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INFLUENCE OF CRUMB RUBBER ON THE MECHANICAL BEHAVIOR OF ENGINEERED CEMENTITIOUS COMPOSITES

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Abstract: With the development of the rubber and automobile industries, the growing amount of waste rubber, rubber products and angle scrap produced from scrap tires has raised ever-increasing environmental concern. The utilization of crumb rubber in concrete has attracted attention in the field of building materials in the past decades. Engineered cementitious composite (ECC) is a kind of composites reinforced with moderate fiber volume fraction, typically 2% by volume. Of special interest is the capability of ECC material to deform to high tensile strains, commonly over 3%, while maintaining very tight crack width. In this study the crumb rubber is used in ECC to partially replace fine silica sand, thus enhancing the greenness of ECC. Two particle size of crumb rubber (40CR and 80CR which means passing sieve is No.40 and No.80, respectively) is used in this research. Furthermore, three different dosages (0, 15%, 25% by volume replacing silica sand) for each crumb rubber size are mentioned in this study. The influence of crumb rubber on the ECC mechanical properties is revealed via compressive strength, flexural deformation and crack width. In this paper, it is found that the addition of crumb rubber into ECC decreases its first cracking strength with enhanced deformation capacity, meanwhile, the compressive strength decreases. The study results prove that it feasible to improve the some certain properties of ECC by replacing silica sand partially with crumb rubber, and also greatly promoting the greenness of ECC.

1 INTRODUCTION

With the development of the rubber and automobile industries, the growing amount of waste rubber, rubber products and angle scrap produced from scrap tires has raised ever-increasing environmental concern. The stockpiles is not only potential to hazard environment, but also these stockpiles are dangerous, not only due to potential environmental threat, but also presents fire hazards and provide breeding grounds for rats, mice, vermin and mosquitoes[1,2]. Over the years, the disposal of waste tire has become one of urgent problems in environment. In several countries, waste tire is burned or used as fuel, which cause many environment problems. In other way, landfills has been unaccepted due to the decreasing available site for waste disposal, and some countries such as France has issued new law to forbid any new landfill. Huge volume of accumulation has been the main waste management problem. So the use of waste tires as a concrete additive is a possible disposal solution.

In the past two decades, significant research work has been carried out to recycle the used tyres by grinding them into small particles (crumb rubber) and to mix them into cement based materials like concrete[3-8]. Results of various research studies indicate that mixed rubber into concrete is beneficial to the deformability and durability[9]. A recent study by Ho et al. (2008) confirmed that rubber aggregate incorporation improves the strain capacity of concrete before macro-crack localization[10].

Although the utilization of rubber powder in concrete has attracted attention in the field of building materials in the past decades, the research on Engineered cementitious composite (ECC) mixed rubber powder is limited. ECC is a unique class of the new generation high-performance fiber-reinforced cementitious composites (HPFRCC) featuring high ductility and medium fiber content, which designed based on micromechanics theory by Victor Li at 1990s. Tensile strain capacity at a range of 3 to 5% has been demonstrated in ECC materials using polyethylene fibers and polyvinyl alcohol (PVA) fibers with fiber volume fraction no greater than 2%[11,12]. Figure. 1 shows a typical tensile stress–strain curve of ECC and its tight crack width[11]. The large strain capacity in ECC is contributed by sequential development of multiple cracks, instead of continuous widening of one localized crack in concrete. The associated high fracture toughness and controlled crack width (typically below 100 μm) make ECCs an ideal material to improve serviceability and durability of the civil infrastructures.

ECC is called green material because of the constituents includes high volume of fly ash which is a by-product of coal burning power plants and usually considered a waste material. In an effort to develop green ECC with local waste materials, Zhou et al have developed a number of ECC mixtures with blast furnace slag (BFS) and limestone powder successfully[13]. In this study, it is attempted to use crumb rubber to replace silica sand partially. On one hand, it consumes the waste rubber reasonably; on the other hand, it reduces the consuming of silica sand, which would improve the greenness of ECC further.

