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FABRICATION AND CHARACTERIZATION OF BIO-INSPIRED STRUCTURAL COMPOSITES

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ABSTRACT

This paper presents the results of mechanical tests performed on bio-inspired structural composites. The details of synthesis process, loading configurations, testing conditions are discussed. Results of the tests clearly show the superiority of the biomimicked layered composites made from concrete and polymer, in terms of toughness over their monolithic counterparts. The implications of the results and their impact on construction technology will be elucidated.

INTRODUCTION

Tough structural materials are desirable for applications such as residential and commercial buildings. Tough structures will mitigate loss of life and property caused by earthquakes, tornados and hurricanes. The main culprit in natural disasters is the presence of dynamic shear forces that demolish brittle brick and mortar buildings. One way to make tough materials is to mimic naturally tough structures such as nacre. Oyster and mother of pearl shells combine hardness of aragonite with the softness of natural polymers. The result is a tough structure with nominal strengths of 194-248 MPa [1] reported for 3-point bend tests performed on abalone and oyster.

The mechanism of toughening of nacre has been debated to be the maximization of inelastic strain, nanoscale asperities causing mechanical interlocking [1] or the continuity of aragonite single crystal tablets through bridges over the polymer layers [2].

Structures made with designs taken from nature include micro-laminated ceramic-metal [3-5], ceramic-organic, as well as organic-organic composites [6]. Biomimicked ceramics synthesized include B_4C layered with Al [7], SiC layered with Al and B_4C layered with polypropylene [3, 8, 9]. Hydroxyapatite scaffolding [10] is an example of biomedical application of biomimicked structures.

It is possible to apply natural schemes of nacre to structural materials by layering hard materials such as concrete with soft polymers such as glue [11]. Mechanical tests on biologically inspired composites show greater toughness associated with composites made of concrete and glue [11]. This paper describes dynamic shear tests performed on these structures

EXPERIMENTAL PROCEDURE

Structural composites tested here were made of layers of concrete separated by thin layers of polymer. Details of the preparation method for the test specimens are presented in Ref [11]. A brief description of the samples follows. There were three composite specimens along with a fourth monolithic control one. They were made with three types of polymers and were named accordingly: Concrete-Gorilla-Glue (GG), Concrete- Bonding Adhesive (CBA) and Concrete-Liquid-Nail (LN). Materials properties are presented below:
Cement: Quikrete^{TM} Quick Setting Cement # 1240 with a compression strength of 20-44 MPa.

Polymer:

1. Liquid Nail^{TM} Glue #LN-275, a Benzene-based synthetic rubber with a shear strength of 0.8- 2.0 MPa
2. Gorilla GlueTM: Polymer with 70% urethane with 30% polymer MDI
3. Quikrete^{TM} Concrete Bonding Adhesive #9908 (Vinyl Acetate Ethylene and Vinyl Al polymer) with a shear strength of 0.7-1.0 MPa

Samples were made by layering Quikrete^{TM} Quickset concrete with the polymers mentioned above. The thickness of concrete layer was about 1-1.5 mm. Biomimicked structures were machined to produce test samples with typical dimensions of 135 mm length, 25 mm width and 6 mm thickness. Special fixtures were made to mount the samples on a shake table. Samples were mounted vertically on the shake table with a dead weight fixed to the top of the samples. The applied load of 8.14N mimicked vertical reinforcement while providing enough shear force to fracture the samples in dynamic shear tests. Actuation of the samples were performed using a typical geology-used shake table with frequencies of up to 425 Hz and a fixed oscillation amplitude of ~ 4 mm.

Strain measurement was achieved by the analysis of the images extracted from videotape shot during the tests. The position of the top and bottom of the samples was measured relative to reference lines and the relative motion of top vs. bottom was calculated from these measurements. The data were plotted in terms of the net motion of the top and bottom vs. time. To obtain the amplitude of the net motion of the sample, a sinusoidal curve was fitted to the data for which the amplitude is reported here.

