Computers and Concrete, Vol. 10, No. 2 (2012) 95-104
DOI: http://dx.doi.org/10.12989/cac.2012.10.2.095

Properties of recycled green building materials applied in lightweight aggregate concrete

Her-Yung Wang*, Darn-Horng Hsiao and Shi-Yang Wang

Department of Civil Engineering, National Kaohsiung University of Applied Sciences, 807, Taiwan, R.O.C

(Received June 4, 2010, Revised May 11, 2011, Accepted June 22, 2011)

Abstract. This study uses recycled green building materials based on a Taiwan-made recycled mineral admixture (including fly ash, slag, glass sand and rubber powder) as replacements for fine aggregates in concrete and tests the properties of the resulting mixtures. Fine aggregate contents of 5% and 10% were replaced by waste LCD glass sand and waste tire rubber powder, respectively. According to ACI concrete-mixture design, the above materials were mixed into lightweight aggregate concrete at a constant water-to-binder ratio (W/B = 0.4). Hardening (mechanical), non-destructive and durability tests were then performed at curing ages of 7, 28, 56 and 91 days and the engineering properties were studied. The results of these experiments showed that, although they vary with the type of recycling green building material added, the slumps of these admixtures meet design requirements. Lightweight aggregate yields better hardened properties than normal-weight concrete, indicating that green building materials can be successfully applied in lightweight aggregate concrete, enabling an increase in the use of green building materials, the improved utilization of waste resources, and environmental protection. In addition to representing an important part of a "sustainable cycle of development", green building materials represent a beneficial reutilization of waste resources.

Keywords: recycled green building materials; waste LCD glass; waste tire rubber powder; lightweight aggregate concrete.

1. Introduction

The high mountains and rapidly flowing water on the island of Taiwan produce enough natural sand to meet the demand of the domestic construction industry. However, natural sand excavation and supply are becoming increasingly difficult due to the dense population, steep terrain, and rising awareness of the need for environmental protection. Thus, a portion of the sand used in construction now has to be imported. The major reservoirs in Taiwan are degraded and congested, reservoir silt continues to build up, and coarse/fine aggregates are increasingly scarce. The government has adopted a water resource policy of removing the reservoir silt to increase storage capacity (Wang *et al.* 2007, Wang *et al.* 2007). Resource recycling techniques can be used to fully convert "waste" to another "new resource", offering environmental protection. If reservoir silt can be converted into lightweight aggregate for engineering purposes, the water storage function of reservoirs can be restored, and the shortage of sand in Taiwan can be alleviated. Converting reservoir silt into lightweight aggregate can efficiently solve the problems associated with the disposition and treatment of

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

reservoir silt.

Lightweight concrete has many favorable engineering properties such as its light weight, high strength, low expansibility, good heat insulation, sound dampening, water and fire resistance, durability, stable volume, easy construction and low cost (Wang 2008, Wang and Tsai 2006, Wang and Sheen 2010, Moulia 2008). In recent years, in an effort to reduce energy consumption and carbon emissions, countries throughout the world have made efforts to study the effect of wastes added to concrete on engineering properties, wastes such as the fly ash made by the Tai-Power Thermal Power Plant and the water-quenched slag powder made by the China Steel Corp. The results of these studies have shown that the addition of an appropriate amount of industrial waste such as water-quenched slag powder or fly ash to replace part of the cement or sand yields better engineering properties and profitability than adding cement alone (Public Construction Commission 2001, Wang and Chiang 2006).

Among Taiwan's optoelectronic industries, TFT-LCD manufacturing occupies the greatest share of output, and Taiwan's TFT-LCD output is among the highest in the world. Without proper treatment, these LCD products would slowly pollute the environment of Taiwan and disrupt its ecology. Because it is difficult to melt waste glass into ash after incineration, its value will be greatly undermined unless it is recycled and reused (Wang *et al.* 2007, Wang and Huang 2009, Wang and Huang 2009, Wang 2009, Wang and Chen 2008, Wang 2010, Lin 2006). The disposal of waste tires is a critical environmental issue in many countries due to their large size and fixed shape, their large storage volume, and the low propensity of the material to break down. The disposal of waste tires in a landfill will shorten the life of the landfill and is not cost-effective. Over the long term, waste tires often damage the surface of the leak-proof coating layer of the landfill (Khaloo *et al*. 2008). The random disposal of waste tires also allows them to serve as breeding grounds for malaria-bearing mosquitoes and other pests that harmful to both the environment and to human health. Furthermore, the dioxin in tires can lead to combustion or fires in landfills that are harmful to the environment. All these factors make waste-tire disposal a problem with significant environmental impact (Ganjian *et al.* 2009, Ghaly and Cahill 2005).

