powder decreases as the age increases. The water absorption of the control group at the ages of 1 day, 7 days, 28 days and 56 days is 14.2%-14.6%, 13.6%-13.8%, 12.5-13.4% and 12.3%-12.8%, respectively. The water absorption increases with the waste LCD glass powder at the age of 1 day. The water absorption of the control group with 20% replacement with waste LCD glass powder is lower than the control group (0%) at the age of 56 days. This may be because the 20% content of waste LCD glass powder is enough to fill up the finer pores, so that the hydration is accelerated, and the porosity inside the specimen is reduced. The water absorption of the PZT group of cement mortar with waste LCD glass powder is slightly lower than that of the control group at various ages. This may be because a part of the fine aggregate is replaced by piezoelectric material, and the fineness of piezoelectric material is larger than that of the fine aggregate, so it can effectively fill up the pores resulting from cementation. Therefore, the water absorption of the specimen with piezoelectric material is lower than that of the control group.

3.5 50 V-SSD resistivity

Fig. 5 shows the resistivity of the control group of cement mortar with piezoelectric material and waste LCD glass powder at the ages of 1 day, 7 days, 28 days and 56 days. The resistivity of the control group with 0%, 10%, 20% and 30% replacement with waste LCD glass powder is

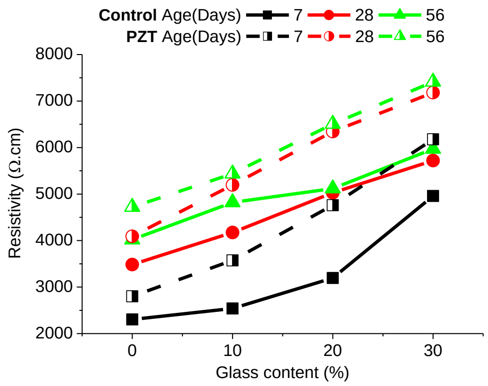

Fig. 6 The 50V-OD resistivity of cement mortar added with Waste LCD glass powder and PZT

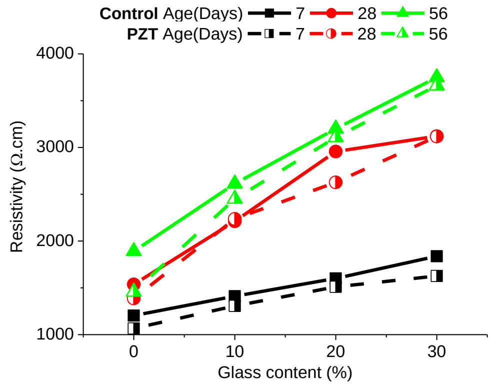

Fig. 7 The 100V-SSD resistivity of cement mortar added with Waste LCD glass powder and PZT

1293-1798 Ω.cm, 1422-2421 Ω.cm, 1870-3244 Ω.cm and 2044-3310 Ω.cm, respectively, and that of the PZT group is 532-681 Ω.cm, 1212-1604 Ω.cm, 1419-3013 Ω.cm and 1566-3201 Ω.cm, respectively. The overall resistivity trend for each age of the PZT group was the same as the control group. The various mix proportions resistivity of the PZT group were lower than the control group in the SSD state. Because PZT has been sintered, it has a sufficient compactness, a low dielectric loss and an excellent conductivity, water helped the electrical conduction, and the PZT group has a lower resistivity.

3.6 50 V-OD resistivity

Fig. 6 shows that the resistivity of the control group at the ages of 7 days, 28 days and 56 days are 2305-4958 Ω.cm, 3485-5721 Ω.cm and 4021-5971 Ω.cm, respectively, and those of the PZT group are 2802-6178 Ω.cm, 4092-7181 Ω.cm and 4722-7413 Ω.cm, respectively. The overall trend shows that the resistivity increases with the replacement of waste LCD glass powder and age. The resistivity of the PZT group is greater than those of the control group, meaning that there is no water filling up the pores once the piezoelectric material is oven-dried. When the piezoelectric material receives electric energy, it develops capacitance in the cement mortar, thus resulting in a higher resistivity.

3.7 100 V-SSD resistivity

Fig. 7 shows that the resistivity of the control group at the ages of 7 days, 28 days and 56 days are 1204-1838 Ω.cm, 1537-3121 Ω.cm and 1891-3749 Ω.cm, respectively, and those of the PZT group are 1066-1627 Ω.cm, 1387-3117 Ω.cm and 1457-3661 Ω.cm, respectively. The overall trend shows that the resistivity increases with the replacement of waste LCD glass powder and age. This is because the waste LCD glass powder contains 62% SiO_2, which is a low dielectric material that is an insulator. Therefore, the resistivity increases with the SiO_2 content.

