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The strain sensitivity of brass fiber reinforced concrete

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ABSTRACT

The structures are challenged by earthquakes and other environmental factors. Structural health monitoring is crucial to protect the lives. The strain gages used in structural health monitoring have low durability and can get point wise measurements which limit their use. In this study, five different concrete mixtures with different brass fiber volume fractions were designed. Along with the control mixture which does not have brass fiber, six mixtures were designed and three cube samples from each mixture were cast and cured. Compression test was conducted with simultaneous measurement of electrical resistance. The brass fiber reinforced concrete has strong linear relationship between the electrical resistance change and strain. Important progress was achieved in development of "Smart Concrete" which can sense its strain and damage.

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1. Introduction

Earthquakes and other environmental factors degrade and damage civil structures. Concrete infrastructures, have materials deteriorations and 30% of the bridges were reported to be structurally not reliable in USA (Reza et al., 2003). Structural health monitoring is vital to protect the people and structures. Commercial metal foil strain gauges measures the strain of a point and they have low durability and short life time. Moreover, many strain gauges have to be used to monitor structure health which increases cost (Chung, 2001). This study is a contribution of developing self-sensing smart materials and structures for the construction industry.

Piezoresistive effect is the change of electrical resistance under application of load (Chung, 1998; Fu et al., 1997). Cementitious materials were tested with two and four electrode methods for electrical resistance. Current application and the voltage measurement were carried out with the same pair of electrodes in the two electrode method while different electrode pairs were used in the four electrode method (Han et al., 2007; Chiarello and Zinno, 2005). Embedded and circumferential electrode methods were used. In circumferential electrode method, conductive band or dyestuffs were stuck around samples. In embedded electrode method, conductive mesh, wire or plate were sink into samples (Chen and Liu, 2008; Teomete and Erdem, 2011; Li et al., 2008; Li et al., 2006).

Tensile strain sensitivity of cementitious composites was tested by split tensile test and high strain sensitivity was obtained (Teomete and Koçyiğit, 2013). There is strong linear relationship between crack length and electrical resistance change of cement composites (Teomete, 2013). Transverse strain sensitivity of cement matrix composites was tested by compression and split tensile tests (Teomete, 2014).

2. Material and Experimental Method

Six different mixes were designed in this study (M0, Br1, Br2, Br3, Br4, Br5). CEM II B-M (L-W) 42,5R cement were used in all mixes. All mixes were prepared according to TS 802 "Design of Concrete Mixes". Water /binder ratio 0.37; silica fume/binder ratio 10%, super-plasticizer/binder ratio 1% was used in all mixes. Commercially available brass fiber which had average length of 1.5 mm and average diameter of 0.5 mm was used in mixes M0, Br1, Br2, Br3, Br4 and Br5 at 0, 0.35, 0.5, 0.8, 1, 1.5% volumetric ratios, respectively. In M0, there is

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not any brass fiber. Super plasticizer was modified polycarboxylates based polymer (ViscoCrete High Tech 30). Aggregates 0-5 mm and 5-15 mm were used according to TS802 grading limits.

7.5 cm cube molds were used for casting samples. The molds have four slots which were 2 mm wide and 55 mm long, on each side. Pure copper wire mesh which has hole size 5 mm, wire diameters 0.6 mm were used as electrodes and placed into molds (Fig. 1(a)). The mix was cast in the mold as in Fig. 1(b). The samples were taken out of molds 24 hours after casting, and cured in water for 28 days.