Waste tires can be shattered, and the resulting rubber powder can be added to concrete for asphalt concrete paving (Malek *et al*. 2008, Hernandez-Olivares and Barluenga 2004) to enhance road surface elasticity, friction and service life (Ganjian *et al.* 2009). This study produces lightweight aggregate concrete using four kinds of recycled green building materials, namely fly ash, slag powder, rubber powder and glass sand. The engineering properties of these materials are then compared with those of normal-weight concrete, and the fresh mix, hardened and durability test results are analyzed. Then, these results are then used to evaluate the applicability of green building materials in concrete and the ability of these materials to contribute to improving the environmental sustainability of the construction industry.

2. Experimental programming

2.1 Experimental material and mixture ratio

This study tests general cement made by the Taiwan Cement Corp., which is Type I Portland cement according to ASTM *C*150 and CNS 61. The cement was sealed with impervious plastic when purchased to ensure quality. F-class fly ash was acquired from Tai-Power Hsin-Ta Thermal

Table 1 Cement, fly ash, furnace powder and waste LCD glass of chemical composition (unit: %)

Items	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	TiO_2	P_2O_5	LoI
Cement	20.74	4.65	3.1	62.85	3.43	2.36	-	-	-	-	2.11
Fly ash	48.27	38.23	4.58	2.84	-	-	1.16	0.2	1.42	-	5.38
Slag	35.47	13.71	0.33	41	6.6	-	-	-	-	-	-
LCD glass	62.48	16.67	9.41	2.7	-	-	0.2	0.64	0.01	0.01	-

Table 2 Analysis of waste rubber powder sieve

Sieve NO.	#30	#50	#100	Chassis	Fineness modulus	Specific gravity
#20~40	121	56.9	65.5	9.6	2.17	0.95
#50~100	2.1	165.5	135	1.8	1.56	0.95

Table 3 Properties for aggregate

Properties of aggregates	Coarse aggregates	Lightweight aggregates	Fine aggregates
Specific gravity	2.65	1.35	2.61
Water absorption in 30 min (%)	-	4.6	-
Water absorption in 24 hr (%)	0.87	10	2.67
Maximum size (in)	1/2"	3/8"	-
Finesse modulus (FM)	6.66	6.28	2.84
Dry-rodded unit weight (kg/m^3)	1572	901	1750

Power Plant and was to CNS 3036 standard. Water-quenched slag powder was produced by China Steel Corp. and ground into a fine powder by China Hi-Ment Corporation. Waste LCD glass sand was crushed by a crusher and passed through a No. #4 sieve to obtain a particle size close to that of natural fine aggregates. Table 1 shows the chemical composition of the four recycled green building materials. Waste tire rubber powder with #30 fineness was obtained from Taiwan Water-jet Technical Co. Analysis of waste rubber powder sieve shown in Table 2. Taiwan Shi-men Reservoir silt was dehydrated, pelletized and sintered to obtain lightweight aggregate particles and then sieve analysis was conducted as per ASTM *C*33 and CNS 3691 to filter off some overly large/small particles and decrease the influence of particle size on water absorption. The lightweight aggregates were then pre-dipped with water for more than 24 h to reduce the water-absorption capacity of lightweight aggregate and decrease the influence of the water-to-binder ratio. Table 3 shows the basic properties of lightweight aggregate, and Table 4 presents the mixture-ratio table.

2.2 Experimental variables and methods

This study applied recycled green building materials to lightweight aggregate concrete and general normal-weight concrete and studied their differences. We used a constant water-to-binder ratio ($W/B = 0.4$), replaced standard sand with recycled green building materials (0%, 5% and 10%), mixed these materials to form lightweight aggregate concrete and general normal-weight concrete, and then studied the fresh-mix properties, hardened properties, and durability and determined the optimal replacement rate of each recycled mineral admixture.