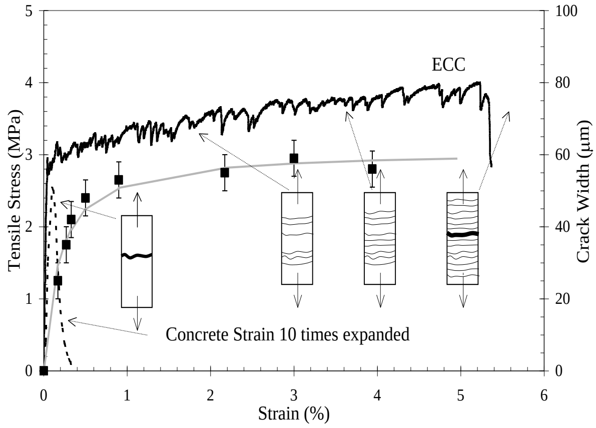


Figure 1: Tensile stress–strain curve and tight crack width control of ECC.

ECC with crumb rubber replacement (three replacement ratios are referred for both rubber particle size in this study) is proposed. This paper focuses on the density and mechanical properties of ECC with the addition of crumb rubber. In the following sections, the experimental program is introduced firstly. The experimental program is useful in understanding the process of experiment. The previous data is then reviewed. Finally, Rubber-ECC properties in terms of density, four-point bending behavior, cracking behavior and compressive strength are reported.

Table 1: Properties of PVA fiber

Diameter (mm)	Length (mm)	Tensile strength (MPa)	Modulus (GPa)	Density (g/cm^3)
39	8	1600	42	1.3

2 EXPERIMENTAL PROGRAMS

2.1 EXPERIMENTAL PROGRAMS

In this paper the ingredients used in the production of ECC mixtures include ordinary Portland cement, fly ash (FA), silica sand, crumb rubber, water, polyvinyl alcohol (PVA) fiber and polycarboxylate-based high water reducer (HRWR). The mechanical and geometrical properties of PVA fiber is described in Table.1. The density of two kinds of crumb rubber is 1.19 g/cm^3 for 80CR and 1.27 g/cm^3 for 40CR, respectively.

Table 2: Mixture proportion of ECC mixture (g/L)

Mix No.	Cement	Fly ash	Sand	Crumb rubber	Water	HRWR	PVA
M1	395	868	459	0	312	6	26
M2	395	868	390	31	312	6	26
M3	395	868	344	51	312	6	26
M4	395	868	390	33	312	6	26
M5	395	868	344	55	312	6	26

In order to investigate the influence of crumb rubber on the performance of ECC, five ECC mixtures with the same water-binder ratio of 0.25 and the same FA- Cement ratio of 2.2 are designed in this study. The mix proportion of all mixture is listed in Table.2. The 80CR is used in M2 and M3, while 40CR is used in M4 and M5. The variable parameter in ECC mixture is the crumb rubber replacement ratio (15%, 25% by volume of silica sand). The standard mixture without crumb rubber is also studied as the control mixture.

2.2 MIXTURES

Five ECC mixtures are all used for four-point bending test, compressive strength. All ECC mixtures are mixed in the standard mixing process. All of the solid ingredients including cement, fly ash, silica sand, and crumb rubber are mixed dry for 3 minutes before adding water. Water and HRWR are then added into the dry mixture for another 2 minutes. Then PVA fiber are slowly added into the motar and mixed for 8 minutes until fibers disperse well. The fresh ECC was then cast into steel formwork and then demolded after 1 day curing. All the specimens are then cured at the temperature of 20° C and relative humidity of 95% for 60 days.

2.3 SPECIMENS PREPARATION AND MEASUREMENT

For each mixture, three specimens are prepared for the bending test and compressive test. The demension of bending specimen and compressive strength specimen is 400*70*16 mm and 70.7*70.7*70.7 mm, respectively. The compressive strength is obtained by averaging the strength of three specimens.

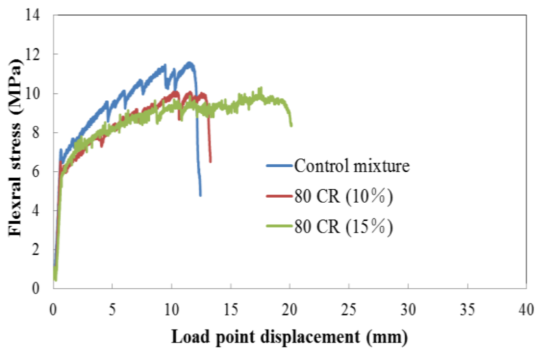
Four-point bending test is conducted under deformation control of 0.75 mm/min. The span length is 300 mm. During the test, the loading stress and load point displacement are recorded on the computerized data recording system. The load-displacement behavior, first cracking strength, flexural strength and toughness index can be obtained from this test. The crack width and the crack number are measured by optical microscope with minimum scale of 10 μm after unloading. The image of the microscope is shown in Figure 2. For each mixture, the average crack width is obtained from the crack number of 30-50 for each specimen. In order to delete the reading error caused by different people during the measuring process, all of the reading work is completed by one person.

