IJE TRANSACTIONS B: Applications Vol. 31, No. 11, (November 2018) 1824-1829

International Journal of Engineering

Journal Homepage: www.ije.ir

Experimental Investigation of Toughness Enhancement in Cement Mortar

S. V. S. Jebadurai, D. Tensing*, G. Hemalatha, R. Siva

Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore, Tamilnadu, India

PAPER INFO

Paper history:
Received 09 May 2018
Received in revised form 15 October 2018
Accepted 26 October 2018

Keywords:
Glass Powder
Natural Rubber Latex
Compressive Strength
Flexural Strength

ABSTRACT

This paper presents the results of investigation carried out to improve the mechanical toughness of cement mortar. Toughness is a basic parameter which has to be improved in brick walls, concrete roads, machine foundations, dams etc. Materials fails due to an impact force and vibrations resulting in minor cracks and bonding failure between bricks, it leads to failure of the structure. In order to avoid the failure toughness has to be enhanced and this can be done by modifying the cement mortar. In this project recycled glass is used in the form of powder less than 45 µm as replacement of cement. Also natural rubber latex is added as 20% replacement of water. Three mortar mix are considered, namely 1:3, 1:4, 1:5. The compressive strength of mortar cubes, and flexural strength are done to determine the strength and toughness of the mortar. Results showed that fracture toughness increased to considerable amount.

***doi**: 10.5829/ije.2018.31.11b.04*

Nomenclature

W_0	area below CMOD curve up to rupture (N mm)	G_F	fracture energy (N/mm²)
W_1	work done by deadweight of the specimen and loading jig (N mm)	$CMOD_C$	area below CMOD curve up to rupture (N mm)
A_{lig}	area of broken ligament (b x h) (mm²)	*P*	Load
m_1	mass of specimen (kg)	*l1*	Center to center support length.
S	loading span (mm)	*l2*	Loading span
L	total length of the specimen (mm)	*B*	Width of the beam
M_2	mass of jig not attached to testing machine but placed on specimen until rupture gravitational acceleration (9.807m/s^2)	*w*	Depth of the beam
g	crack mouth opening displacement at the time of rupture (mm)	*a*	Crack depth

1. INTRODUCTION

Million tons of waste glass is being generated annually in India. These waste glass are disposed as landfills which is unsustainable to our environment [1]. Use of these waste glass in concrete is an important step towards development of environmentally friendly, energy-efficient and economical material. The mortar and concrete has been a popular construction material in the world. It is well known that glass is an inert material which does not undergo any chemical reaction, has good pozzolanic reaction, can be scaled downed to microns [2, 3]. On the other hand, manufacturing of cement, a key ingredient used for the production of concrete, is a major source of greenhouse gas emissions. Manufacturing of one ton of cement results in emission of approximately one ton of carbon dioxide (CO_2) to the atmosphere. Cement production also involves emission of moderate quantities of NOx, SOx, and particulates [4-9]. The use of supplementary cementations materials (SCMs) to offset a portion of the cement powder in concrete is a promising method for reducing the environmental impact of the industry. Several industrial by-products have been used successfully as SCMs, including silica fume (SF), ground granulated blast furnace slag (GGBFS), and fly ash [10]. These materials are used to create blended cements which can improve

*Corresponding Author Email: *dtensing@karunya.edu* (D.Tensing)

Please cite this article as: S. V. S. Jebadurai, D. Tensing, G. Hemalatha, R. Siva, Experimental Investigation of Toughness Enhancement in Cement Mortar, International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 31, No. 11, (November 2018) 1824-1829

concrete durability, early and long term strength, workability, and economy [6]. One material which has potential as a SCM but which has not yet achieved the same commercial success is waste bottle glass. Glass has a chemical composition and phase which is comparable to traditional SCMs. It is abundant, can be of low economic value. It is realized that mixed-color waste glass offers desired chemical composition and reactivity for use as a supplementary cementations material (SCM) for enhancing the chemical stability, pore system characteristics, moisture resistance and durability of concrete. Previous efforts to recycle waste glass [11-18] in concrete have focused on the use of crushed glass as replacement for aggregate in concrete [13]. In this paper a combination of glass powder and SBR latex has to be used to replace cement and water [19, 20]. Combinations of these two materials can exploit the useful properties of both and yield composites with excellent strength and durability properties [8].

