Slant shear strength of hybrid concrete made with old and new parts using reactive and inert waste powders

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ABSTRACT

Manufactured reactive powders, as a silica fume, are usually used in production of high strength concrete with for retrofitting purposes of concrete structures. The efficiency of inert waste glass powder in hybrid concrete fabrication has not been widely investigated, thus further studies are essentially considered in this area. In the present study, hybrid concrete prisms with size of 10x10x30 cm have been made with old ordinary concrete (OC) and new high strength concrete (HSC). High strength of new concrete part of these prisms is achieved via using of waste glass powder, silica fume and mixture of them. The roughness of interfacial surface between old and new parts of hybrid concrete is improved in various manners with utilizing sand blast, holes and grooves. Performance of these elements has been measured in terms of slant shear strength and mode of failure. The results have been shown that there is a relatively similar strength with using retrofitted concrete made with the used powder which includes silica fume, glass powders, and their mixture, the mixture of both powders, namely, silica fume and waste glass powders is regarded a best choice in the present stud. It is demonstrated also that the grooved interface between old and new concretes induces proper strength equivalent to 89% of control concrete prisms strength.

KEYWORDS : waste glass powder; hybrid concrete prism; interfacial surface between concretes; green concrete.

1. INTRODUCTION

In any concrete structure that has been built or under construction, the engineers may face main problem in engineering history which is deterioration of reinforced concrete material (Tayeh et el.,2012). Since the time they found out this problem, they have been searching for solutions to ensure the effective structural management. So, the suitable solution for this problem is represented by good bond repairing or retrofitting by a material with high compressive strength and reasonable durability. During few years ago, researches launched to find solutions for concrete deterioration with limited concentration on using of high strength concrete as retrofitted material. HSC is among the trendiest promising cementitious materials that developed with potential to be a viable solution for improving the resilience and sustainability of the existed infrastructure because of its high strength, durability and energy absorption capacity compared with ordinary concrete. High performance concretes are typically made by cement (basically with dosage more than conventional concrete), super-plasticizer, silica fume, fine sands (maximum grain size of 0.8 mm) (Habel et al., 2006) with steel fibers as optional component (Sarsam and Mohammed, 2014). The superior compressive and tensile strengths of this concrete can be attributed to the presence of fine compounds. It was previously demonstrated in many studies (Graybeal,2006; Pfeifer et al., 2009; Graybeal, 2009) that HSCs are highly strong against chemical attack, abrasion, freeze-thaw cycles, and chloride penetration. Common sorts of HSC are fiber reinforced concretes (FRC) (Brandt, 2008), slurry infiltrated fiber concrete (SIFCON) (Naaman and Homrich, 1989), multi-scale cement composite (MSCC) (Rossi, 1997), hybrid fiber concretes (HFC) (Markovic, 2006), high performance fiber reinforced cement composites (HPFRCC)

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(Naaman, and Reinhardt, 2006), engineered cementitious composite (ECC) (Li, 2003, Li et al., 2001), ultra high performance fiber reinforced concrete (UHPC) (Wile et al., 2011; Smarzewski and Barnat-Hunek, 2017), etc. The retrofitting of deteriorated concrete with HSC material needs repairing new concrete required to place next to old defective one (Momayez et al. 2005). Accordingly, a weak bond will be arising between old and new concretes in hybrid concrete members (Momayez; Yuan and Marosszeky, 2005). Thus, to produce a durable and effective bond in these structures, a proper repair is considered main requirement (Ali and Ambalavanan, 1999; Mu et al., 2002). Some endeavors (Harris et al., 2011; Santos and Julio, 2011; Vaysburd and Emmons, 2000; Azad and Hakeem, 2013; Denarié and Brühwiler 2006; Juli et al., 2004; Garbacz et al., 2005) have been started recently to investigate the behavior of hybrid concrete. Based on the aforementioned literature review, the performance of hybrid concrete made with ordinary concrete and HSC has not been studied extensively. Thus, more investigations in this direction are considered necessary. In addition, the influence of the waste glass powder on the mechanical properties of hybrid concrete has not been examined so far.

The objectives of present work are:

1- To evaluate the efficiency of waste glass powder in enhancing the mechanical properties of hybrid concrete made with old OC and retrofitted new HSC.

2- To investigate the effect of roughening mode for the interfacial surface between OC and HSC on the slant shear strength of hybrid concrete.