Figure 2: Image of microscope.

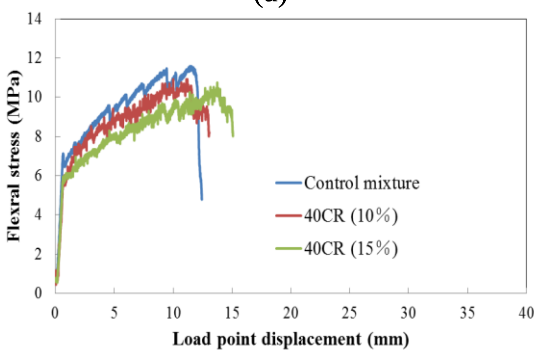
3 PREVIOUS RESEARCH WORK REVIEW

In the previous research work, in order to improve the deformability and get the better replacement ratio using crumb rubber partially replace silica sand, authors did some work about the rubberized ECC. All of the raw material used to produce rubberized ECC was the same as that used in this study. There were three replacement ratios (0, 10%, 15% by volume replacing silica sand) for each crumb rubber size. The four-point bending test was used to determine the effects of the different mixtures. All of the specimens used to do bending test were cured at the temperature of 20° C and relative humidity of 95% for 14 days before testing.

The results of bending test are shown in Figure 3[14]. Each curve for the mixtures is typical to represent the bending property for each mixture. As displayed in Fig.3, compared with the control mixture, the mixtures with the replacement ratio of 15% both exhibit the larger deformability, while there is no improvement in the bending property for the mixtures with replacement ratio of 10%. So it increases the replacement ratio further to 25% in this study, and the mixture with replacement ratio of 10% is not used.



(a)



(b)

Figure 3: Flexural stress – load point displacement relation from bending test.

4 RESULTS AND DISCUSSIONS

4.1 COMPRESSIVE STRENGTH

The material compressive properties for different mixtures can be found in Table 3. As listed in Table.3, as expected, compressive strength of ECC specimens decreases about 35% with the addition of crumb rubber compared with control mixture. But there is no obvious change between the replacement ratio of 15% and 25% for each crumb rubber size. The loss of compressive strength after adding crumb rubber can be attributed to the weak bonding between crumb rubber particle and matrix. And the crumb rubber can be considered the artificial flaw due to the much lower elastic modulus than silica sand.

Table 3: Compressive strength

Mix number	Mix1	Mix2	Mix3	Mix4	Mix5
fc' (MPa)	54	38	34	34	33

4.2 FLEXURAL PROPERTY OF RUBBERIZED ECC

The flexural stress-load point displacement curves for all mixtures are shown in Figure 4(a) and (b). The chosen curve obtained by testing three specimens in Fig.4 is representative for observing effect of crumb rubber on flexural behavior. In the flexural stress–deflection curves, it defines the point of end of the linear stage as the first cracking strength, while the maximum flexural stress is defined as the flexural strength, and the corresponding deflection is defined as the flexural deflection capacity.

Figure 4(a) shows the curves for A case which mixed with smaller rubber particle size of 80 CR. It can be seen from A case that the first cracking strength gets lower as the ratio of replacement of rubber powder increase, denoting that it lower the toughness of ECC for using rubber powder replace silica sand. It can be explained by the mechanism that the bonding between the matrix and rubber powder is much weaker than silica sand. It is observed that the deformability increases as the replacement ratio increase. The loading point displacements of ECC after adding crumb rubber are 1.5-2.9 times that of control mixture, which is expected in this study. A possible mechanism contributes to the increase of deformability in ECC is that the crumb rubber particle act as the artificial flaw which make the crack opening easier in ECC matrix. And that is beneficial to achieve the saturated multiple cracking behavior, thus improve the deformability of ECC[15].