Table 4 Mixture proportions of LAC (unit: kg/m^3)

Mix No.	Binding materials			Coarse aggregate	Substitution %	Fine aggregate			Water
	Cement	Fly ash	Slag			Sand	Glass	Rubber	
N	398	32	32	872	0	885	-	-	185
*NG*5					5	840.7	44.2	-	
*NG*10					10	796.5	88.5	-	
*NR*5					5	840.7	-	44.2	
*NR*10					10	796.5	-	88.5	
*NGR*5					2.5	840.7	22.1	22.1	
*NGR*10					5	796.5	44.25	44.25	
L				545	0	690	-	-	
*LG*5					5	655.5	34.5	-	
*LG*10					10	621.0	69.0	-	
*LR*5					5	655.5	-	34.5	
*LR*10					10	621.0	-	69.0	
*LGR*5					2.5	655.5	17.25	17.25	
*LGR*10					5	621.0	34.5	34.5	

A slump test was performed on all fresh-mix concrete samples. Engineering properties such as compressive strength and ultrasonic-pulse velocity were tested at 7, 28 and 56 days. The concrete slump test was conducted as per CNS 1176; the unit weight test was as per CNS 11151; the compressive strength was determined as per CNS 1232; the splitting strength test was as per CNS 3801; the ultrasonic-pulse velocity test was as per ASTM *C*597; and the sulfate-attack test was as per ASTM *C*1012. In the sulfate-attack test, the specimens were prepared as per ASTM *C*1012, cured in saturated limewater for 7 days, dried for 24 h in an oven at 100 ± 5^{o}C, and immersed in saturated sulfate solution for 24 h. This dry-wet sulfate-attack test was repeated for 5 cycles to evaluate the influence of sulfate attack on lightweight concrete.

3. Results and analysis

3.1 Properties of recycled green building materials

The properties of the recycled green building materials used in this study are shown in Tables 1 to 3. Slag powder contains 41% CaO, the closest content to that of cement (62.85%) of any of the materials used here, and replacing cement with an appropriate amount of slag powder can lower the hydration heat and the internal temperature-ramping rate of the concrete at an early age. Waste glass sand (62.48%) and fly ash (48.27%) have higher SiO_2 contents than cement (20.74%). Replacing cement with an appropriate amount of fly ash would enhance the ability of the aggregate to flow and would increase the mortar volume and concrete plasticity. Because little fly ash takes part in hydration at an early age, the early age strength is low; however, the strength improves as the pozzolanic reaction develops, resulting in good late-age strength. Breaking waste LCD glass and adding it to concrete as an aggregate is a feasible resource utilization. The specific gravity of lightweight aggregate (1.35) is smaller than normal-weight aggregate (2.65), and the unit weight of lightweight aggregate (901 kg/m^3) is also lighter than common coarse aggregate (1572 kg/m^3); therefore, using lightweight aggregate can decrease deadweight and strengthen seismic resistance. The water absorption of lightweight aggregate (10%) is higher than normal-weight aggregate (0.87), so care must be taken when mixing the concrete. The main component of rubber is carbon, so it has a low unit weight; adding waste rubber to concrete will hamper its workability and compressive strength but can improve its expansibility, which improves resistance to repetitive loading. Thus, rubber can be added to minor structures in a concrete project.

3.2 Fresh concrete properties

As shown in Table 5, because lightweight aggregate particles have a low density, light particle-packing load, smaller vertical pressure and smaller horizontal-lateral push compared with normal aggregate particles, thicker grout is used to prevent lightweight aggregate particles from floating and to ensure that the aggregate surface is covered with enough grout. The designed slump in this study is 150 mm~180 mm. No visual bleeding or segregation occurred after mixing each group of concrete. The slump of normal-weight concrete was measured as 150 mm~173 mm and the slump of lightweight concrete was 151 mm~175 mm; all samples met the designed slump specification. When waste glass sand was added at 5% and 10%, the slump increased by 6 mm and 15 mm, respectively, possibly because waste glass sand consists of irregular lamellar particles with edges and corners. These particles interact each other and, although individual particles hardly move, moisture can lubricate particles and result in increased slump. Adding waste rubber powder decreased the slump compared with the control group, and the slump decreased as the amount of waste rubber powder added increased. This finding is consistent with the results of Hsiung (Hsiung *et al.* 2004), who reported that concrete workability decreased after adding rubber powder to concrete. Because waste glass sand (2.42) and waste rubber powder (0.95) have lower unit weights than standard sand (2.61), the unit weight of fresh concrete decreases as the replacement rate increases.

