Investigation on Magnetic Concrete for Additive Manufacturing

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BACKGROUND

The field of additive manufacturing has expanded to include ceramic and concrete materials. This growth in the construction sector has allowed for 3D printing to produce low cost, complex structures that require little in terms of formwork and have a potential to reduce material waste. The technical problems with using concrete include setting time and layer adhesion between deposited layers due to the high cement content. The lack of aggregate in these mixes also decreases the early strength of the print.

In our research, multiple methods of analysis are used to identify which parameters in the material and environment can be controlled and tuned using magnetic fields (MF) for process improvement and create a potentially stronger print that cures faster

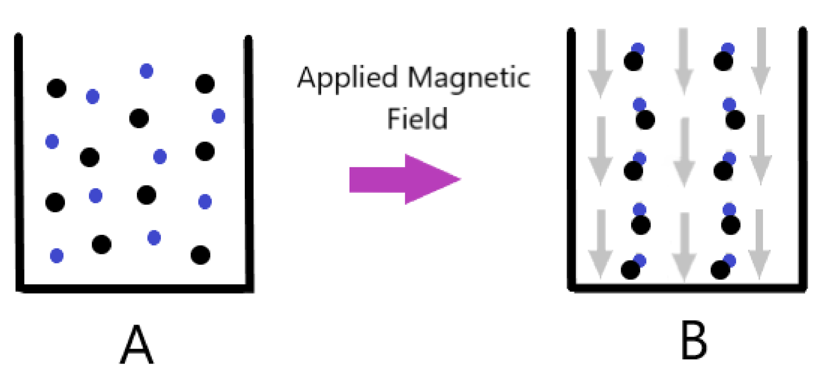

Fig. 1. Proposed response of magnetorheological cement A) without MF, particles are randomly distributed; B) the ferrous particles in the mortar align with the flux path of the applied MF

OBJECTIVES

The following were explored to address current problems with concrete 3D printing :

- **Additives to Cement Matrix** → This will modify material properties of conventional cement to improve performance
- **Cement Mortar Rheology** → Studies the fluid for control of the cementitious material before and after deposition.
- **Calorimetry on Fresh Pastes** → To understand which variables affect the rate of hydration and curing process in concrete structures
- **X-Ray Diffraction** → Aids in identifying the products of hydration and quantity of minerals present.
- **Magnetic Field Exposure** → To determine effects on material setting time and curing of fresh cement pastes as shown in Fig.3.

MATERIALS

The cement mortar compositions included different proportions (Table 1) of Type I Portland Cement, Class F fly ash, super plasticizer, nanoparticles (silica and alumina fibers), and micronized magnetite powder

Mix ID	Mix Constituents	Composition (%)					
		Portland Cement	*Fly Ash*	Nanomaterials: *Nano Silica*	Nanomaterials: *Nano Alumina*	*Magnetite*	*Super Plasticiser*
R_1	PC+SP	100	-	-	-	-	0.15
R_2	PC+FA+SP	50	50	-	-	-	0.15
R_1NS	PC+SP+NS	100	-	0.25	-	-	0.15
R_1NA	PC+SP+NA	100	-	-	0.25	-	0.05
R_2NS	PC+FA+SP+NS	50	50	0.25	-	-	0.15
R_2NA	PC+FA+SP+NA	50	50	-	0.25	-	0.05
R_1M	PC+SP+M	95	-	-	-	5	0.15
R_2M	PC+FA+SP+M	50	45	-	-	5	0.15
R_1NSM	PC+SP+NS+M	95	-	0.25	-	5	0.15
R_1NAM	PC+SP+NA+M	95	-	-	0.25	5	0.05
R_2NSM	PC+FA+SP+NS+M	50	45	0.25	-	5	0.15
R_2NAM	PC+FA+SP+NA+M	50	45	-	0.25	5	0.05