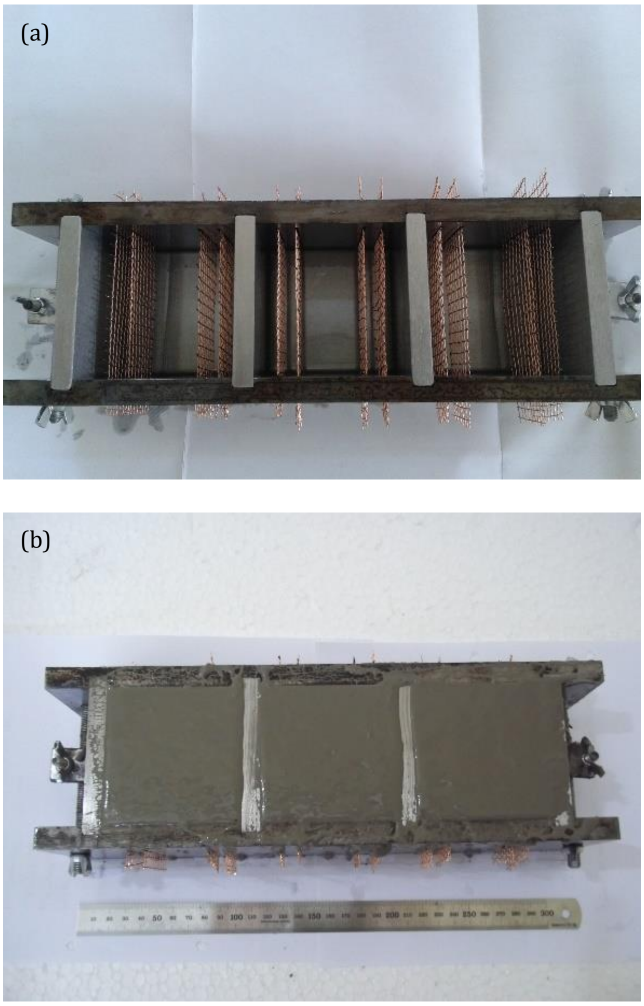
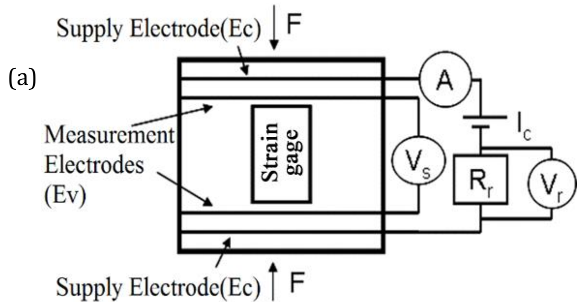


Fig. 1. (a) Mold and electrodes; (b) After casting.

Compression test was applied in order to investigate the relations between compressive strain and electrical resistance change as in Fig. 2. Shimadzu mechanical testing machine was used for the tests with a load rate of 0.5 mm/min. During the test, DC 20 V was supplied to outer two electrodes while potential difference between inner electrodes were measured as V_s (Fig. 2(a)). The reference resistance R_r=1000 Ohms was used and its voltage was recorded was V_r. The current in the circuit was measured as I_c. Voltages, V_s and V_r, current I_c, sample strain, load were recorded at a rate of 10 Hz during the test (Figs. 2(a, b)). Glass fiber epoxy composites were used to isolate the sample from steel plates during the test.



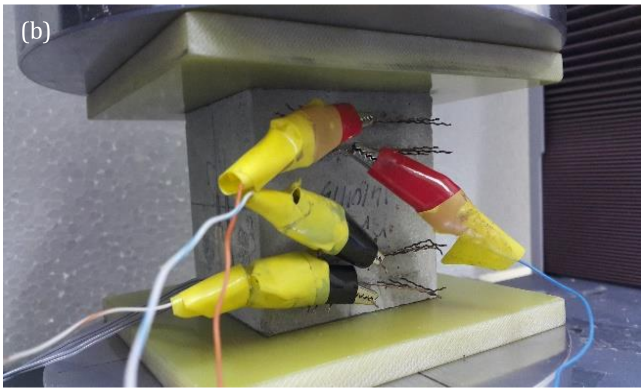


Fig. 2. (a) Test circuit; (b) The sample at test.

The resistance of the sample (R_s) at any time of the test were determined by using Ohms law as in Eq. (1).

$$R_s = \frac{V_s}{I_c}. \tag{1}$$

The percent change of the electrical resistance of the sample (%R) was determined by Eq. (2). R_{so} is electrical resistance of sample without load.

$$\%R = \left(\frac{R_s}{R_{so}} - 1\right) \times 100\,. \tag{2}$$

Performance measures were defined in this study. These are gage factor (K) and linearity (LE). Gage factor (K) is the change in electrical resistance per unit strain and determined by Eq. (3). The higher the gage factor, the more sensitive to strain the sensor is. Commercial strain gages have a gage factor of 2. Linearity (LE) is the percent of maximum difference (Δ_{max}) between input-output curve (%R versus strain curve) and fitted linear regression line, to full scale output (R_{fs}) as in Eq. (4). As the linearity decreases, the error in strain measurement decreases.

$$K = \frac{(R_s - R_{so})/R_{so}}{\Delta\varepsilon}, \tag{3}$$

$$\%LE = \left(\frac{\Delta_{max}}{\%R_{fs}}\right) \times 100\,. \tag{4}$$

3. Results and Discussion

In this study, six different mixtures were designed and tested with compression test. The relation between strain and electrical resistance change was determined.

