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STUDYING THE EFFECT OF REPLACEMENT OF AGGREGATES WITH RECYCLED CRUSHED GLASS USED TO PRODUCE TILES

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ABSTRACT: In this paper the effect of replacement fine and coarse aggregates with recycled crushed glass on the fresh and hardened properties of Tiles at ambient and elevated temperatures was studied. The percentage of replacement of 0–100% of aggregates with fine waste glass, and coarse waste glass, were considered. Samples were produces and cured at room temperatures (20–22^{o}C), heated in the oven to the desired temperatures, allowed to cool to ambient temperature, and then tested for their residual compressive strength.
Overall performance of the recycled glass tiles showed very good strength and absorption properties without being overly sensitive to any of the mix or production parameters. It is believed that there is a lot of promise for the further production and use of these tiles

ملخص: في هذه الورقة تمت دراسة تأثير استبدال الحصى الناعم والخشن بالزجاج المعاد تدويره على خصائص البلاط في درجات الحرارة المحيطة والمرتفعة مع نسبة استبدال 0-100٪ من الحصى والزجاج ، والزجاج الخشن من النفايات .وقد تمت عملية إنتاج العينات في درجة حرارة الغرفة (20 22^{o}C)، ثم يتم تسخينها في الفرن إلى درجة الحرارة المطلوب، وتترك لتبرد لدرجة حرارة الغرفة، ومن ثم يتم إخضاعها لاختبار الإجهاد والقوة تحت الضغط.

وأظهر الأداء العام للبلاط المصنوع من الزجاج المعاد تدويره قوة جيدة جدا وخصائص امتصاص دون حساسية مفرطة لأي من المعاملات المحتلفة لطرق الإنتاج.

1. INTRODUCTION

In Gaza strip, one can observe a low awareness of the problem of waste treatment especially with dangerous waste. Locally waste of glass produced by peoples is one of the problems that require attention. Everybody knows that glass is not biodegradable material. It does not dissolve, that is why it affects the environment. In order to reduce the locally waste of glass produced in Gaza Strip, the crushed glass can be used in tiles.

1.1 Glass Reuse and Recycling in Gaza Strip

A study published in Gaza Strip by UNRWA mentioned that the composition of the solid waste is estimated to be 79.81%, of the household solid waste consist of organic material, sand 7.21%, plastic and rubber 5.02%, cloth 1,.9%, glass 0.85%, metals 2.22% and carton 2.02 % [1 and 2]. Another statistics published by the municipality of Gaza showed that organic material accounts for 65% of the household solid waste, carton and paper 12%, plastics 11%, metals 3.5%, glass 1.5% and others 7%. The amount of waste glass

considerably increased due to the last Israeli aggression and the upcoming reconstruction of destroyed buildings [2].
There is no glass recycling so far in Gaza Strip. It might be feasible to reuse crushed glass in roof coating instead of asphalt and also in floor tiles. Therefore, a feasibility study of potential reuse or recycling is recommended.
For many years, the recycling and waste management industry has struggled with the problem of identifying or developing reliable markets for mixed-color broken glass. To date, only low value applications are available, which do not utilize the physical and other inherent properties of the glass.
Recent researches made it possible to use such glass as aggregate in concrete, either in commodity products, with the only objective to utilize as much glass as possible, or in value-added products that make full use of the physical and esthetic properties of color-sorted crushed glass. Seung et al. showed the advantages to have the mixing ratio of the crushed waste glass aggregate about 30%.

Foreign countries have been taking much effort to recycle waste glass bottles. A bottle recovery system has already been established, through which empty bottles previously containing alcoholic beverages, refreshing beverages, condiments, milk, etc. are collected, washed, and reused. In addition, broken bottles and bottles previously containing chemicals, cosmetics, etc. are melted to be reused or crushed and turned into paving material, block material, glass marble, glass tile, glass fiber, lightweight blowing agents, etc. [4–6]. In Korea, empty used bottles are similarly reutilized in that they are collected, sorted, and crushed to be used mostly as a raw material for new bottles. However, only negligible proportions of the total used bottles are actually currently being recycled. Therefore, we have sought to evaluate the recyclability of domestic waste glass as a fine aggregate for concrete and other secondary processed construction materials [7].