METHODOLOGY

Magnetorheology- A modification of a rheology test which includes a magnetic field created by an electromagnet. (Fig 2.) The sample paste was loaded into a cylindrical container and a vane rotor was inserted to measure the stress and viscosity while the shear rate ramped up and down for three cycles. Throughout the test, the sample is subjected to a magnetic flux density of 0.1 Tesla equivalent to 1000 Gauss

Calorimetry- Cement reacts with water to produce calcium hydroxide (CH) and calcium silicate hydrate gel (C-S-H) during the first 48 hours. So two samples of each cement composition were placed in the calorimeter to measure the rate of hydration in the pastes. One sample was under no MF and another sample was after exposure to MF.

XRD- Powder x-ray diffraction analysis was conducted on four samples of each cement paste composition. Two samples were at 2 days of curing before magnetic (BM) exposure and after magnetic (AM) exposure. The other two samples were BM & AM at 28 days of curing. This was to determine if short-term and long-term cement hydration was affected by the MF

Fig. 2. Magnetorheological setup using an electromagnet

Fig. 3. Stiffening of mortar from a previously fluid mixture after MF exposure

Fig. 4. Preliminary test print using a clay 3D printer

RESULTS

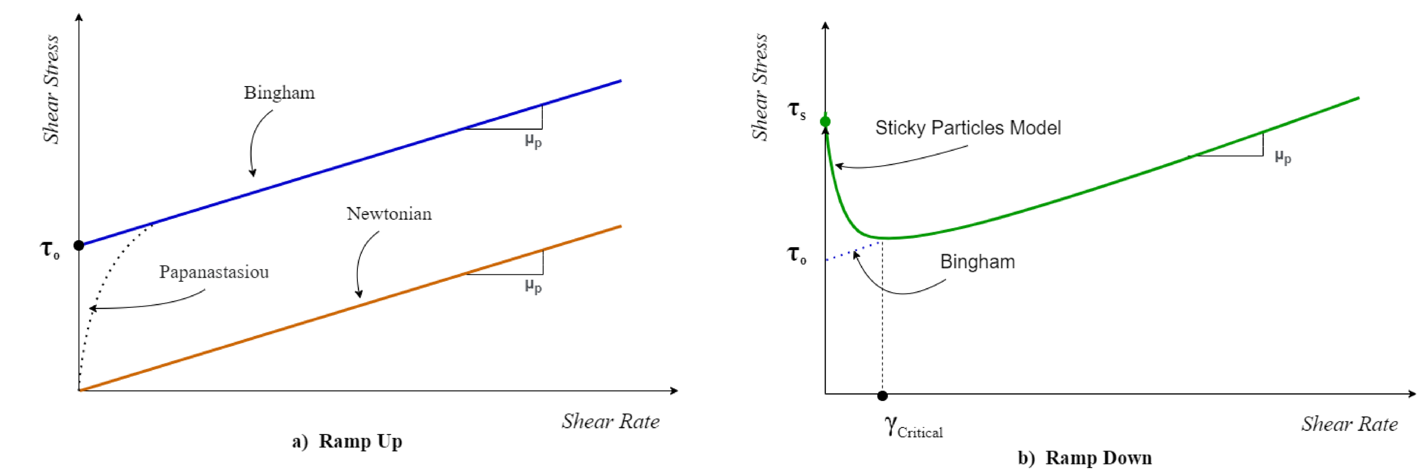

Fig. 5 The governing models during the rheology and magnetorheology experiments

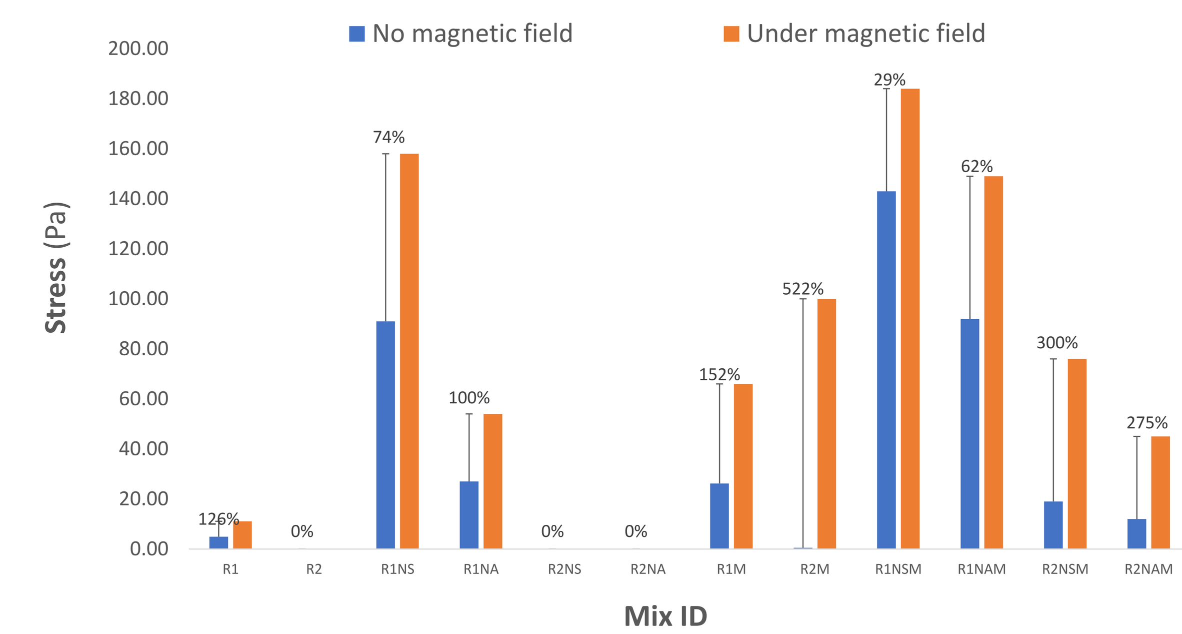

Fig. 6. The effect of a magnetic field in yield stress (τo). Cement-fly ash systems with nanoparticles (R2M, R2NSM, R2NAM) exhibit a large % increase in τo

CONCLUSIONS

Additives to Cement Matrix

- Nanoparticles act as a barrier to the poles on ferrous material which enables sliding of molecules as shown in Fig.7.

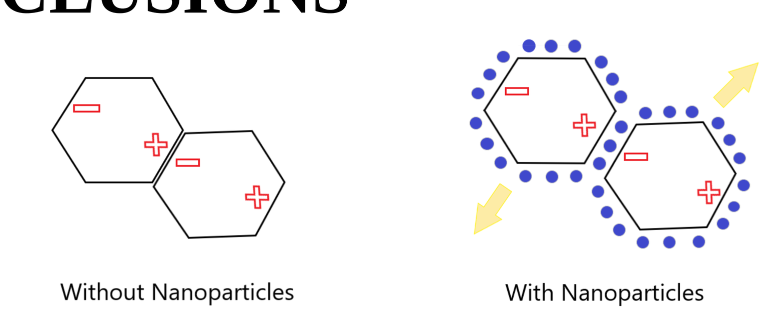

Fig. 7 Effect of nanoparticles

- Fly ash increases the fluidity of the mix, while also changing Bingham behavior to Newtonian behavior shown in Fig. 5

Cement Paste Rheology

- Identified yield stress (τo), stiffening stress (τs) and plastic viscosity (µp)
- Correlated responses to models, Newtonian, Bingham & Sticky Particles Model

Further Investigation :

- Finish analysis of magnetic field exposure and hydration process
- Print cement-fly ash mixes using the clay 3D-printer shown in Fig. 4.
- Design and implement a setup to expose the mortar to a magnetic field without disrupting the print progress.

Literature

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