RESULTS

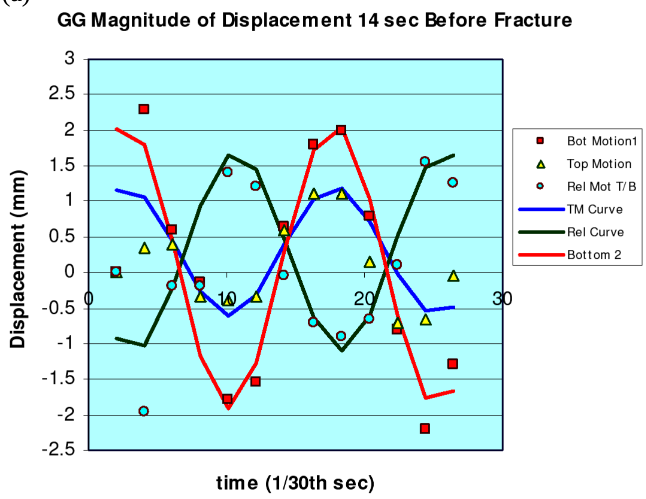
The preliminary results of dynamic shear tests on biomimicked structures made from concrete and polymer are presented here. Table 1 lists the history of actuation of each sample leading to its fracture. They are presented in the order of exposure starting with low frequencies followed by higher frequency actuation. Number of cycles at higher frequencies indicates final portion of dynamic shear life. As an example, the monolithic sample was exposed initially to a 100 Hz frequency with an amplitude of 4 mm followed by frequencies of 150, 200 and 250 Hz. This sample fractured after 16 cycles at 250 Hz.

Table 1. History of actuation of each sample in terms of frequency and number of cycles, N denotes the number of cycles to fracture

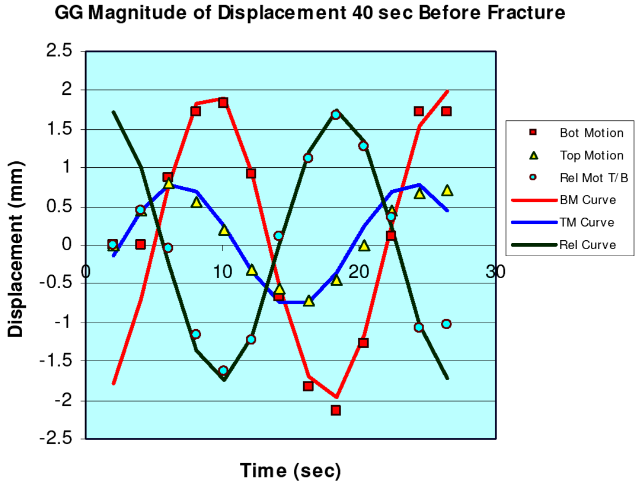
	N	Hz	sec
CBA	24	200	6
	60	300	12
	48	350	7.5
GG	32	300	6
	9	200	6
	12	125	5
	207	250	55
LN	36	125	17
	26	150	9
	122	210	35
	53	250	12
Mono	20	100	14
	17	150	6
	60	200	19
	70	250	16

Results of measurements of the amplitude of the cyclic displacement of the top and bottom of the samples were plotted (Figures 1a-c). These plots show the change in the amplitude of the top of the sample as cracks started to grow within the LN and GG samples. The sinusoidal nature of the motion of the top and bottom is evident from the pictures.

(a)



(b)



(c)

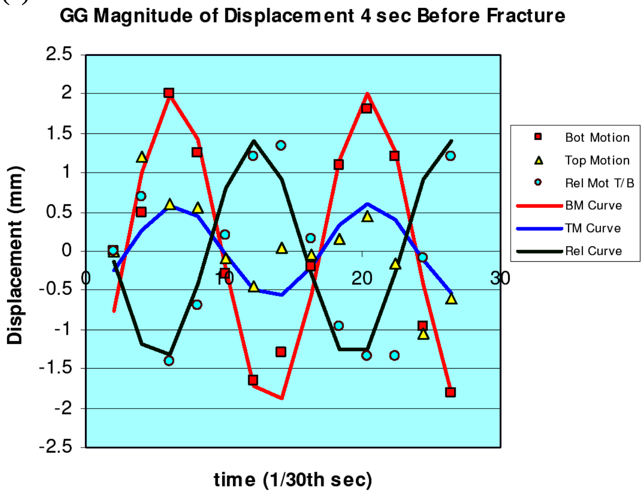


Fig. 1. Plots of the magnitude of displacement of the top, bottom and relative top to bottom of GG sample taken at various stages of dynamic shear tests. (a) 40 sec before fracture, (b) 14 sec before fracture and (c) 4 sec before fracture

The interesting characteristics of the plots is the fact that relative displacement of the top of the samples with respect to bottom which becomes maximum when the shake table meets its dead ends during each cycle.