3.8 100 V-OD resistivity

Fig. 8 shows that the resistivity of the control group at

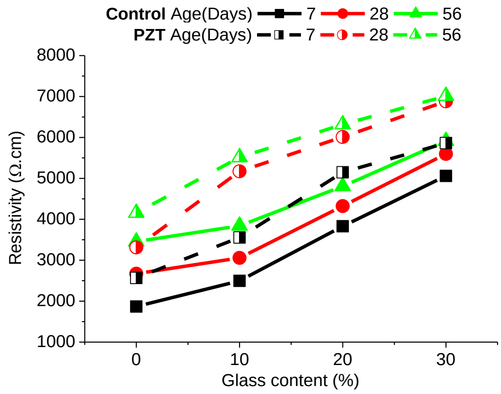

Fig. 8 The 100V-OD resistivity of cement mortar added with Waste LCD glass powder and PZT

the ages of 7 days, 28 days and 56 days are 1869-5059 Ω.cm, 2671-5597 Ω.cm and 3455-5913 Ω.cm, respectively, and those of the PZT group are2567-5863 Ω.cm, 3312-6883 Ω.cm and 4155-7011 Ω.cm, respectively. The overall resistivity trend for each age of the PZT group was the same as the control group. The various mix proportions resistivity of the PZT group were higher than the control group. The overall trend shows that the resistivity increases with the replacement of waste LCD glass powder and age. Figure 6 and 8 shows the 50 V-OD resistivity of the control group and PZT group at the ages of 28 days are 3485-5721 Ω.cm and 4092-7181 Ω.cm, the 100 V-OD resistivity of the control group and PZT group are 2671-5597 Ω.cm and 3312-6883 Ω.cm. This implies that the resistivity generated during the delivery process decreases under high voltage. Because the voltage increase improves conductivity inside the specimen, the resistivity is reduced.

3.9 Compressive strength and resistivity

Fig. 9 shows that the strength of the control group and PZT on Day 28 range from 29.5 to 31.8 MPa and from 25.1 to 29.0 MPa, respectively. The resistivity at 50 V and 100 V electricity in a SSD state for the control group are in the ranges of 1870-3244 Ω.cm and 1537-3121 Ω.cm, respectively, whereas the 50 V and 100 V electricity in an OD state for the control group are in the ranges of 3485-5721 Ω.cm and 3312-6883 Ω.cm, respectively. The

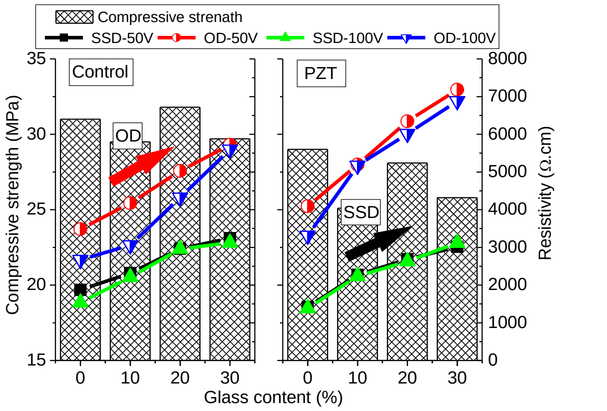

Fig. 9 Compressive strength and resistivity at the age of 28 days

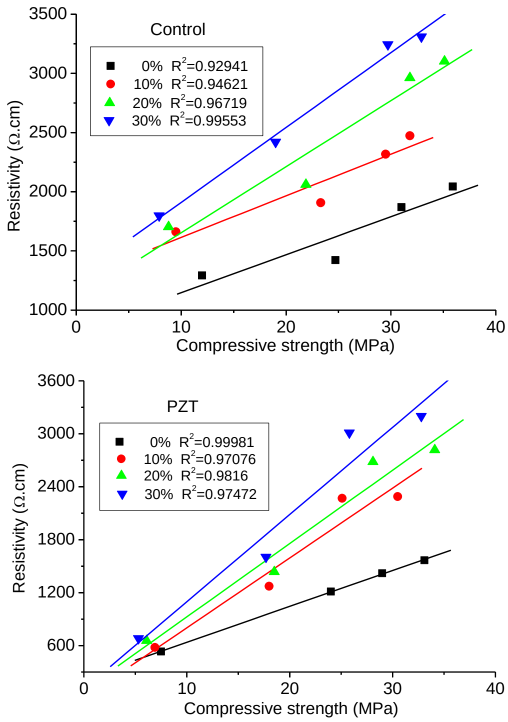

Fig. 10 Compressive strength and 50V-SSD resistivity linear regression of cement mortar added with Waste LCD glass powder and PZT