Table 5 Fresh properties

NO.	Slump (mm)	Unit weight (kg/m^3)
N	157	2276
*NG*5	160	2223
*NG*10	173	2290
*NR*5	153	2242
*NR*10	150	2211
*NGR*5	154	2271
*NGR*10	150	2218
L	160	1808
*LG*5	166	1778
*LG*10	175	1782
*LR*5	156	1838
*LR*10	152	1784
*LGR*5	154	1787
*LGR*10	151	1782

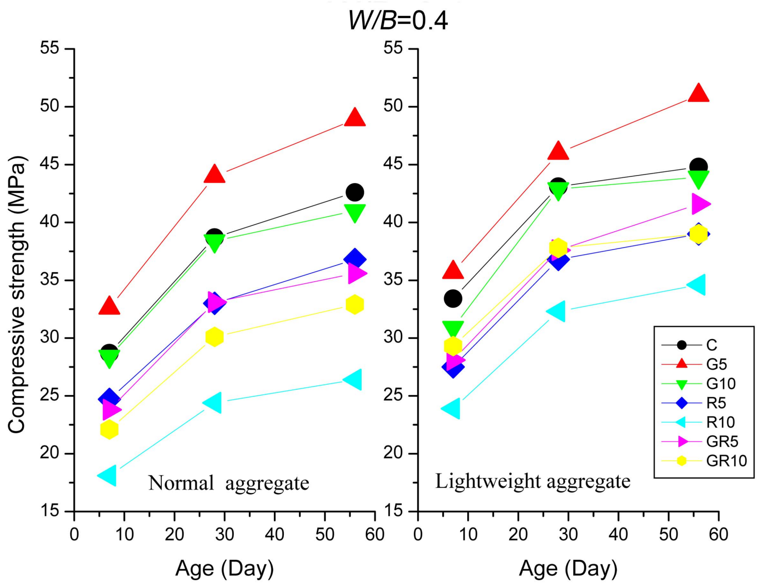

Fig. 1 Concrete compressive strength and the relationship between ages

3.3 Compressive strength

As shown in Fig. 1, the compressive strength of lightweight aggregate concrete is 24~35.7 MPa at 7 days and 32.3~46 MPa at 28 days; all compressive-strength values were 5~33% greater than that the corresponding values for normal-weight concrete. When the replacement rate with waste glass sand was 5%, the highest compressive strength, 50 MPa, was achieved at 56 days. As the replacement rates of waste glass sand and waste rubber powder increase, the compressive strength tends to decrease.