2. EXPERIMENTAL PROGRAM

2.1 Materials

The used materials in the hybrid concrete are similar to those for normal concrete in addition to powders (i.e. silica fume and waste glass powder) and superplasticizer. In HSC, fine materials are employed alone with utilizing water-cement ratio lesser than that for ordinary concrete. Ordinary Portland cement has been used in current study, with properties given in Table 1. River sand with specific gravity and density of 2.67 and 1828 kg/m^3, respectively has been utilized in present concrete mixes. This aggregate is well washed; air dried and separated according the standard set of sieves. Sieve analysis has been performed for fine aggregate using grades meeting with the standard limitations of ASTM (2007) as given in Table 2. Partially crushed gravel has been employed as coarse aggregate with a maximum size of 20 mm. Clean and free from contamination tap water has been used in fresh concrete mixing and hard concrete curing. Two types of powder have been used, namely, gray silica fume and white waste glass powder shown in (fig. 1) to produce very high strength concrete which is employed as new part of hybrid concrete element. The properties of the used silica fume are tabulated in Table 3. The chemical composition and physical properties of the used glass powder are shown in Tables 4 and 5 respectively. Hence, there is no pozzolanic reactivity of this powder in concrete mix due to that their particles size is greater than 100μm as demonstrated by Ankur and Randheer (2012).

Table (1) : Characteristics of the used cement

Property	Initial setting time	Final setting time	Specific gravity	fineness	Density
Test Results	151 min.	2.25 h	3.2	306 m^2/kg	1400 kg/m^3

Table (2) : Grading of the used sand

Sieve No.	**% Passing**	**passing limits ASTM C33 [27]**
9.5 mm	100	100
4.75 mm	100	95-100
2.36 mm	85	80-100
1.18 mm	72	50-85
600 μm	51	25-60
300 μm	21	10-30
150 μm	3	2-10

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Waste Glass Powder Silica Fume

Fig (1) : The Powders used in HSC

Table (3) : Physical and chemical properties of silica fume

Property	Magnitude
% Retain on 45 micron sieve	2
Bulk density (kg/m^3)	1002
Pozzolanic activity (%)	128
% Moisture content at 105^{o}C	0.06
% Loss on Ignition at 750^{o}C	0.38
%Silicon Dioxide (SiO_2)	

Table (4) : Chemical composition of waste glass powder

Composition	% by mass
SiO_2	67.78
CaO	24.32
Al_2O_3	3.00
MgO	2.60
Na_2O	1.99
SO_3	1.00
SrO	0.76
Fe_2O_3	0.68
K_2O	0.36
TiO_2	0.10
P_2O_5	0.11
MnO	0.03

Table (5) : Physical properties of waste glass powder

Specific Gravity	2.60
Density	1.3 gm/cm^3
Fineness Passing 850 μm	95%

A reasonable dosage of superplasticizer (i.e. given in Table 6) has been used in present work to obtain the workable high performance concrete mixes with very low water-cement ratio (w/c).

2.2 Mix Proportions and Mold Dimensions:

Hybrid concrete samples have been prepared with two concrete strata, namely, ordinary concrete (substrate portion) that represent old deteriorated concrete and newly cast high strength concrete (retrofitted portion). Silica fume, waste glass powder and mixture of silica fume and glass powder is used to fabricate a new concrete part of hybrid concrete with high strength. Due to the effect of the interface

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between old and new concretes on the strength of hybrid concrete, many roughening modes have been employed. In order to achieve the required strength, mix design is performed for OC and HSC with taking into account the strength and workability. Four concrete mixes are designed according to ACI and selected in present study, namely, OC and HSC made with three different powders as given in Table 3. Standard cubes with size of 100x100x100mm have been made using these mixes to measure concrete compressive strength at age of 28 days.

Table (6) : Selected concrete mixes of present OC and HSC

Material	**Normal Concrete (kg/m³)**	**Mix Proportions for HSC (Kg/m³)**		
Cement ©	400	900	900	800
Sand (S)	600	1008	1008	800
Gravel (G)	1200	-	-	-
Silica Fume (SF)	-	225	-	120
Glass Powder (GP)	-	-	225	160
Water (W)	220	171	202.5	160
Super Plasticizer (SP)	-	67.5	67.5	64.8

Special molds (Fig. 2) are used in fabrication of present hybrid concrete specimens with specific dimensions (Fig. 3).