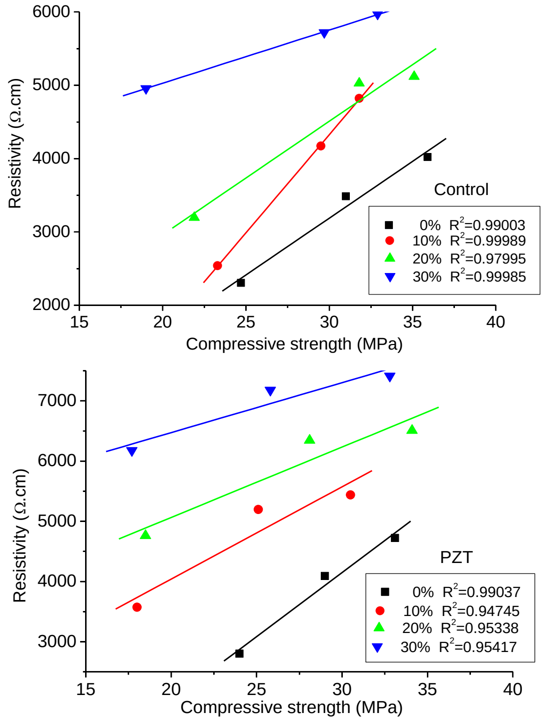

Fig. 11 Compressive strength and 50V-OD resistivity linear regression of cement mortar added with Waste LCD glass powder and PZT

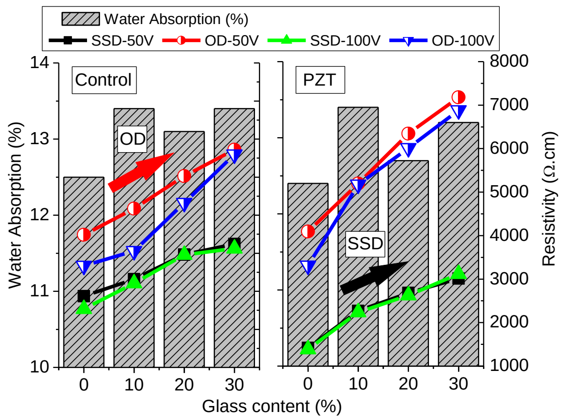

Fig. 12 Water absorption and resistivity at the age of 28 days

resistivity of the waste LCD glass powder in the SSD and OD states increases with the replacement. Fig. 10 show the linear regression and correlation coefficient (R^2) value of the compressive strength and 50 V-SSD resistivity of the cement mortar with piezoelectric material and waste LCD glass powder. The R^2 value of the control group is 0.929-0.995, and that of the PZT group is 0.970-0.999. Fig. 11 show the compressive strength and 50 V-OD resistivity. The R^2 value of the control group is larger than 0.979, and that of the PZT group is larger than 0.947. The R^2 values are greater than 0.7, indicating a high correlation. The 50 V-SSD resistivity and the 50 V-OD resistivity are positively correlated with the compressive strength.

3.10 Water absorption and resistivity

Fig. 12 shows that the water absorptions of the control group and PZT on Day 28 range from 12.5% to 13.4% and from12.4% to 13.4%, respectively. Fig. 13 illustrates that the compressive strength and water absorption showed the opposite trend. The resistivity at 50 V and 100 V electricity in a SSD state for the control group are in the ranges of 1870-3244 Ω.cm and 1537-3121 Ω.cm, respectively, whereas the 50 V and 100 V electricity in an OD state for the control group are in the ranges of 3485-5721 Ω.cm and 3312-6883 Ω.cm, respectively. Resistivity at 50 V of the electric field environment in the SSD and OD states is higher than Resistivity at 100 V of the electric field environment. This implies that the resistivity generated during the delivery process decreases under high voltage. Fig. 14 show the linear regression and correlation coefficient (R^2) value of