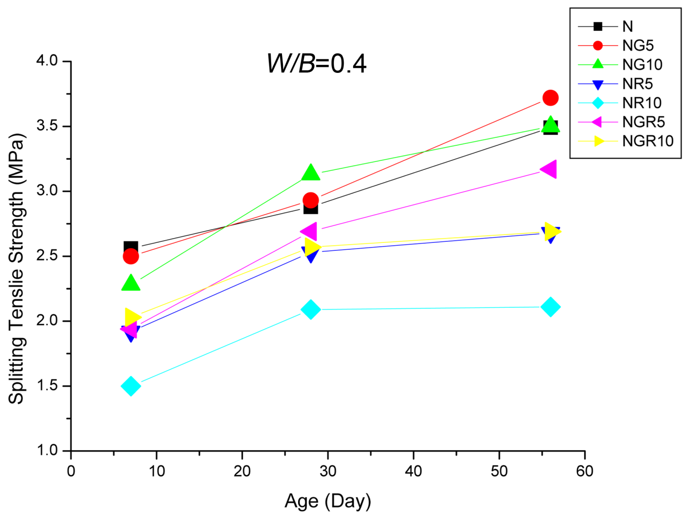

Fig. 2 Splitting of normal concrete strength and the relationship between ages

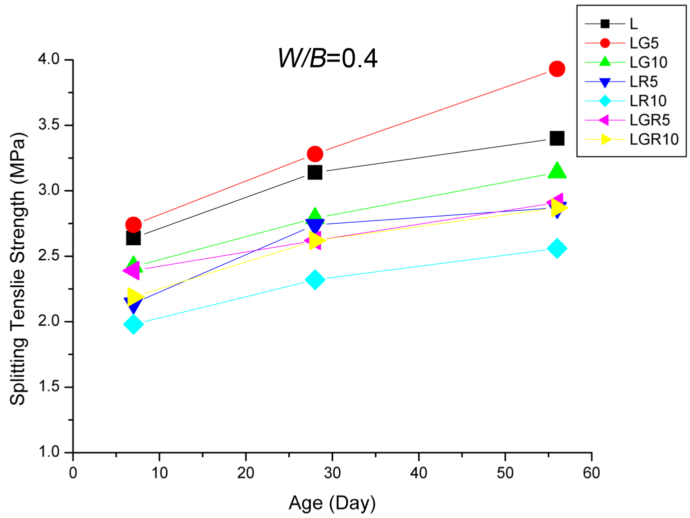

Fig. 3 Splitting of lightweight aggregate concrete strength and the relationship between ages

3.4 Splitting strength

As shown in Figs. 2 and 3, the splitting strength of lightweight aggregate concrete tends to be higher than that made using normal-weight aggregate and displays an increasing difference as the age increases. Replacement with waste glass sand at 5% yields the highest splitting strength-higher than that of control group (*N*, *L*). Replacement with waste rubber powder at 5% and 10% yields a lower splitting strength than the control group, and the splitting tensile strength falls as the replacement rate rises. Mixing both waste glass sand and waste rubber powder yields a splitting

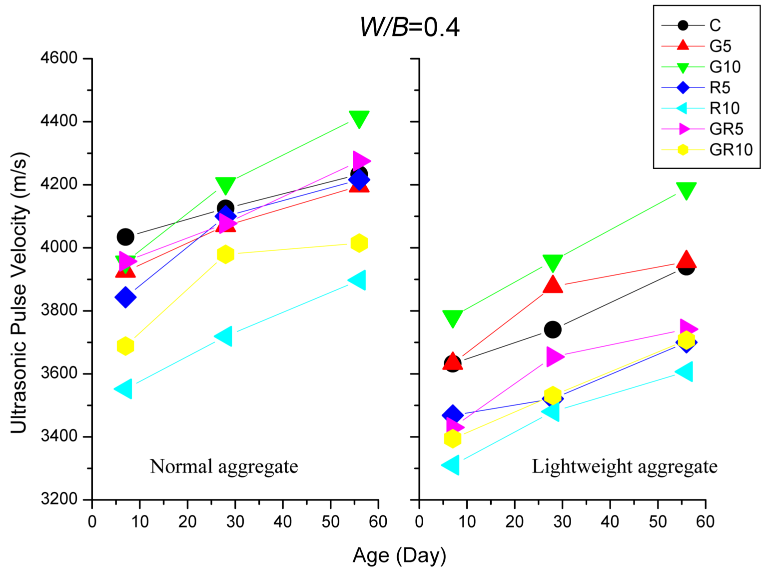

Fig. 4 Concrete ultrasound and the relationship between ages

strength lower than the control group but higher than the test group with waste rubber alone. This result indicates that mixing these two materials results in better properties than using waste rubber alone.

3.5 Ultrasonic-pulse velocity

As shown in Fig. 4, the ultrasonic-pulse velocity of normal-weight concrete is 3552~4034 m/s at 7 days, 3719~4204 m/s at 28 days and 3897~4415 m/s at 56 days. These values are all higher than the corresponding velocities of lightweight concrete, which has an ultrasonic pulse velocity of 3310~3728 m/s at 7 days, 3531~3926 m/s at 28 days and 3607~4188 m/s at 56 days. The waste glass sand group has the highest replacement rate of 10%. Because the unit weight of the waste LCD glass sand was less than natural sand, the larger volume of an equal weight of LCD glass sand and the smaller particles of this material enable waste LCD glass sand to better fill the internal voids in concrete. Therefore, increasing the replacement rate with waste LCD glass sand increases the ultrasonic-pulse velocity.