The potential applications are basically limitless, and it is expected that commercial production of specialty glass concrete products will have a major impact on the economics of glass recycling [8].
This study covers the technical aspects of some of engineering applications. A number of recycled glass paving tile test samples were manufactured using low technology procedures. The main process parameter to be altered was the percentage of aggregates which was replaced by waste glass as. The performance of the tiles was assessed in terms of their flexural strength, abrasion and absorption capacity. The recycled glass tiles showed very good strength and absorption properties without being overly sensitive to any of the mix or production parameters. It is believed that there is a lot of promise for the further production and use of these tiles.

1.2 Quantities of solid waste in Gaza:

Table 1 shows the quantities of solid waste in Gaza strip from the period of 2001 to 2010 among which the amount of waste [3].

Table 1: Amount of waste glass generated in Gaza strip in Tons from 2001 to 2010:

Material	Organic	Paper	Plastic	Metals	Glass	Others
Year	65%	12%	11%	3.5%	1.5%	7%
2001	92015	16987	15572	4955	2123	9909
2002	98548	18193	16677	5306	2274	10613
2003	105545	19485	17861	5683	2436	11366
2004	113038	20869	19130	6087	2609	12173
2005	121064	22350	20488	6519	2794	13038
2006	129659	23937	21942	6982	2992	13963
2007	142950	26391	24191	7697	3299	15395
2008	153099	28264	25909	8244	3533	16488
2009	163969	30271	27749	8829	3784	17658
2010	175611	32420	29719	9456	4053	18912

1.3 Previous work with Recycled Glass

Previous work with recycled glass has involved the development of processes for manufacturing paving or mosaic tiles from sintered recycled glass. Brown et al used powdered glass and up to 10% clay binder to form a composite material. Clay binder was necessary to give a green strength for transfer to the kiln before final firing. It was found that green strength was affected by the amount of clay binder, particle size, pressing pressure and amount of water. Fired tiles strength was found to be considerably greater than that of commercial clay based tiles. Higher stiffness and strength were obtained with smaller particles, less water and binder, and greater pressing pressure. Pressing pressure was ranged from 10 MPa to 40 MPa. Binder content was ranged from 4% to 20%. Kiln heating rates of between100 ºC/hr and 350 ºC/hr gave essentially the same properties, while lower rates resulted in lower strength and stiffness. Slow cooling was important. The strength and stiffness of the samples was greatest when the peak kiln temperature was between 920 °C and 950 ºC. The maximum modulus of rupture was found to be approximately 4.8 X 10^6 kg/m^2 (47.1 MPa). [9].

The making of mosaic glass from ground waste glass is described by Liu et al. used several types of chemical binder to produce mosaic glass of the required texture. The glass was formed into samples and sintered by firing at 640 °C – 800 ºC for 30 minutes before slow cooling. The tiles fired at temperatures of 720 ºC had bending strengths of 1.90 - 3.22 times stronger than those fired at 640 ºC, and that strength tended to increase with firing temperature. The maximum bending strength obtained was 10.56 kg/cm^2. Specimens fired at 640 ºC had water absorption of up to 5.25%, while those fired at temperatures at least 720 ºC had no appreciable absorption [10].

2.0 EXPERIMENTAL METHODS

As mentioned before the process parameter is the percentage of waste glass used to replace the aggregates in making tiles. For this reason number of samples were manufactured and tested, each has a defferent percentage of waste glass.

This scenario was adopted to reach the optimum ratio of waste glass which can be used in the application so as not to prejudice the standards. A testing program and timetable were scheduled for preparation and processing of samples, afterwhich all results where recorded and compared. All tests were implemented according to the international standards such as: the American Society for Testing and Materials (ASTM), British Standards (BS) and the Palestinian Standards which will the our source for the requirements of each application.

The crushed glass is a combination of coarse and fine particle. The terms coarse and fine designate particle size, which were taken with reference to a US#200 sieve. Fine particles will pass through a US#200 sieves, whereas coarse particles will be retained. Table 2 shows the sieve analysis done for the glass used in specimen productions [11].

Table 2: Sieve Analysis of Glass

Sieve#	Opening Sieve (mm)	Wt Retained Commutative (g)	% Retained	% Passing
4.00	4.75	0.74	23.81	76.19
10.00	2.00	2.15	69.06	30.94
12.00	1.70	2.36	75.87	24.13
13.00	1.18	2.78	89.22	10.78
40.00	0.43	3.09	99.29	0.71
200.00	0.08	3.12	100.00	0.00

Tiles are composed of two bonded layers, the upper one having a smooth surface and constituted of cement, usually white cement, mixed with predetermined amounts of marble chips or other hard stone, and of powdered stone or marble. The lower layer shall be constituted of ordinary Portland cement, sand, and aggregate mostly between 0.1 mm and 2.0 mm in size. The main action was replacing aggregate by glass.