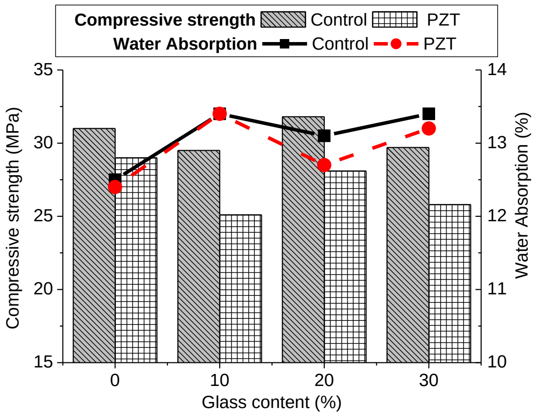

Fig. 13 Compressive strength and water absorption at the age of 28 days

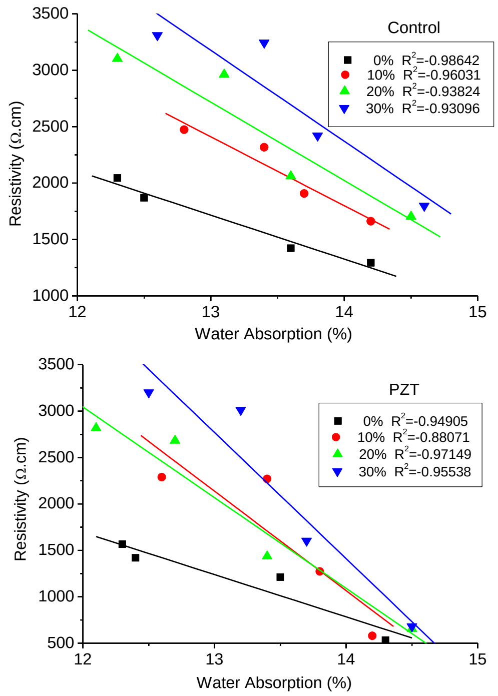

Fig. 14 Water absorption and 50V-SSD resistivity linear regression of cement mortar added with Waste LCD glass powder and PZT

the water absorption and 50 V-SSD resistivity of cement mortar with piezoelectric material and waste LCD glass powder. The R^2 values of the control group are above -0.931, and those of the PZT group with glass powder replacements of 0%, 10%, 20% and 30% are -0.949, -0.881, -0.971 and -0.955, respectively. Fig. 15 show the compressive strength and 50 V-OD resistivity. The R^2 value of the control group is above -0.907, and those of the PZT group are -0.968, -0.828, -0.923 and -0.904, respectively. The R^2 values are greater than 0.7, indicating a high correlation. The 50 V-SSD resistivity and 50 V-OD resistivity are negatively correlated with the water absorption.

4. Conclusions

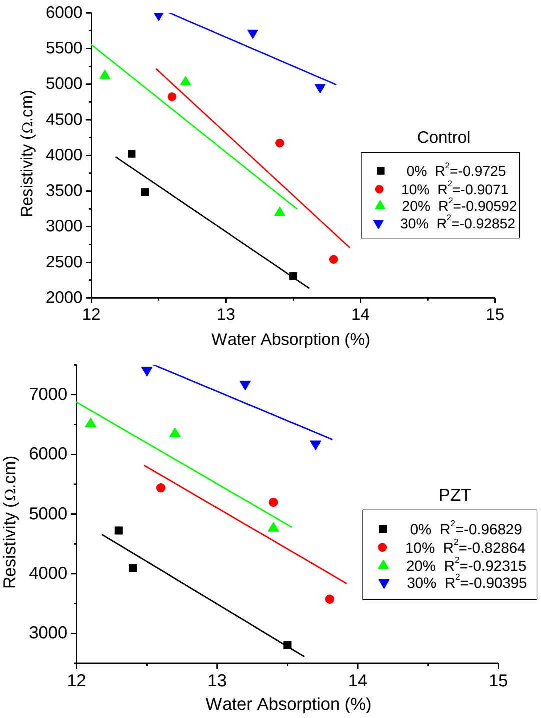

Fig. 15 Water absorption and 50V-OD resistivity linear regression of cement mortar added with Waste LCD glass powder and PZT