2. MATERIALS

2. 1. Fine Aggregate The specific gravity of the fine aggregate taken for the study was 2.64 and it was confirming to zone 2 of IS: 383-1970. The sand were dried before use to avoid problem of buckling.

2. 2. Cement In this investigation, Ordinary Portland Cement (OPC) of 53 grade were used. The specific gravity of OPC were found to be 3.15. The results of the tests conducted to determine the properties of cement is presented in Table 1 [7, 14].

2. 3. Natural Rubber Latex Natural rubber latex was used to improve physical and mechanical behavior of hardened mortar. It was mixed with portable water as 20% of its volume fraction [21].

2. 4. Waste Glass The waste glass used in the test was mixed color glass. This glass was obtained from local recycled glass manufacturer. The glass was grounded to make glass powder of size less than 45 µm [3, 5]. The specific gravity of glass powder was 2.78. Results of tests to determine the properties of glass powder is given in Table 1. The initial and final setting time were find out by using Vicat apparatus. 40% of glass powder replaced with cement and the initial and final setting time were taken. It can be seen that addition of glass powder increased the setting time of cement indicating that it acts as a retarder [11].

The chemical composition of the OPC and glass powder was done using EDAX test and the results are presented in Table 2. It can be observed that glass powder has more silica content which is favorable component to increases the strength of mortar [19].

TABLE 1. Properties of Cement and Glass powder

S. No	Property	Glass Powder	OPC (53 Grade)
1	Color	mixed-color	lithish-grey
2	Particle size	<45 µm	<45 µm
3	Specific gravity	2.7	3.15
4	Consistency	30%	28%
5	Initial setting time	45 min (with OPC)	35 min
6	Final setting time	210 min (with OPC)	178 min

TABLE 2. Chemical composition of waste glass powder with OPC 53 grade

S. No	Chemical Composition (% Mass)	OPC (53 Grade)	Glass Powder
1	Silicon dioxide (SiO_2)	21.56	79.77
2	Aluminum oxide (Al_2O_3)	5.39	1.25
3	Ferric oxide (Fe_2O_3)	3.39	0.33
4	Magnesium oxide (MgO)	1.19	1.89
5	Calcium oxide (CaO)	65.5	-
6	Sulphur tri oxide (SO_3)	2.76	-
7	Albite (Na)	-	10.02
8	Feldspars ($KAlSi_3O_8$)	-	0.23
9	Wallastonite (Ca)	-	6.31
10	Chromium oxide (Cr_2O_3)	-	0.20
11	Loss of ignition	1	-
12	TOTAL	100.79	100

3. COMPRESSIVE STRENGTH OF CUBES

3. 1. Mortar Cube Preparation In the preparation of mortar mix for test specimens, cement, sand, glass powder and natural rubber latex were mixed in a ratio of 1:3, 1:4 and 1:5 by its weight. The water cement ratio was taken as for 0.35, 0.38, and 0.40. The mortar specimens were cast in cube mould of size 7.01cm x 7.01cm x 7.01cm to determine the compressive strength. Control specimens were cast without replacement with glass powder and natural latex. Two type of replacement was done i) replacement of cement with glass powder, ii) replacement of cement with glass powder and water with natural latex. The percentage of glass powder mixed with OPC was taken as 40%. The natural latex was added as volume fraction and 20% replacement with water was done [21]. The mix ratio and the quantity of material taken for the study are shown in Table 3.

3. 2. Cube Tests Compressive strength test was performed on compression testing machine. Three cubes were tested for each mix ratio and the average value of

TABLE 3. Mix ratio and quantity of material

S. No	Mix ratio	W/C	Cement (g)	Glass powder (g)	Sand (g)	Natural latex (ml)	Water content (ml)
1	1:3	0.35	486	285	2037	181	907.8
2	1:4	0.38	387	228	2175	180	900.4
3	1:5	0.4	324	180	2262	179	893.1

these three was reported. The comparative study were made on each mortar mix of 1:3, 1:4 and 1:5 with partial replacement of cement with glass powder as 40% and natural rubber latex as 20% and the test result were taken on 7, 14 and 28 days of curing.

4. RESULTS AND DISCUSSIONS

The results of the cube compression tests of mortar cube are shown in Figure 1(a-c).

