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Granite Sludge Reuse in Mortar and Concrete

[1]Husam D. Al- Hamaiedeh and [2]Waleed H. Khushefati
[1]Department of Civil Engineering, [2]Department of Civil Engineering,
College of Engineering, King Abdulaziz University, P.O. Box 80204, Jeddah,
21589, Saudi Arabia

Abstract: The disposal of solid wastes produced in granite industry to the environment without any treatment cause not only economical but also serious environmental problems. In this study Granite Powder (GP) which produced as solid waste from the cutting and polishing of granite rocks was reused as additive to mortar and concrete cement. Incorporation of GP in mortar and concrete in ratios of 10, 20, 30 wt.% improved mortar and concrete compressive strengths and the concrete workability. The experimental results show that GP can be used to replace cement or fine aggregate in concrete which provide not only solve an environmental problem by safe disposal of GP but also reduce the stress on the limited natural resources and the cost of concrete production.

Key words: Granite, cement, concrete, compressive strength, workability

INTRODUCTION

The availability of marble and granite rocks beside the high demand on these materials in the Kingdom of Saudi Arabia (KSA) increased the investment in this sector. Marble and granite industries are responsible for producing huge amount of solid wastes from the cutting and polishing of the parent rocks. Usually these wastes are disposed to the environment without any treatment causing not only economical but also serious environmental problems. Reuse of industrial solid waste as raw materials for other industries is the best solution for this problem. Among the industries that capable to incorporate different types of solid wastes are concrete and ceramic industries. Recently, many investigations have been conducted to study the feasibility of reusing different industrial solid wastes. The advantages of partial replacement of cement in the preparation of mortars by construction rubble, tire rubber ash, blag furnace slag, silica fumes and fly ash have been reported by Alvarez Cabrera *et al*. (1997), Al-Akhras and Smadi (2004), Cerulli *et al*. (2003) and Rao (2003). Al-Hamaiedeh *et al.* (2010) reported that replacing Portland cement by oil shale ash in ratios up to 30% did not affect the physical and mechanical properties of cement paste and slightly reduced the compressive strength of mortar. Similar results have been recorded when Portland cement have been replaced by Tripoli in ratios up to 20% El-Hasan and Al-Hamaideh (2012) and Binici *et al*. (2007) have studied the effect of replacing fine aggregate by marble and limestone dusts on some mechanical properties of concrete. In another study Binici *et al*. (2008) investigated the effect of using granite and marble as recycled aggregates on the durability and fresh concrete properties. Many researchers have demonstrated that ceramic industry is also very capable of incorporating and reusing different types of industrial waste materials (Anderson and Jackson, 1983; Alleman, 1989; Bazadjiev *et al*., 1991; Dominguez and Ulmann, 1996; Dondi *et al*., 1997; Da Silva *et al.*, 1998; Caligaris *et al*., 2000; Oliveira and Rabelo, 2001; Pisciella *et al*., 2001; Pereira *et al*., 2004; Monteiro *et al*., 2004; Oliveira and Rabelo, 2001; Knight, 1999; Ferreira *et al*. 1999). Al-Hamaiedeh *et al.* (2010) showed that replacing pentonite which is one of the raw materials in ceramic industry by marble sludge slime significantly reduced the shrinkage values of the produced ceramic tiles, while keeping the other physical and mechanical properties. The objectives of this study are to study the effect of incorporating Granite Powder (GP) in cement, mortar and concrete on some properties of cement pastes, mortar and concrete. Incorporation of GP includes either adding different amounts of GP to the cement in the mix or partially replacing cement by GP in these mixes. The effects of incorporating GP in cement on the consistency, soundness and setting time of cement paste have been

Corresponding Author: Husam D. Al- Hamaiedeh, Department of Civil Engineering, P.O. Box 80204, Jeddah, 21589, Saudi Arabia
Tel: 00966567439435 Fax: (009662) 6952179

explored. The effect of incorporating GP in mortar and concrete on their compressive strength and concrete workability also has been studied.