1. The flow increases with the replacement of waste LCD glass powder, and the flow of the control group is higher than that of the PZT group.
2. The compressive strength of the control group is 31.8 MPa when the replacement of waste LCD glass powder is 20%, and the compressive strength of the control group is higher than that of the PZT group. This may be because the piezoelectric material replaces 5% of the fine aggregate, and because the piezoelectric material is non-absorbent, it cannot effectively be combined with the fine aggregate and cement.
3. The addition of waste LCD glass powder is helpful to reduce water absorption and internal porosity. The water absorption of the control group with 20% replacement of waste LCD glass powder is slightly less than that with 0% replacement, and the water absorption of the PZT group is lower than that of the control group.
4. The resistivity increases with age, and the control group is higher than the PZT group in the SSD state. Because the piezoelectric material PZT has been sintered, it has sufficient compactness, low dielectric loss and excellent conductivity; therefore, the resistivity of the PZT group is lower. The control group is lower than the PZT group in the OD state. The piezoelectric material receives electric energy, the piezoelectric material forms a capacitance in the cement mortar, resulting in a higher resistivity.
5. The resistivity of the waste LCD glass powder in the SSD and OD states increases with the replacement. This is because the waste LCD glass powder contains 62% SiO_2, which is a low dielectric material that is an insulator.

6. Resistivity at 50 V of the electric field environment is higher than Resistivity at 100 V of the electric field environment. This implies that the resistivity generated during the delivery process decreases under high voltage. Because the voltage increase improves conductivity inside the specimen, the resistivity is reduced.
7. The linear regression of the 50 V-SSD and 50 V-OD resistivity have a good positive correlation with the compressive strength, and the water absorption has a good negative correlation with the resistivity. The R^2 values are greater than 0.7, indicating a high correlation.
8. This study for the analysis of the electricity properties (resistivity), the PZT group added piezoelectric powders and the control group has its significant difference, which proves that piezoelectric powder has excellent conductivity, which was conducive to the development of nondestructive testing of buildings.

References

ASTM C109, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars, ASTM International, USA.

ASTM C150, Standard Specification for Portland Cement, ASTM International, USA.

ASTM C33, Standard Specification for Concrete Aggregates, ASTM International, USA.

ASTM C597, Standard Test Method for Pulse Velocity Through Concrete, ASTM International, USA.

ASTM C642-90, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, ASTM International, USA.

ASTM C94, Standard Specification for Ready-Mixed Concrete, ASTM International, USA.

Chaipanich, A. (2007), “Dielectric and piezoelectric properties of PZT-silica fume cement composites”, *Curr. Appl. Phys.*, **7**(5), 532-536.

Cheng, C.H. (2004), “Discussion TFT-LCD manufacturing waste status”, *Recyc. Indus. News*, **11**(3), 03-05.

Chiou, Y.H. (2010), “Electrical resistivity determination of cement-based binder using embedded four-terminal probe method”, Master’s Thesis, National Kaohsiung University of Applied Sciences, Kaohsiung.

Dong, B. and Li, Z.J. (2005), “Cement-based piezoelectric ceramic smart composites”, *Compos. Sci. Technol.*, **65**(9), 1363-1371.

Dong, B., Liu, Y., Han, N., Sun, H.F., Xing, F. and Qin, D. (2014), “Study on the microstructure of cement-based piezoelectric ceramic composites”, *Constr. Build. Mater.*, **72**, 133-138.

Dong, B., Xing, F. and Li, Z.J. (2011), “Cement-based piezoelectric ceramic composite and its sensor applications in civil engineering”, *ACI Mater. J.*, **108**(5), 543-549.

Du, H. and Tan, K.H. (2013), “Use of waste glass as sand in mortar: Part II–Alkali-silica reaction and mitigation methods”, *Cement Concrete Compos.*, **35**(1), 118-126.

Hou, T.C., Chiou, Y.H., Pan, H.H. and Chang, C.H. (2010), “Electrical resistivity measurement of cement-based binders using embedded four-terminal probe method”, *Proceeding of the 4th ACF International Conference*, Taipei, Taiwan.

Hu, T.L. (2011), “An electromechanical approach for assessing the unconfined uniaxial compressive strength of cement mortars”, Master’s Thesis, National Kaohsiung University of Applied Sciences, Kaohsiung.

Huang, W.L. (2009), “A study on waste LCD glass applied in self-compacting concrete”, Master’s Thesis, National Kaohsiung University of Applied Sciences, Kaohsiung.

Hwang, H.H. (2001), “Effects of waste glass for aggregate Substitution on the engineering properties of concrete”, Master’s Thesis, National Yunlin University of Science and Technology, Yunlin.