1:3 mortar: The 7 day mortar strength was increased by 22% when cement was replaced with glass powder. The presence of silica in the glass powder enhanced the alkali-silica reaction and contributed to the increase in mortar strength and also the finely ground powder filled the pores in the mortar to make it more dense, thereby enahncing its mechanical properties. When compared to the control mix when replacement was done for cement with glass powder and water with natural rubber latex an increase in mortar strength 39% was acheived. Natural rubber latex being an elastomeric material increased the density and binding property of the mortar. However, there was no increase in compressive strength when cement was replaced with glass powder and increase in strength was marginal at 28 days and it was 25%.

1:4 mortar: The increase in compressive strength at 7days was 15% for replacement with cement and 29% when natural latex rubber was added. However, at 28 days the replacement of cement decreased the compressive strength.

5. FLEXURE TEST

5. 1. Preparation of Specimens

To determine the fracture energy of concrete notched beam was used. Beam specimens were cast in beam mould of size 500mm x 100mm x 100mm for the three-point flexural strength test [20] according to ASTM C348 and ASTM C305 test standards. According to JCI-S-001-2003, the specimen should be beams of rectangular cross section with a notch at the mid-length to a depth of 0.3 times the beam depth. The depth of cross-section of the specimen shall be not less than 4 times the maximum aggregate size. The width of the cross-section of the specimen shall be not less than the 4 times the maximum aggregate size. As per the codal provisions the depth of the notch was kept as 40 mm. This was introduced during the casting process by using steel sheets. Control specimens were prepared for 1:4 and 1:5 mortar mixes and specimens with 40% replacement with glass powderand 20% replacement with natural rubber latex were prepared.

5. 2. Testing of Specimens

The flexural strength test were performed on universal testing machine (Figure 2 a and b) using beam samples. Three-point test on cement and mortar with 1:4 and 1:5 ratio of samples were casted to test for 7, 14 and 28 days to find out fracture energy fracture toughness. A complete load versus crack mouth opening displacement (CMOD) curve was obtained. Figure 3 (a-f) illustrates the load vs. CMOD for 1:3, 1:4 and 1:5 mortar mixes with and without replacement.

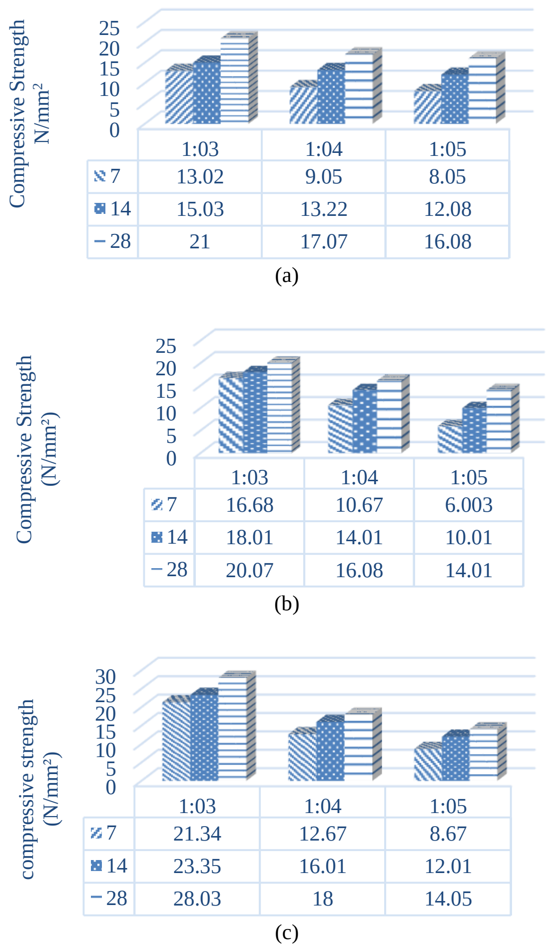

Figure 1. (a) Compressive strength for Control mix of mortar cube; (b) Compressive strength of mortar cube-replacement with glass powder; (c) Compressive strength of mortar cube – replacement with glass powder and rubber latex

(a)

(b)

Figure 2. (a) Experimental set up for Fracture test; (b) Mortar beam with pre-induced notch and crack formation

5. 3. Fracture Energy It is the energy required to open unit area of crack surface and it does not depend on the size of the structure and is a material property. This is an important property that predicts whether the failure if the material is brittle or ductile. Many researchers have presented empirical relations for determining the fracture energy of by three point method. In this work the relations presented by Japan Concrete Institute Standard [9] are considered and shown in Equations 1 and 2.