Fig (2) : Molds of hybrid concrete

2.3 Preparation of the Hybrid Concrete Specimens.

In old part (substrate part) preparation, dry components (cement and aggregates) are mixed for 30s followed by adding some of water with mixing for another 30s. The mixer is stopped for 3-5 min to give the mixture a time for absorption. Thereafter, the remaining water is introduced and mixing was continued for a period of 2-2.5 min. The concrete was cast (Fig. 4) in the molds in three layers of fresh concrete with average compaction of 35 blows per layer and some blows on the side of the mold to get rid of the interrupted air. Finally, the leveling of surface has been performed for the freshly molded concretes. The filled molds are stored in the lab

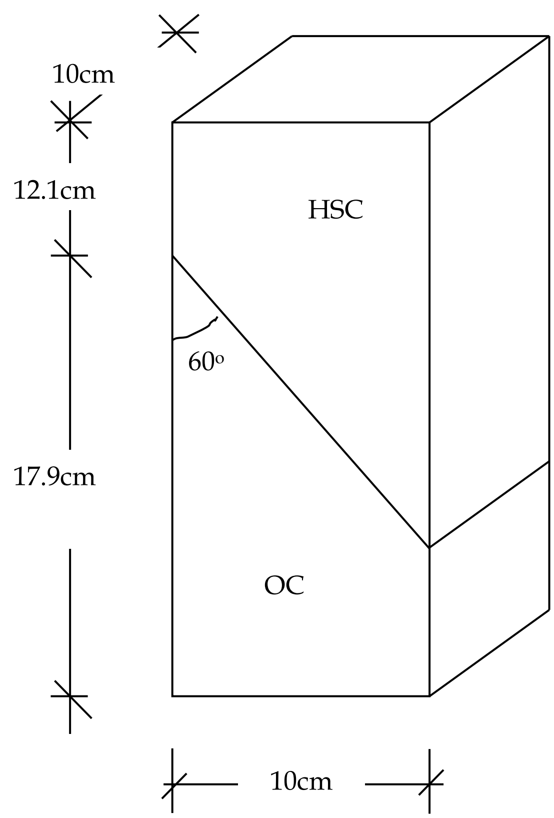

Fig (3) : Dimensions of hybrid concrete mold at temperature of 24°C for 24 hours. Thereafter, the molds are removed and hardened concrete samples (Fig. 5) are stored in the water for 28 days at the lab temperature.

Fig. 4: Casting of ordinary concrete (substrate part)

Fig (5) : Hardened ordinary concrete sample

Roughness of the interfacial surface between OC and HSC has been improved to provide suitable bond between these parts. Three modes of treatment are selected to prepare roughed interface, namely, holes with depth of 1cm, grooves with depth of 1cm and sand blast as depicted in Fig. 6. The upper new part of HSC for hybrid concrete samples is cast using three mixes of HSC given in Table 3. HSC mix is prepared by mixing dry materials for 3 min followed by adding 60% of the required water with mixing for another 3 min. The remained 40% of the water has been added to the superplasticizer and mixed. The mixture is introduced to the concrete batch and the mixing has been performed for 10-15 min. Fresh HSC is cast on the old normal concrete substrate with treated surface as fast as possible to prevent the rapid setting of the fresh HSC. New HSC concrete is poured in one layer over old concrete with taping on the mold sides to prevent air voids in the mix and finally the upper surface has been leveled with the mold edge (Fig. 7). Twenty samples (Table 7) of hybrid concrete prism have been used to measure their compressive and slant shear strengths.

a- Grooves

b- Holes

c- Sand blast

Fig (6) : Surface treatment of the ordinary concrete substrates

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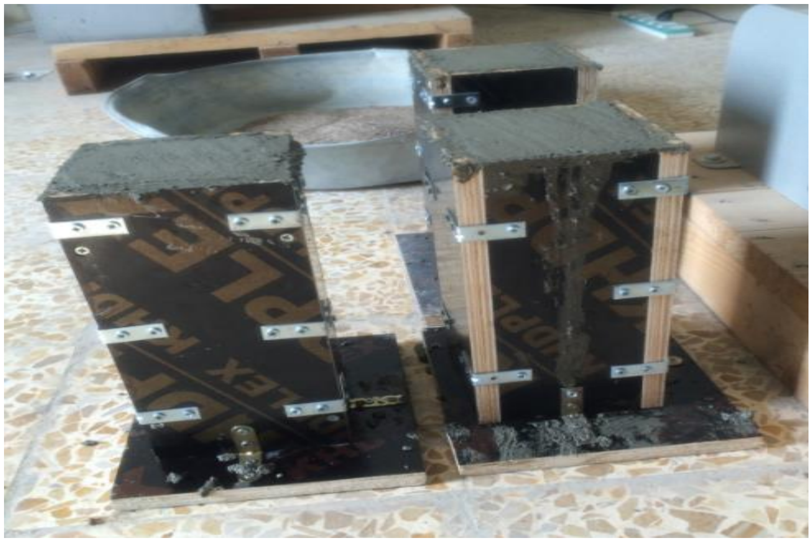