Six specimens were produced to study and analyze the effect of adding waste glass in the samples under the following criterion:

1. The percentage of crushed glass used to produce the specimens were 0%, 25%, 50%, 75% and 100%.

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2. Samples with zero waste glass were produced as a reference for the other samples.

3. Waste glass was determined as a percentage of aggregate.

Many researches were made in order to get the ideal percentage of the components. The best percentage was found to be, (1: 1: 2.5: 0.65) for cement: quartz: aggregate: water respectively [13- 15], accordingely this result was adopted in this study. For samples in Table 1, 2.8 kg of cement and quartz where used for all percentages (0%, 25%, 50% 75% 100%) of the aggregate which weighted (0, 1.422, 2.844, 4.266, 5.688) kg respectively

All data and percentages of the other samples (T.I - T.V) are illustrated in Table 3.

Table 3: Details of the tested specimens:

Sample	Glass			Aggregate		Cement		Quartz		Water
	% aggregate	Weight (kg)	Volume (L)	Weight (kg)	Volume (L)	Weight (kg)	Volume (L)	Weight (kg)	Volume (L)	Volume (L)
[	0	0	0	10.44	3.970	2.8	0.889	2.8	1.057	1.8
T.II	25	1.422	0.992	7.83	2.977	2.8	0.889	2.8	1.057	1.8
T.III	50	2.844	1.985	5.22	1.985	2.8	0.889	2.8	1.057	1.8
T.IV	75	4.266	2.977	2.61	0.992	2.8	0.889	2.8	1.057	1.8
T.V	100	5.688	3.970	0	0	2.8	0.889	2.8	1.057	1.8

Table 4 shows the mixture quantity which were used to produce the samples. Data in Table 5 was used to calculate the quantities of the mixed materials in one cubic meter of tiles. All data and percentages of other samples are presented in Table 3.

Table 4: Details of the tested specimens.

Cement (kg)	2.63
Sand (kg)	5.25
Aggregate (kg)	3.87
Water (L)	1.5

Table 5, shows the quantity used for producing 1 m^2 of tiles with 3 cm black layer thickness.

Table 5: Details of the tested specimens

Sample	Glass			Aggregate		Cement		Quartz		Water
	% aggregate	Weight (kg)	Volume (L)	Weight (kg)	Volume (L)	Weight (kg)	Volume (L)	Weight (kg)	Volume (L)	Volume (L)
T.I	0	0	0	2088	0.611	560	0.137	560	0.163	0.28
T.II	25	284.421	0.1527	1566	0.458	560	0.137	560	0.163	0.28
T.III	50	568.841	0.3054	1044	0.305	560	0.137	560	0.163	0.28
T.IV	75	853.262	0.458	522	0.153	560	0.137	560	0.163	0.28
T.V	100	1137.682	0.6107	0	0	560	0.137	560	0.163	0.28

2.1 Procedure of Producing Specimens:

All specimens were subjected to the same conditions during production process. First cement and quartz were mixed properly, then adding aggregate to the mixture. With contieous adding of water. The specimens were produced using ordinary tile making machine. Both surface leveling and curing should be done accurately.

The production process was designed to be uncomplicated and reproducible. Much of the process involved readily available and non-specialized tools and equipment.

3.0 TESTS REQUIRED FOR APPLICATIONS:

For tiles three main tests were required; flexural, absorption and abrasion tests.

3.1 Flexural Testing: ASTM C78

Compact setup was fabricated in the laboratory to perform flexural test on the samples. The setup was calibrated using a digital load cell. Specimen of 250 mm X 250 mm X 25 mm size was tested for flexural with two opposite edges simply supported and the other two were free. Each specimen was rested on a 12 mm diameter of high carbon steel bar. These tiles were subjected to a center line load excerted by the 12 mm bar. Before applying the loads, the specimen were properly leveled and centered.The load was applied gradually. The load readings were recorded until the tile was crushed.

3.2 Absorption Test ASTM C67

Absorption testing was carried out instead of ASTM C67, According to ASTM C67; the pieces were first dried in an oven at a temperature of about 110°C for period of 24 hour, then cooled to room temperature and weighed. This weight was recorded as dry weight W(d). Next, the specimens were immersed into a water tank at room temperature and left for 24 hour after which the sppeciemns were removed from the water and blotted dry to remove the shiny surface and were weighed again to get the saturated weight, W(s). The weight of water absorbed divided by the dry weight equals the percentage of absorption [7] as shown in Eq. (1):

$$\%o\boldsymbol{Absorption} = \frac{\boldsymbol{W(s)-W(d)}}{\boldsymbol{W(d)}} \qquad \textbf{(1)}$$

Where W(s) is the saturated weight

W(d) is the dray weight

The tiles used in absorption test were used from the pieces of tiles which were previously used in the flexure test.