$$G_F = \frac{0.75W_0+W_1}{A_{lig}} \quad (1)$$

$$W_1 = 0.75\left(\frac{s}{l}m_1 + 2m_2\right)g.CMOD_C \quad (2)$$

5. 4. Fracture Toughness (Kic) It is the property that describes the ability of a material containing a crack to resist fracture. If the fracture toughness of a material is high it indicates that the material will undergo ductile fracture, a desirable property for cement based structures subjected to adverse loads [15]. It is believed

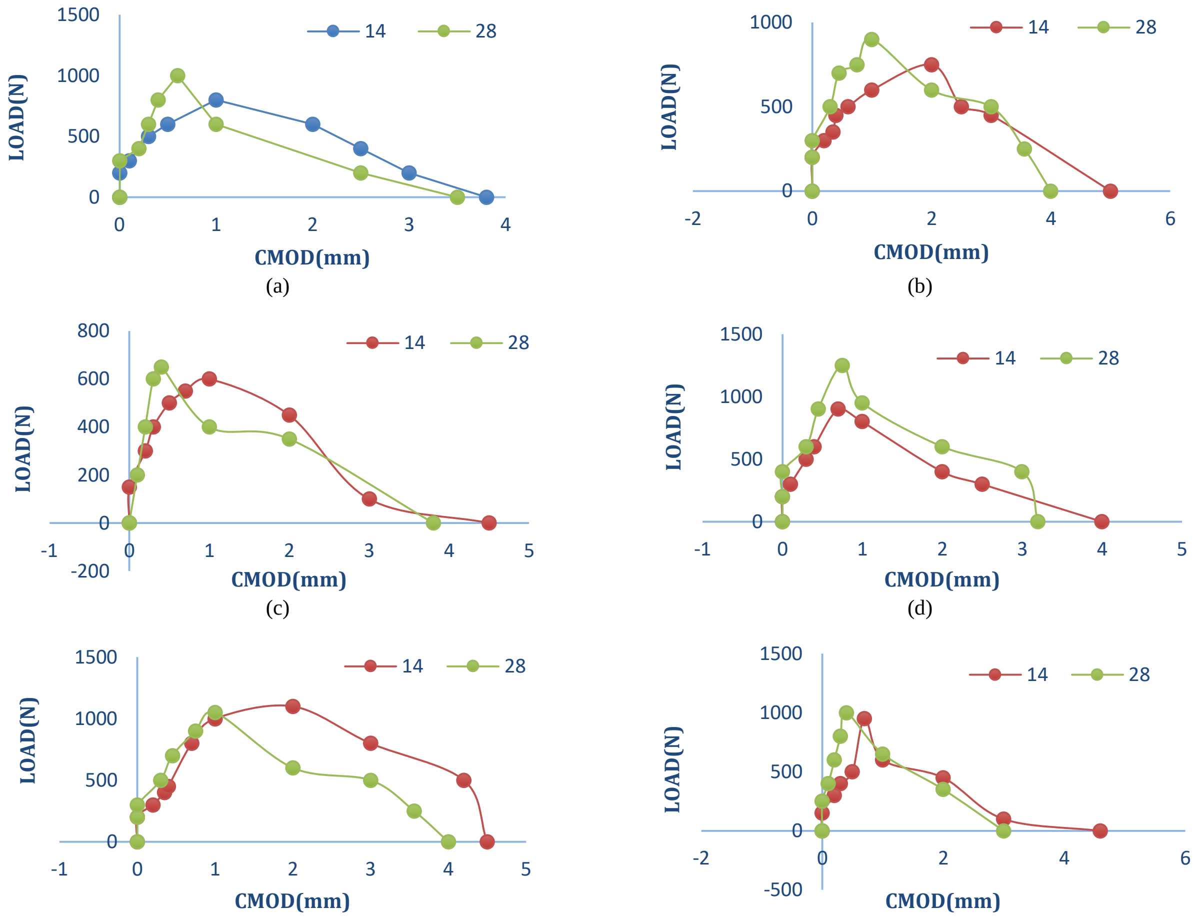

Figure 3. (a) 1:3 mortar beam without latex; (b) 1:4 mortar beam without latex; (c) 1:5 mortar beam without latex; (d) 1:3 mortar beam with glass powder and latex; (e) 1:4 mortar beam with glass powder and latex; (f) 1:5 mortar beam with glass powder and latex

that crack starts to propagate in concrete as the crack tip stress intensity factor reaches the fracture toughness value. A large number of research efforts has been made in studying the fracture toughness of normal strength concrete and cement mortar to measure the K_{ic} and G_f. In this work the equations asgiven by Alam et.al [12] are used as shown in Equations 3 and 4 and tabulated in Tables 4 and 5.