The strain-%R graph of M0 is presented as shown in Fig. 3(a). M0 have a gage factor of K=21, linearity of LE=%15 and correlation coefficient is R^2=0.93. M0 is 10 times more sensitive than commercial strain gages while not having any fibers.

Br1 which has 0.35% fiber is almost 2.5 times more sensitive than M0 and almost 24 times more sensitive than commercial strain gages. It has gage factor of K=47, linearity of LE=6%. The change in electrical resistance had a strong linear relationship with strain with a correlation coefficient of 0.99 as shown in Fig. 3(b).

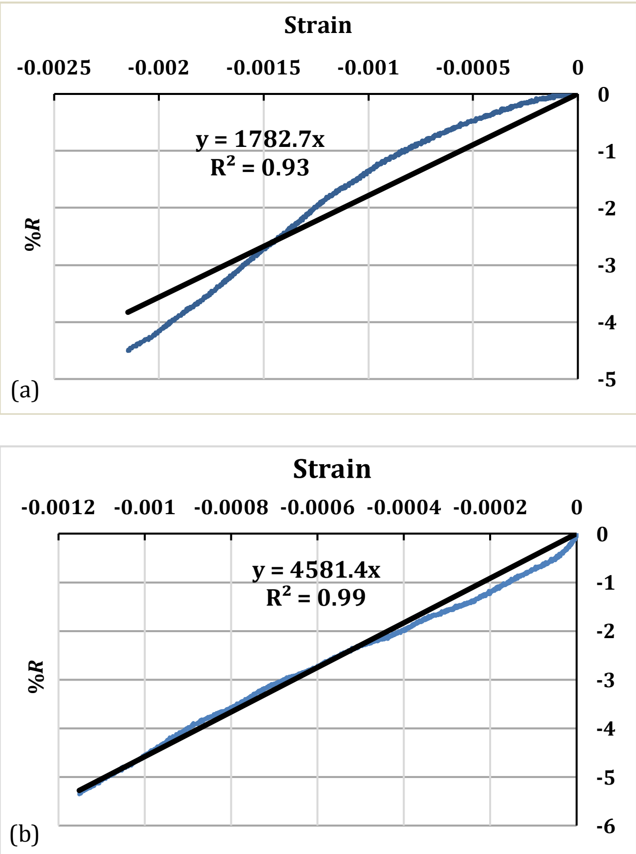


Fig. 3. Strain-the percent change of electrical resistance: (a) M0 mixture without fiber (K=21, LE=15%, R^2=0.93); (b) Br1 (0.35%) mixture (K=47, LE=6%, R^2=0.99).

Br2 having 0.5% brass fiber volume fraction has the gage factor of K=58, linearity of LE=8% as shown in Fig. 4(a).

The strong linear relationship between the changes in electrical resistance-strain had a correlation coefficient of 0.99. The gage factor of Br2 is almost 27 times more sensitive than commercial strain gages.

The mixture Br3 has 0.8% fiber volume fraction. It has gage factor of K=53, linearity of LE=3%. The correlation coefficient of best fit line to the data is 0.99 (Fig. 4(b)).

The mix Br4 having 1% brass fiber volume fraction has a gage factor of K=60, linearity of LE=6%. It is almost 30 times more sensitive than commercial strain gages. The correlation coefficient of fit line is R^2=0.99 (Fig. 5(a)).

The gage factor of Br5 having 1.5% brass fiber volume fraction is K=40, which is 20 times more sensitive than commercial metal strain gages. Br5 had a linearity of LE=5%. The electrical resistance change and strain has a correlation coefficient of 0.99 which testifies the strong linear relationship seen in Fig. 5(b).