However, the ASTM standard has no specific size of the specimen. As the specimen of constant thickness gets smaller, the specific surface (the ratio of surface area-to-volume) gets larger. Theoretically, this could influence the amount of absorption.

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In order to facilitate testing, there was some experimentation with modifying the ASTM C67 procedure. It was generally found that, the weight prior to any oven drying almost the same as the weight after oven drying. Thus, initial tests were carried out using no drying phase at all.

4.0 RESULTS AND DISCUSSION

4.1 Flexural Test

When flexural tests were conducted for tiles samples in accordance to ASTM C78, the results of the tested samples, generally, came over the desired value 5.5 MPa according to the Palestinian specifications. The end rates came as follows:

The standard sample which included 0% waste glass bore 6.14 MPa, the pressure rate decreased to 5.95 and 5.59 MPa for the samples contained 25% and 50% waste glass respectively. Then, it was noticed that pressure increased for the samples contained 75% and 100% to reach 5.73 and 6.03 MPa respectively. The best line fit was shown in Fig. 2. It was noticed that the pressure decreased for the sample contained 50% waste glass before it rises again. The results could be explained further by the fact that, concrete strength is typically controlled by the bond strength between cement matrix and aggregate. If natural aggregate with relatively rough surfaces is replaced by crushed glass particles with relatively smooth surfaces, a drop in strength and reduction of ductility would be expected. Table 6 and Fig. 1, show the tested samples of flexure tests.

Table 6: Samples values of the flexural test

Item	**T.I**	**T.II**	**T.III**	**T.IV**	**T.V**	**Standards**
Glass Percentage	**0**	**25**	**50**	**75**	**100**	
Stress (Mpa)	6.14	5.59	5.59	5.73	6.03	Min (5.5 Mpa)

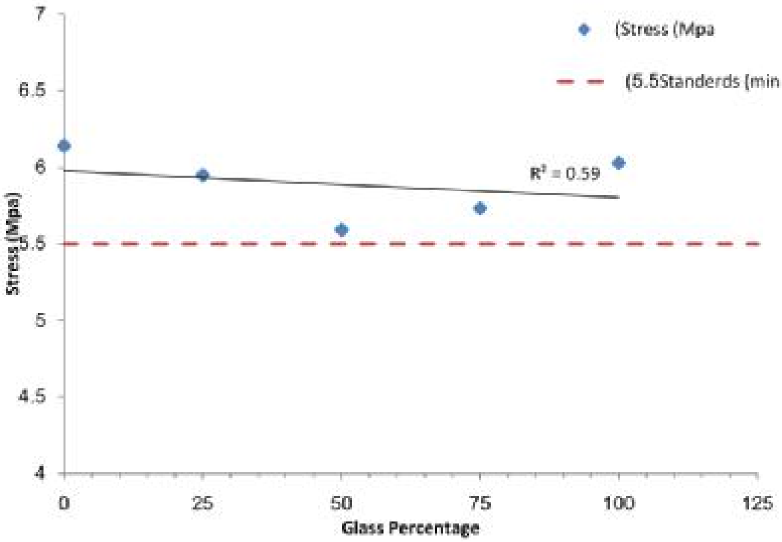

Fig. 1: Tested samples bearing rates of flexure tests

4.2 Absorption Test

Absorption is also an important characteristic of tiles. The Palestinian specifications determined the maximum absorption rate in tiles to be 9%. However, when conducting the tests in accordance to ASTM C 67, in general, higher absorption rates for tiles were found. In fact, the results confirmed our conclusion. The absorption rate for the standard sample which contained 0% waste glass was 7.45% and decreased for the samples contained 25% waste glass to 7.27%, and continued to decrease generally. According to the collected data, it was found that samples contained 75% and 100% waste glass showed slightly higher absorption rates in comparison to the decreasing rates in the other samples. This can be explained as a result of the minor changes in the quantities mixed.

Table 7 and Fig. 2, illustrate the collected results.