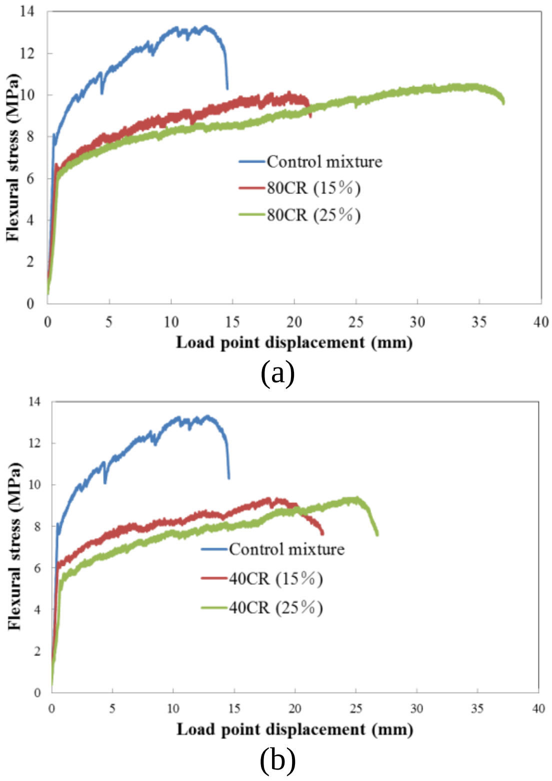


Figure 4: Flexural stress – load point displacement relation from bending test for Mix 1,2,3,4,5.

Figure 4(b) shows the curves for B case which mixed with larger rubber particle size of 40 CR. Similar to A case, it shows the same change trend for B case. The loading point displacements of ECC after adding crumb rubber are 1.5-2.0 times that of control mixture. But the deformability of B case is lower than that of A case as the same replacement ratio. This can be explained that the size of rubber powder of 80 CR is more suitable to act artificial flaw than of 40CR. Wang and Li reported that controlling the size of the artificial flaw is essential to effectiveness of improving the ductility of ECC[15].

4.3 CRACKING BEHAVIOR

It is observed that specimens of all mixtures exhibit multiple micro-cracking behaviors under bending test, as is shown in Figure 5. Crack width control many transport properties in cracked concrete material and has a direct impact on durability[16,17]. So it is necessary to investigate the crack width. The crack width in this paper is measured by optical microscope. The average of crack width for each mixture is shown in Table. 4. It is seen obviously that the crack width get tighter after adding crumb rubber. The explained mechanism is that adding crumb rubber reduce the toughness of matrix, which make the crack opening easier. And that is beneficial to the fiber-bridging effect which is responsible for the tight crack width. Another alternative mechanism is that crumb rubber particles are pulled-out which means the rubber particles embeded in the matrix stengthen the bridging effect between the crack surface[18].

Table 4: Average crack width

Mix number	Mix1	Mix2	Mix3	Mix4	Mix5
Average crack width(μm)	52	31	30	36	37

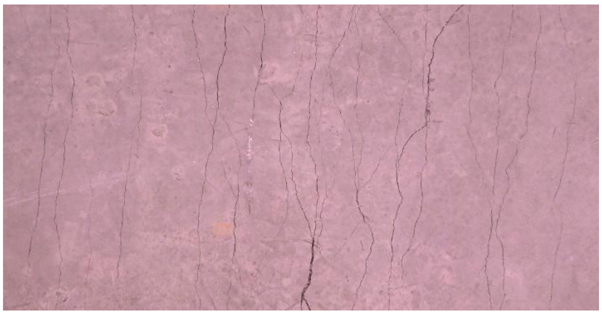


Figure 5: Multiple cracking along the length of the specimen.

5 CONCLUSIONS

In this paper, it is attempted to develop ECC using rubber powder partially replace silica in order to improve the greenness of ECC and expects to enhance the deformation capacity of ECC. The influences of rubber powder on the mechanical behavior of ECC are studied. The following specific conclusions can be drawn from this study:

1. Compressive strength of ECC specimens decreases about 35% after adding crumb rubber compared with control mixture. But there is no obvious change between the replacement ratio of 15% and 25% for each crumb rubber size.
2. The deformation capacity gets improved after adding crumb rubber. And the

deformability increases as increasing the content of crumb rubber. And, the first cracking strength decreases as increasing the content of crumb rubber, denoting the toughness of ECC decreases. To some degree, the rubber powder act as the artificial flaw making matrix easier to crack which is beneficial to achieve the saturated cracking behavior, thus increase the deformability.