Jaitanong, N., Chaipanich, A. and Tunkasiri, T. (2008), “Properties 0-3 PZT-Portland cement composites”, *Ceram. Int.*, **34**(4), 793-795.

Jou, J.M. (2003), *Piezoelectricity Mechanics*, Chuan Hwa Science and Technology Book Co, Taiwan.

Kuo, W.T., Chen, S.H., Wang, H.Y. and Lin, J.C. (2013), “A study on the mechanical and electricity properties of cement mortar added with GGBFS and piezoelectric powder”, *Constr. Build. Mater.*, **49**, 251-256.

Li, G.J., Quan, J., Gong, H.Y. and Sun, L.C. (2009), “Research progress in cement based piezoelectric composites”, *Mater. Rev.*, **23**(12), 52-55.

Li, X., Huang, S.F., Liu, F.T. and Xu, D.Y. (2008), “Properties of 0-3 cement-based piezoelectric composites modified by carbon black”, *J. Build. Mater.*, **11**(3), June.

Li, Z.J., Gong, H.Y. and Zhang, Y.J. (2009), “Fabrication and piezoelectricity of 0-3 cement based composite with nano-PZT powder”, *Curr. Appl. Phys.*, **9**(3), 588-591.

Matos, A.M. and Coutinho, J.S. (2012), “Durability of mortar using waste glass powder as cement replacement”, *Constr. Build. Mater.*, **36**, 205-215.

Schwarz, N. and Neithalath, N. (2008), “Influence of a fine glass powder on cement hydration: comparison to fly ash and modeling the degree of hydration”, *Cement Concrete Res.*, **38**(4), 429-436.

Schwarz, N., Cam, H. and Neithalath, N. (2008), “Influence of a fine glass powder on the durability characteristics of concrete and its comparison to fly ash”, *Cement Concrete Compos.*, **30**(6), 486-496.

Shayan, A. and Xu, A. (2006), “Performance of glass powder as a pozzolanic material in concrete: A field trial on concrete slabs”, *Cement Concrete Res.*, **36**(3), 457-468.

Sun, M.Z., Pan, H.H. and Lee, P.C. (2007), “Simulation of cement-based piezoelectric composite material on piezoelectric strain constants”, *TCI 2007 Concrete Engineering Symposium*, Taipei, November.

Tan, K.H. and Du, H. (2013), “Use of waste glass as sand in mortar: Part I-Fresh, mechanical and durability properties”, *Cement Concrete Compos.*, **35**(1), 109-117.

Vijayakumar, G., Vishaliny, H. and Govindarajulu, D. (2013), “Studies on glass powder as partial replacement of cement in concrete production”, *Int. J. Emerg. Technol. Adv. Eng.*, **3**(2), 153-157.

Wang, H.Y. (2009), “A study of the effects of LCD glass sand on the properties of concrete”, *Waste Manage*, **29**(1), 335-341.

Wang, H.Y., Chen, S.H., Chang, S.C. and Lin, J.C. (2015), “The study for engineering properties of cement mortar added with fly ash and piezoelectric materials”, *Struct. Eng.*, **30**(4), 107-120.

Wang, H.Y., Tzeng, H.H., Huang, W.L., Chiu, Y.W. and Lin, Y.H. (2009), “A study of application of recycling green building materials in the South of Taiwan”, *The 2th Green Materials Symposium in Taiwan*, Mainland China, Hong Kong, No.07, Page 6, Kaohsiung, July.

Wang, H.Y., Wang, C.C., Chang, S.C. and Lin, J.C. (2016), “A study of engineering and electricity properties of cement mortar added with recycled materials and piezoelectric powders”, *Constr. Build. Mater.*, **113**, 297-305.

Xing, F., Dong, B. and Li, Z.J. (2009), “The study of pore structure and its influence on material properties of cement-based piezoelectric ceramic composites”, *Constr. Build. Mater.*, **23**(3), 1374-1377.

Xu, L.F., Chen, W., Zhou, J. and Li, J. (2006), “Preparation and properties of fine scale 1-3 piezoelectric ceramic polymer composites”, *J Wuhan Univ. Technol.*, **28**(6), June.

Zhao, P., Kim, S.J. and Hinderliter, B. (2015), “Investigation of cement–sand-based piezoelectric composites”, *J. Intel. Mater. Syst. Struct.*, **27**(12), 1666-1672.

CC