This was not the case for the mono and CBA samples which fractured without an appreciable change in the amplitude of the top of the sample.

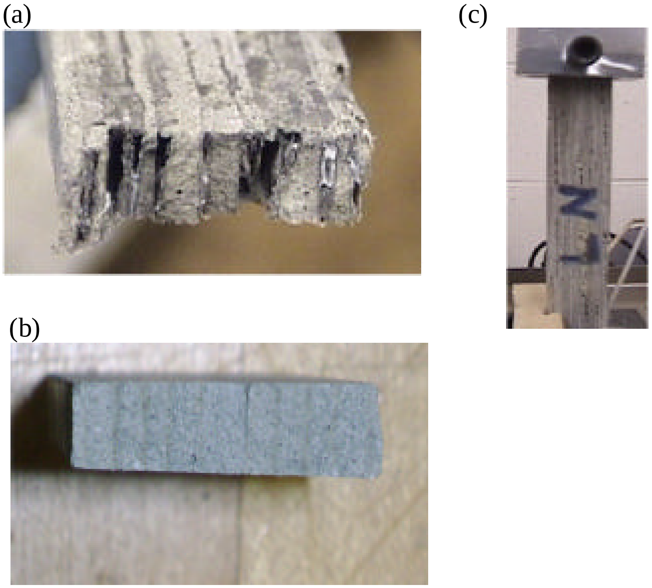


Figure 2 (a) Fracture surface of GG sample along with (b) mounting configuration of the LN sample. The direction of oscillation was perpendicular to the plane of the page, (c) fracture surface of the monolithic sample

Table 2 Amplitude of the cyclic motion of the bottom, top and relative top to bottom for GG samples at various stages of actuation

Time to fracture (sec)	Amplitude of Cyclic Motion of Bottom, Top and T/B (mm)		
	Bottom	Top	Top Relative to Bottom (T/B)
4	2	0.6	1.4
14	2	0.9	1.4
40	2	0.8	1.75

DISCUSSION OF RESULTS

As seen from the displacement plots reported for the GG and LN samples, maximum bending of the samples take place mostly when the shake table has reached the two dead points on each cycle. The magnitude of the bending can be obtained from the extent of relative motion of the top vs. the bottom of the samples (see Fig. 1c). The magnitude of the force can be calculated from the mass of the weight attached to the top of the sample and from the acceleration of the sample in each cycle.

Fracture surfaces of the LN and GG samples exhibit stepwise fracture. (Fig. 2a). However, the fracture surfaces of the monolithic and CBA samples were mainly flat (Fig. 2b). This is consistent with brittle fracture, typical of ceramics. The stark difference between the CBA adhesives and other glues function lies in the chemical composition difference between these samples (check out the omposition of each of the two composites. The mounting configuration is shown in Fig. 2c.

The results of the tests clearly demonstrate the superior toughness of the biomimicked structures compared to the monolithic control specimen. While the monolithic structure fractured at a frequency of 250 Hz, at which most other samples, break, however, its fracture is abrupt. The relative motion of the top of the monolithic sample as well as the CBA sample is small. (e.g. top of the sample does not bend significantly (e.g. less than 1 mm). Nevertheless, the GG and LN samples both show significant relative motion of the top vs. bottom. (e.g. the GG sample had a relative motion of top close to 10 mm in the last two cycles). The GG sample cracked at a frequency of 300 Hz, This was noted from the large amplitude of the relative motion of top vs. bottom of the sample. The cracked sample continued to withstand vibration for over 200 more cycles before complete fracture.

CONCLUSIONS

Dynamic shear tests performed on biomimicked composites made from layered concrete and glue shows the following

1. Monolithic and at least one composite show abrupt fracture.

2. Composites made with Liquid Nail^{TM} and Gorilla Glue^{TM} develop cracks during tests, however they continue to carry load many cycles later exceeding 200 for the former composite.
3. Fractured surfaces of the monolithic sample and concrete bonding adhesive composite were mainly flat while the other two layered composites show stepwise fracture.

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