3.6 Sulfate-attack test

As shown in Figs. 5 and 6, after 5 cycles of sulfate immersion, the weight loss of normal-weight

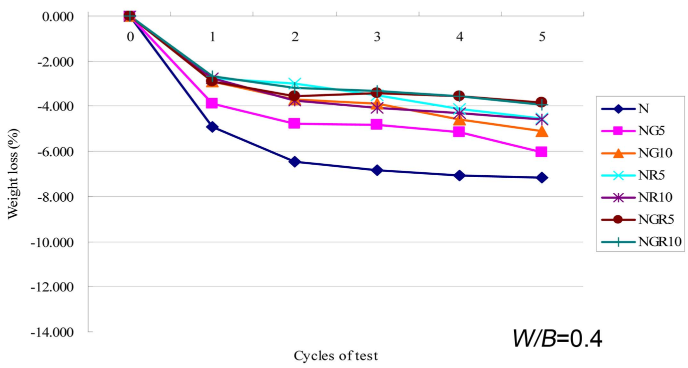

Fig. 5 Sulfate-resistant normal concrete test of the percentage of weight loss

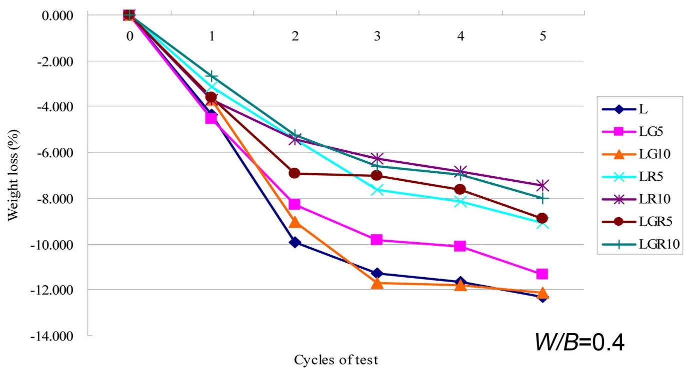

Fig. 6 Sulfate-resistant lightweight concrete test of the percentage of weight loss

concrete was -2.753~-7.184%, while the weight loss of lightweight concrete was -2.667~-12.326%, indicating that normal-weight aggregate has better sulfate-attack resistance than lightweight aggregate. Among all test groups, the concrete specimen with a mixture of waste glass sand and waste rubber powder had the best sulfate-attack resistance, indicating that mixing these two materials yields a greater benefit to sulfate resistance than using one material alone.

4. Conclusions

1. Adding fly ash and slag to concrete can decrease cement consumption because the internal Pozzolanic reaction improves concrete strength and durability. The lightweight aggregate can also reduce seismic impact. Because glass contains a large amount of SiO_2, belongs to the class of Portland materials, and has physical properties close to those of concrete, this addition is a feasible resource-utilization route.
2. When the $W/B = 0.4$, the slumps of normal-weight concrete containing waste glass sand, rubber powder and a mixture of the two were 160~173 mm, 150~153 mm and 150~154 mm, respectively; and the slumps of lightweight concrete were 164~175 mm, 152~156 mm and 151~154 mm, respectively. All samples fell within the designed slump range of 150 mm~180 mm.
3. After adding green building material at various mixture ratios to lightweight aggregate concrete, the compressive strength reached 24 MPa at 7 days, 46 MPa at 28 days and then 50 MPa at 56 days; waste glass sand at a 5% replacement rate had the highest compressive strength.
4. Adding green building materials to lightweight concrete increased the splitting strength; waste glass sand at a 5% replacement rate had the highest splitting strength-higher than the control group. The splitting strength of a mixture of two kinds of green building materials was lower than the control group but higher than concrete made using waste rubber alone.
5. The ultrasonic-pulse velocity of normal-weight concrete was 3897~4415 m/s and was higher than lightweight concrete, which has a velocity of 3607~4418 m/s at 56 days. The waste glass sand group with a 10% replacement rate had the greatest ultrasonic-pulse velocity.
6. Normal-weight aggregate had better sulfate-attack resistance than lightweight aggregate; the mixture of the two green materials had a better resistance than concrete made using either material alone.

Acknowledgments

The authors would like to thank the National Science Council of the Republic of China, Taiwan, for financially supporting this research under Contract No. NSC 99-2221-E-151-051.