Fig (7) : Hybrid concrete samples after casting of HSC part

Table (7) : Concrete samples used in measuring of slant shear strength

No.	Sample designation	Type of concrete	Number of prepared samples
1	Control	Ordinary Concrete (OC)	2
2	SFH	Hybrid concrete (silica fume and holes)	2
3	SFGr	Hybrid concrete (silica fume and grooves)	2
4	SFSB	Hybrid concrete (silica fume and sand blast)	2
5	GRH	Hybrid concrete (waste glass powder and holes)	2
6	GPGr	Hybrid concrete (waste glass powder and grooves)	2
7	GPSB	Hybrid concrete (waste glass powder and sand blast)	2
8	(SF+GP)H	Hybrid concrete (mixed silica fume and waste glass powder with holes)	2
9	(SF+GP)Gr	Hybrid concrete (mixed silica fume and waste glass powder with grooves)	2
10	(SF+GP)SB	Hybrid concrete (mixed silica fume and waste glass powder with sand blast)	2
Total		20 samples	

3. Results and Discussion.

3.1 Compressive strength of the concrete cubes

The average compressive strength (Table 8) has been recorded for three cubes made with each concrete mix at 28 day age. Highest strength can be observed with using silica fume in HSC in comparison to waste glass powder due to the conventional pozzolanic reactivity of silica fume.

Table (8) : Compressive strength of concrete cubes

No.	Concrete type	Compressive Strength MPa at 28-day age
1	Normal concrete	30.4
2	HSC with silica fume	158
3	HSC with waste glass powder	98
4	HSC with silica fume and glass powder	137

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3.2 Strength of the hybrid concrete

The behavior of hybrid concrete prisms under compressive load has been examined in terms of their slant shear strength. This property is calculated as listed in Table 9 using the following expression:

Slant shear = Maximum applied compressive force / slant area of the specimen … (1)

where, slant area of the specimen = 115.47 cm2

Table (9) : Slant shear strength of hybrid concrete prisms

No.	Sample designation	Slant shear strength (MPa)
1	Control	17.88
2	SFH	6.26
3	SFGr	16.53
4	SFSB	9.64
5	GRH	6.26
6	GPGr	15.00
7	GPSB	14.24
8	(SF+GP)H	10.17
9	(SF+GP)Gr	15.93
10	(SF+GP)SB	10.85

The average slant shear strengths of the hybrid concrete prisms with interfacial surface treated with holes, sand blast and grooves are 7.57 MPa, 11.58 MPa and 15.82 MPa, respectively. In the other words, slight reduction of 11% in the strength can be observed with using grooved interface in comparison to control prism strength. Accordingly, a remarkable improvement in the hybrid concrete strength can be achieved with using grooved interfacial surface between old and new concretes. The average slant shear strength has been measured with respect to the used powders, namely, silica fume, waste glass powder and their mixture as 10.82 MPa, 11.84 MPa and 12.32 MPa, respectively. It is observed that the strengths of the retrofitted concretes made with silica fume and waste glass powder are relatively similar and equivalent to 64% of control sample strength. However, the mixture of both powders is regarded a best choice in the present study.

3.3 Failure modes of the hybrid concrete samples

The failure mode of the hybrid concrete specimens is varied such as columnar, interfacial and combined failures (Fig. 8). Failure mode for each specimen is given in Table 10. It is obvious that the failure pattern for the hybrid concrete with grooved interfacial surface gives similar failure to that of control ordinary concrete specimen. Moreover, the type of the utilized powder in HSC has no remarkable effect on the failure mode of hybrid concrete with grooved interface.

Columnar failure Interfacial failure Combined failure

Fig (8) : Failure modes of concrete specimens

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Table (10) : Failure mode of each hybrid concrete sample

No.	Prism designation	Mode of failure
1	Control	Columnar
2	SFH	Interface
3	SFGr	Columnar
4	SFSB	Interface
5	GPH	Interface
6	GPGr	Columnar
7	GPSB	Columnar
8	(SF+GP)H	Interface
9	(SF+GP)Gr	Columnar
10	(SF+GP)SB	Columnar +Interface (combined) failure

4. CONCLUSIONS

According to the measurements of current experimental work, several conclusions can be drawn as hereunder: -

1- Waste glass powder can be used with the equivalent efficiency to silica fume in enhancing slant shear strength for hybrid concrete made with old and new parts.

2- Reasonable bond between old ordinary concrete and new HSC can be achieved via grooved interfacial surface between these concrete parts in hybrid concrete element.

3- Failure mode at collapse of the hybrid concrete with grooved interfacial surface was not affected by the pozzolanic reactivity of the used powders in HSC.

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