3. The addition of crumb rubber make crack width tighter which is contributed to improving the bridging effect between the surfaces of crack, consequently, improve its durability.

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REFERENCES

[1] Naik, T.R, Singh, S.S., 1991. Utilization of discarded tires as construction materials for transportation facilities. Report No. CBU-1991-02, UWM Center for By-products Utilization. University of Wisconsin-Milwaukee, Milwaukee, 16 pp.

[2] Singh, S.S., 1993. Innovative applications of scrap-tires. Wisconsin Professional Engineer, 14－17

[3] Garrick, G.M., 2005. “Analysis and testing of waste tire fiber modified concrete.” Thesis (PhD), B.S., Louisiana State University

[4] Hernández-Olivares, F., Barluenga, G., Parga-Landa, B., Bollati, M., Witoszek, B, 2007. “Fatigue behaviour of recycled tyre rubber-filled concrete and its implications in the design of rigid pavements.” Construction and Building Materials, **21**: 1918-1927.

[5] Khatib, Z.K., Bayomy, F.M., 1999. “Rubberized Portland cement concrete.” Journal of Materials in Civil Engineering, **11**: 206-213.

[6] Sukontasukkul, P., Chaikaew, C., 2006. “Properties of concrete pedestrian block mixed with crumb rubber.” Construction and Building Materials, **20**: 450-457

[7] Topcu, I.B., 1995. “The properties of rubberized concretes.” Cement and Concrete Research, **25**: 304-310.

[8] Donaldson, L., 2010. Research news; concrete revolutionises road construction. Materials Today 13, 10.

[9] Turatsinze, A., Bonnet, S., Granju, J.L., 2005. “Potential of rubber aggregates to modify properties of cement based-mortars: improvement in cracking shrinkage resistance.” Construction and Building Materials, **21**: 176-181.

[10] Ho, A.C., Turatsinze, A., Vu, D.C., 2008. In: Alexander, M.G., Beushausen, H.D, Dehn, F., Moyo, P. (Eds.), “On the Potential of Rubber Aggregates obtained by Grinding End-of-life Tyres to Improve the Strain Capacity of Concrete.” Taylor & Francis Group, London, pp. 123-129.

[11] Li, V. C., 1998. “Engineered Cementitious Composites—Tailored Composites Through Micromechanical Modeling,” Fiber Reinforced Concrete: Present and the Future, N. Banthia, A. A. Bentur, and A. Mufti, eds., Canadian Society for Civil Engineering, Montreal, Quebec, Canada, 64-97.

[12] Li, V. C., Wu, C., Wang, S., Ogawa, A. and Saito, T., 2002. “Interface Tailoring for Strain-Hardening Polyvinyl Alcohol-Engineered Cementitious Composite (PVA-ECC),” ACI Materials Journal, **99(5)**: 463-472.

[13] Jian Zhou., Shunzhi Qian., M. Guadalupe Sierra Beltran., Guang Ye ., Klaas van Breugel., Victor C. Li., 2009. “Development of engineered cementitious composites with limestone powder and blast furnace slag.” Materials and Structures, DOI 10.1617/s11527-009-9549-0.

[14] Zhigang, Zhang, and Shunzhi Qian., 2012. “Influence of Rubber Powder on the Mechanical Behavior of Engineered Cementitious Composites,”// Proceedings of SusCoM2012 Conference, October 18-22, 2012, Wuhan, China, October.

[15] Wang, S. and V. C. Li, 2004. "Tailoring of Pre-existing Flaws in ECC Matrix for Saturated Strain Hardening," Proceedings of FRAMCOS-5, Vail, Colorado, U S A, April, pp. 1005-1012.

[16] Lepech, M., and Li, V. C., 2005. “Water Permeability of Cracked Cementitious Composites,” Proceeding of Eleventh International Conference on Fracture, Turin, Italy.

[17] Lepech, M., and Li, V. C., 2005. “Durability and Long Term Performance of Engineered Cementitious Composites,” Proceedings of International RILEM Workshop on HPFRCC in Structural Applications, Honolulu, HI.

[18] M. M. Reda Taha, M., A. S. El-Dieb, M. A. Abd El-Wahab, and M. E. Abdel-Hameed., 2008. “Mechanical, Fracture, and Microstructural Investigations of Rubber Concrete,” Journal of Materials in Civil Engineering, **20**: 640-649.