$$K_{ic} = \frac{p(l_1 - l_2)\sqrt{a}}{Bw^2} \times \frac{3}{2(1-{}^{a}/_{w})^{\frac{3}{2}}} \times Y \qquad (3)$$

$$Y = 1.989 - 1.33\frac{a}{w} - \frac{\left[3.49 - 0.68\frac{a}{w} + 1.35(a/w)^2\right]\frac{a}{w}(1-\frac{a}{w})}{(1-\frac{a}{w})^2} \qquad (4)$$

1:3 mortar: The fracture energy at 14 days was found to increase by a marginal value of 4 and 6% at 28 days. The fracture toughness increased by 23% at 14 days and 18% at 28 days.

1:4 mortar: The fracture energy at 14 days was found to increase by 18% and an increase of 33% at 28 days. The fracture toughness increased by 36% at 14 days and 22% at 28 days.

1:5 mortar: The fracture energy at 14 days was found to increase by a marginal value of 6% but decrease at 28 days. The fracture toughness increased by 26% at 14 days and there was no increase in the toughness at 28 days.

6. CONCLUSION

In order to study the use of glass power and natural rubber latex as partial replacement of cement an experimental investigation was carried out. In this study glass powder was taken as 40% replacement of cement. 20% of water was replaced with natural rubber latex for improving the energy absorption. Compression tests on mortar cubes and flexure tests on beams with slit openings to study the fracture energy were carried out. Tests were done on 1:3, 1:4 and 1:5 mortar samples. Following conclusions are made based on the experimental observations.

The presence of glass power in cement decreases the alkali-silica reaction because of the reaction of silica in glass powder, and this in turn increases the pozzolanic activity.

This pozzolanic reaction in mortar was evidenced by the increase in compression strength for all the mortar specimens namely 1:3, 1:4, 1:5.

Fracture energy and fracture toughness was found to increase for 1:3 and 1:4 specimens whereas increase was not observed for 1:5 specimens.

Based on the observations it is concluded that addition of glass particles and natural rubber has a positive influence for richer mixes of 1:3 and 1:4, however for leaner mixes the proportion of glass powder may be increased for better results.

TABLE 4. Fracture energy and fracture toughness of mortar beam without replacement

S. No.	Mixture	Fracture energy (N/mm^2)		Fracture toughness (M.Pa)	
		14 days	28 days	14 days	28 days
1	1:3	149.37	310.53	0.230	0.320
2	1:4	138.47	160.04	0.180	0.251
3	1:5	117	242	0.140	0.210

TABLE 5. Fracture energy and fracture toughness of mortar beam with replacement

S. No.	Mixture	Fracture energy (N/mm^2)		Fracture toughness (M.Pa)	
		14 days	28 days	14 days	28 days
1	1:3	155.6	330	0.300	0.390
2	1:4	169.6	238	0.280	0.320
3	1:5	128	146	0.190	0.210

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چکیده

این مقاله نتایج تحقیقات انجام شده برای بهبود سختی مکانیکی ملات سیمان را ارائه می‌دهد.سختی یک پارامتر اساسی است که باید در دیوارهای آجری، جاده‌های بتنی، بنیادهای ماشین، سد و غیره بهبود یابد. مواد به علت نیروی ضربه و ارتعاش که منجر به ترک جزئی و شکست پیوند بین آجر می‌شود، منجر به شکست ساختار نمی‌شود. برای جلوگیری از سختی شکست باید افزایش یابد و این می‌تواند با تغییر ملات سیمان انجام شود. در این پروژه شیشه بازیافت شده به شکل جایگزینی سیمان به شکل پودر کمتر از ٤٥ میکرومتر استفاده می‌شود. همچنین لاتکس لاستیک طبیعی به عنوان جایگزینی ٢٠٪ جایگزین آب اضافه می‌شود. سه مخلوط ملات در نظر گرفته شده است، یعنی ١:٣، ١:٤ و ١:٥. استحکام فشاری مکعب‌های ملات و قدرت خمشی برای تعیین مقاومت و سختی ملات ساخته شده است. نتایج نشان می‌دهد که چقرمگی شکست به میزان قابل توجهی افزایش می‌یابد.

doi*: 10.5829/ije.2018.31.11b.04*