Table 7: Samples values of the absorption test

Item	T.I	T.II	T.III	T.IV	T.V	Standards
Glass Percentage	0	25	50	75	100	
Absorption Rate %	7.45	7.27	6.8	6.95	7.27	Max 9%

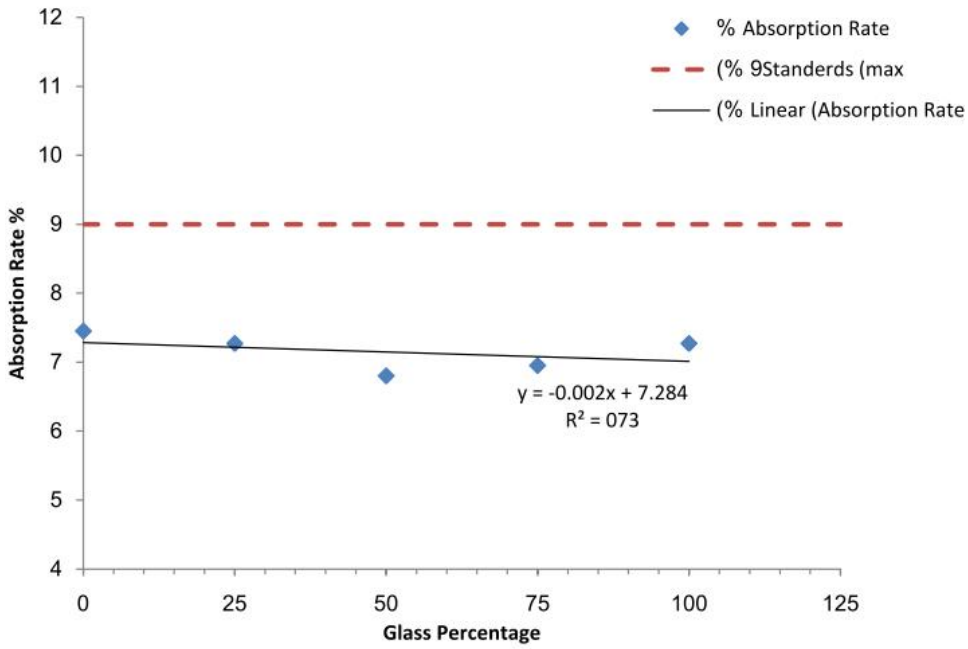

Fig. 2: The absorption rate

4.3 Abrasion test:

Abrasion tests are important and vital test for tiles. The Palestinian specifications set the abrasion value for tiles to be 3.2 mm. The collected results of the experemints showed that the abrasion resistance of the samples increased as the percentage of waste glass rised. In the standard sample contained 0% waste glass, the abrasion rate was 2.49 mm before it started to decrease reaching 1.35 mm for the samples contained 50% waste glass. The declination continued to reach 0.55 and 0.9 mm for the samples contained 75% and 100% waste glass respectively. This could be explained as waste glass has higher abrasion resistance than the aggregate. Table 8 and Fig. 3, would further illustrate the collected results.

Table 8: Samples values of the abrasion test

Item	T.I	T.II	T.III	T.IV	T.V	Standards
Glass Percentage	0	25	50	75	100	
Abrasion Resistance (mm)	2.49	3.2	1.65	0.55	0.9	Max 3.2 mm