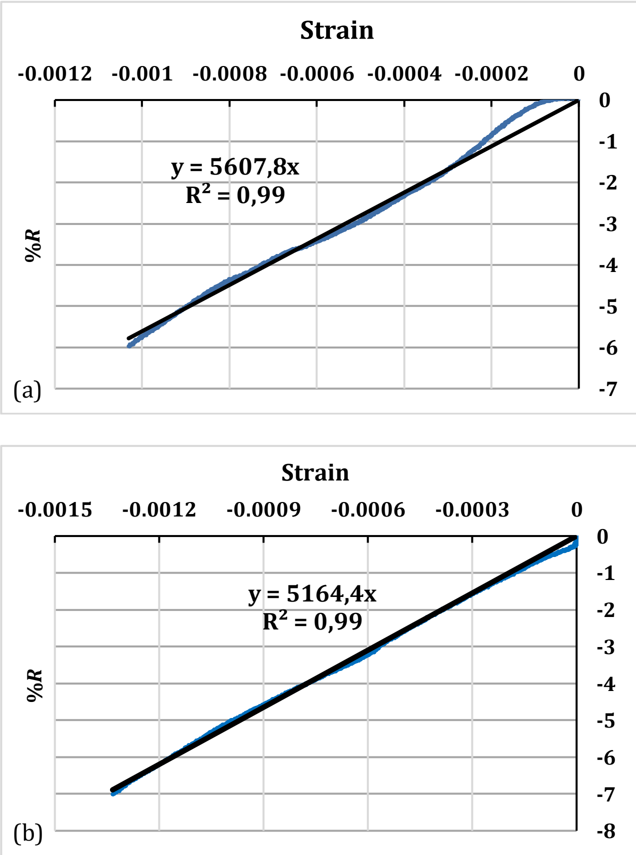


Fig. 4. Strain-the percent change of electrical resistance: (a) Br2 (0.5%) mixture (K=58, LE=8%, R^2=0.99); (b) Br3 (0.8%) mixture (K=53, LE=3%, R^2=0.99).

4. Conclusions

Six different brass fiber reinforced cement based concrete mixes were designed with different volume fraction of brass fiber. Three cube samples were cast and cured from each mix. Compression test was applied to each cube sample. Strain and electrical resistance was measured simultaneously. The relation between the changes in electrical resistance and strain were examined to evaluate the strain sensitivity of mixtures. The results obtained are as follows:

- Under compressive strain, micro crack and voids closed, fiber-matrix, fiber-fiber and matrix-matrix contact increased which led to decrease of electrical resistance.
- Tested brass fiber reinforced concrete mixes have higher strain sensitivity than metal foil strain gages. Gage factors as high as 60 were obtained for brass fiber reinforced concrete while metal foil strain gages had gage factor of 2.
- The brass fiber reinforced concrete had a strong linear relationship of strain – electrical resistance change.

- Brass fiber reinforced concrete mixes were more sensitive to strain than the concrete which did not have any brass fiber.

The results obtained in this study are important steps to develop smart concrete which senses its strain and damage.

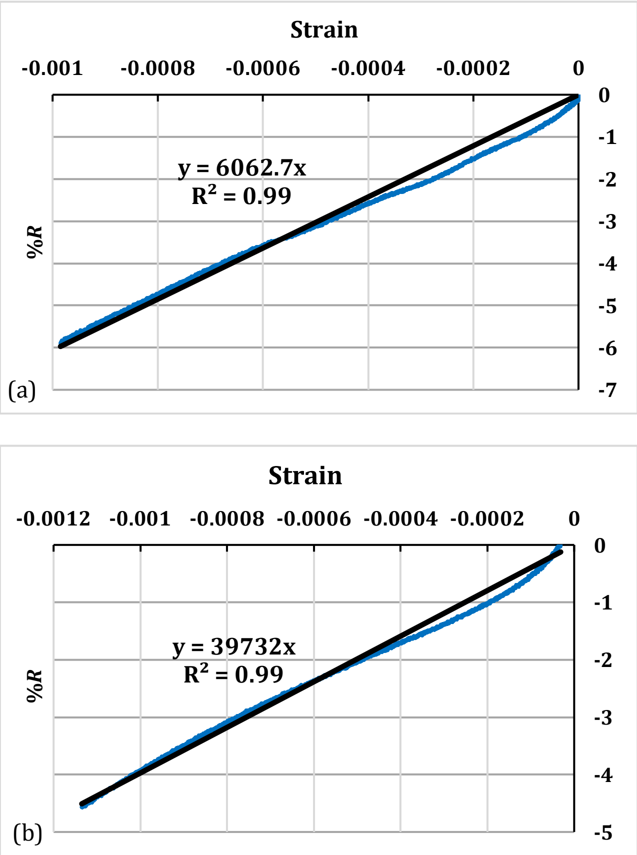


Fig. 5. Strain-the percent change of electrical resistance: (a) Br4 (1%) mixture (K=60, LE=6%, R^2=0.99); (b) Br5 (1.5%) mixture (K=40, LE=5%, R^2=0.99).

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