References

Batayneh, M.K., Marie, I. and Asi, I. (2008), "Promoting the use of crumb rubber concrete in developing countries", *Waste Manage,* **28**(11), 2171-2176.
Benazzouk, A., Douzane, O., Langlet, T., Mezreb, K., Roucoult, J.M. and Que´neudec, M. (2007), "Physico-mechanical properties and water absorption of cement composite containing shredded rubber wastes", *Cement*

Concrete Comp., **29**(10), 732-740.
Ganjian, E., Khorami, M. and Maghsoudi, A.A. (2009), "Scrap-tire-rubber replacement forEshmaiel Ganjian, Morteza Khorami and Ali Akbar Maghsoudi (2009), "Scrap-tyre-rubber replacement for aggregate and filler in concrete", *Constr. Build. Mater.,* **23**(5), 1828-1836.
Ghaly, A.M. and Cahill, J.D. (2005), "Correlation of strength, rubber content and water: cement ration in rubberized concrete", *Can. J. Civil Eng.,* **32**(6), 1-7.
Hernandez-Olivares, F. and Barluenga, G. (2004), "Fire performance of recycled rubber-filled high-strength concrete", *Cement Concrete Res.,* **34**(1), 109-117.
Hsiung, C., Cheng, R. and Yuen, Y. (2004), "Study on compressive strength test of waste rubber concrete", *National Chinese Core J.*, **182**, 40-42.
Khaloo, Ali R., Dehestani, M. and Rahmatabadi, P. (2008), "Mechanical properties of concrete containing a high volume of tire-rubber particles", *Waste Manage,* **28**(12), 2472-2482.
Lin, K.L. (2006), "The effect of heating temperature of thin film Transistor-liquid crystal display (TFT-LCD) optical waste glass as a partial substitute partial for clay in eco-brick", *J. Clean. Prod.*, **15**(18), 1755-1759.
Mouli, M. and Khelafi, H. (2008), "Performance characteristics of lightweight aggregate concrete containing natural pozzolan", *Build. Environ.,* **43**(1), 31-36.
Public Construction Commission (2001), "Instruction manual of fly ash/slag concrete in public construction", Public Construction Commission, Taipei.
Su, N., Chang, R.C. and Chang, H.F. (2001), "Study of waste tire rubber powder applied in concrete", National Science Council Project No. NSC 89-2211-E-224-036.
Wang, H.Y (2010), "Mix proportions and properties of CLSC made from thin film transition liquid crystal display optical waste glass", *J. Environ. Manage*, **91**(3), 638-645.
Wang, H.Y. (2008), "Study on durability of densified high-performance lightweight aggregate concrete", *Comput. Concrete*, **4**(6), 499-510.
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. and Chen, J.S. (2008), "Study of thin film transition liquid crystal display (TFT-LCD) optical waste glass applied in early-high-strength controlled low strength materials concrete", *Comput. Concrete*, **5**(5), 491-501.
Wang, H.Y. and Chiang, L.T. (2006), "Study on microscopic property of interfacial region of high performance lightweight concrete mixed with pozzolanic material", Master's thesis.
Wang, H.Y. and Huang, W.L. (2009), "A study on the properties of fresh self-consolidating glass concrete (SCGC)", *J. Constr. Build. Mater.*, **24**(4), 619-624.
Wang, H.Y. and Huang, W.L. (2009), "Durability of self-consolidating concrete using waste LCD glass", *J. Constr. Build. Mater.*, **24**(6), 1008-1013.
Wang, H.Y. and Tsai, K.C. (2006), "Engineering properties of lightweight aggregate concrete made from dredged silt", *Cement Concrete Comp.*, **28**(5), 481-485.
Wang, H.Y., Chen, C.S., Wang, S.Y., Chen, C.C. and Chen, F.L. (2007), *Study on mixture ratio and properties of waste LCD glass applied in Controlled Low-Strength Material (CLSM) concrete*, Taiwan Concrete Institute 2007 Concrete Engineering Symposium, No. I-5, 12, Taipei.
Wang, H.Y., Lin, R.Y. and Shih, C.C. (2007), *Influence of high temperature high pressure curing on compressive strength and elasticity modulus of lightweight aggregate concrete*, the Third National Lightweight Aggregate Concrete Symposium, 67-82.
Wang, P.K., Lin, J.Y., Yang, C.P. and Cheng, T.M. (2007), "Island Habitants-Taiwan environment survey report", *Rhythms Monthly, Tzu Chi Culture and Communication Foundation*, 114-117.
Wang, H.Y. and Sheen, Y.N. and Hung, M.F. (2010), "Performance characteristics of dredged silt and high-performance lightweight aggregate concrete", *Comput. Concrete*, **7**(1), 53-62.

NB