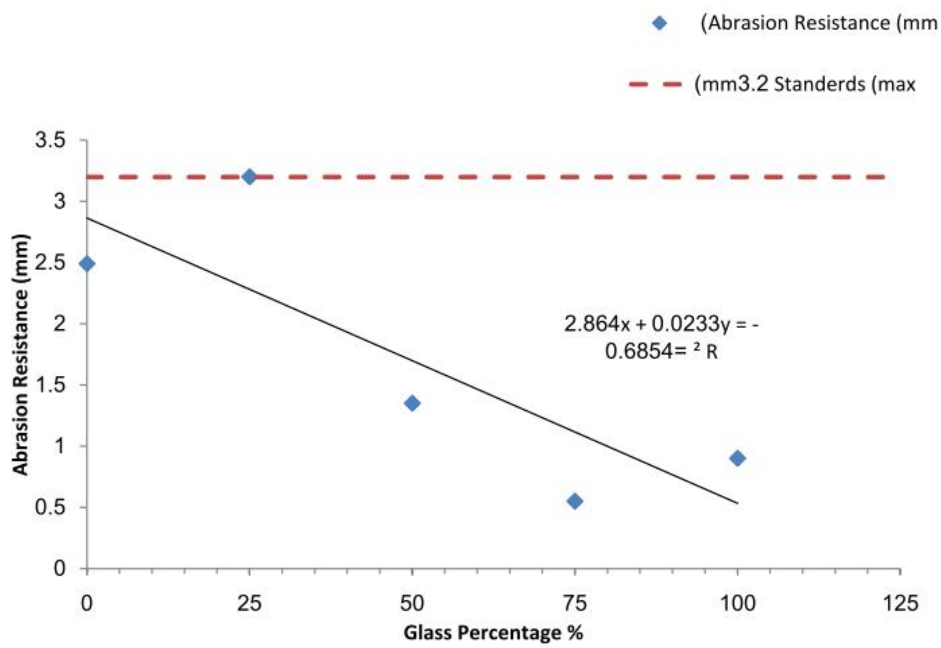

Fig. 3: The abrasion resistance rate

5.0 CONCLUSIONS

The performance of the tiles was assessed in terms of their flexural strength, abrasion and absorption capacity.

It was noticed that pressure decreased for the samples contained 50% waste glass before it raised again, this because the concrete strength is typically controlled by the bond strength between cement matrix and aggregate. Natural aggregate with relatively rough surfaces was replaced by crushed glass particles with relatively smooth surfaces; accordingly a drop in strength and reduction of ductility was reported.

The absorption rate for the standard sample contained 0% waste glass was 7.45% and decreased for 25% waste glass samples to 7.27%, and continued to decrease generally. According to the collected data, it was found that samples contained 75% and 100% waste glass showed slightly higher absorption rates compared with the decreasing rates in the other samples. This can be explained as a result of minor changes in quantities used or samples mechanism work.

In the standard sample contained 0% waste glass, the rate of abrasion was 2.49 mm and decreased to 1.35 mm for samples contained 50% waste glass. The declination continued to reach 0.55 and 0.9 mm for the samples contained 75% and 100% waste glass respectively. This could be explained as waste glass has higher abrasion resistance than the aggregate.

Overall Performance of the recycled glass tiles showed very good strength and absorption properties without being overly sensitive to any of the mix or production parameters. It is believed that there is a lot of promise for further production and use of these tiles.

REFERENCES

[1] El-Hawi, M., (1997). An introductory review to solid waste management, Ministry of Planning, Gaza city, Palestine.

[2] A. Juda and Husni Al-Najar (2001) Solid waste management in the Gaza Strip Case Study Ministry of Health, Gaza.

[3] Agro vision, (2010). Gaza Solid Waste Disposal Project, Final Report. Gaza Municipality. Palestinian National Authority.

[4] S.B. Park, Development of recycling and treatment technologies for construction waste, Construction and transportation technology research report, Ministry of the Environment of ROK, Seoul, 2000, pp. 153– 156.

[5] Glass Bottle Recycling Council, Glass Bottle Recycling, Pamphlet of Glass Bottle Recycling Council, GBRC of ROK, Seoul, 1994, pp. 25–35.

[6] Clean Japan Center, Research on the Status of the Recycling Technology Development (Reuse of the Glass Bottle Cullet for Other Purposes), Clean Japan Center report, CJC of Japan, Tokyo, 1997, pp. 1– 20.

[7] Ministry of the Environment, 1999 National Waste Generation and Treatment Status, Ministry of the Environment report, Ministry of the Environment of ROK, Seoul, 2000.

[8] OECD, Use of waste materials and by-products in road construction, Organization for Economic Cooperation and Development report, Paris, 1977, pp. 10– 15.

[9] Brown, I.W.M. and K.J.D. Mackenzie, 1982. Process design of a ceramic-like body from recycled waste glass. Journal of Materials Science, pp. 2164-2193.

[10] Liu, Li, and Zhang (2009)Testing of Recycled Glass and Inorganic Binder Paving Tiles PROJECT CONSULTANT: University of Washington

[11] Nansu, J S Chen, 2002. Engineering Properties of Concrete Made With Cycled Glass Resources [J], Conservation and Recycling, June 2002,Volume35 Essue4, p259-274;

[12] Jiang Wenjiu, 2003. Recycle of waste glass, Shanghai Building materials [J], 2003.3; JTJ052-2000.

[13] ASTM C 78 - 84 (1984). Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).

[14] ASTM C 67 - 92a (1992). Standard Test Methods of Sampling and Testing Brick and Structural Clay Tile.

[15] ASTM C 293 - 79 (1979). Standard Test Method for Flexural Strength of Concrete (Using Beam with Center-Point Loading).