MATERIALS AND METHODS

The cement used in this study was Ordinary Portland Cement (OPC) and classified as Saso-SSA143/1979 according to the Saudi standard. The Granite powder GP was obtained from the largest granite industrial company in the Middle East Saudi Binladin group company Jeddah-KSA. The density of GP has determined according to ASTM D 854-00 standard. A chemical analysis of granite powder and OPC (Table 1), were performed using X-RAY Simultaneous XRF type ARL 9800 XP. The chemical compositions of OPC mixtures containing different granite powder ratios were determined using raw mix design software (Table 2 and 3). The sieve analysis of aggregate has conducted using ELE sieve shaker Pascal, to prepare well graded aggregates. Concrete mixes were prepared using ATILON mixer capacity of 280 L and mortar mixes prepared using ELE mixer. Mortar cubes and concrete cylinders were tested for compressive strength using Walter + bai ag (w+b) testing machine.

Experimental set up and procedure: Two experimental sets were conducted; the first set involved investigating the effect of partial replacement of cement by GP in mass ratios of 10, 20 and 30% on the properties of cement paste, mortar, and concrete. The investigated cement paste properties included normal consistency, setting time and soundness. The properties of mortar and concrete included the compressive strength of mortar and concrete and concrete workability. The second set involved investigating the effect of adding GP to cement in mass ratios of 10, 20 and 30% of cement on the above properties. The first set involved preparation of four mixes from cement and GP, the mass of each mix was 650 g. A pure cement mix with (0% GP) was used as reference sample, the other three mixtures involved cement replacement by GP in mass ratios of 10, 20 and 30% respectively. The normal consistency and setting time for the above mixes were determined using vicat apparatus, soundness was determined using typical Le Chatelier apparatus. Mortar cubes using the above mixes were mad according to ASTM C 100 standard with mass ratios (water: binder: sand) of (0.485:1:2.75). Each mortar mix was made from sand and binder (cement and GP) as shown in (Table 4). The compressive strength of the mortar cubes was determined at ages of 3, 7 and 28 days. A total number of twelve mortar cubes, three cubes from each mixture were tested at each age. Concrete mixes using the above cement and GP mixes as binder were designed according to ASTM C 39 standard (Table 5). Concrete workability (slump) has been determined and the compressive strength of concrete at ages of 3, 7 and 28 days have been recorded. The second set involved repeating the above experiments by adding GP to cement instead of replacing cement by GP. The masses of GP added to cement were 10, 20 and 30% of the cement mass.

The presented experimental results were the average of three test results. The average values and standard deviations were calculated using excel software program, and the calculated standard deviations were less than 5%.

RESULTS AND DISCUSSION

In terms of chemical composition, the major differences between GP and cement are the low alkaline earth oxide content (particularly MgO and CaO) and high argillaceous SiO_2, Al_2O_3 and Fe_2O_3) contents of GP compared to cement composition (Table 1). The ratios of argillaceous content SiO_2, Al_2O_3, and Fe_2O_3 in GP are 62%, 12.2 and 9.3%, respectively, these ratios are higher than there ratios in OPC which are 19.9, 5.37 and 3.18%, respectively. However, the calcareous CaO ratio in GP is 4.1% it is too small in comparison to its ratio in OPC 63.65. The addition or replacement of OPC by GP is expected to change the ratio between argillaceous and calcareous content of the mix which consequently affect the cementing properties of the cement paste. When OPC was replaced by GP in ratios up to 30% the SiO_2 content increased from 19.94 to 32.56%, while CaO content decreased from 63.65 to 45.79% (Table 2). The same trend was noticed when GP was added to OPC in ratios up to 30% the SiO_2 content increased from 23.73 to 29.61%,while CaO content decreased from 58.29 to 49.95% (Table 2). The change in the argillaceous-calcareous ratios mainly SiO_2 and content CaO is expected to have an effect on the behavior of both cement pastes and concrete mixes as it will be seen in the results of the conducted experiments.

Table 1: Chemical composition of Granite Powder (GP) and Ordinary Portland (OPC) Cement

Component	SiO_2%	Al_2O_3%	Fe_2O_3%	CaO%	MgO%	SO_3%	K_2O%	Na_2O%
OPC	19.94	5.37	3.18	63.65	2.59	2.88	0.82	0.1
GP	62.00	12.20	9.30	4.10	0.23	0.10	4.40	3.3

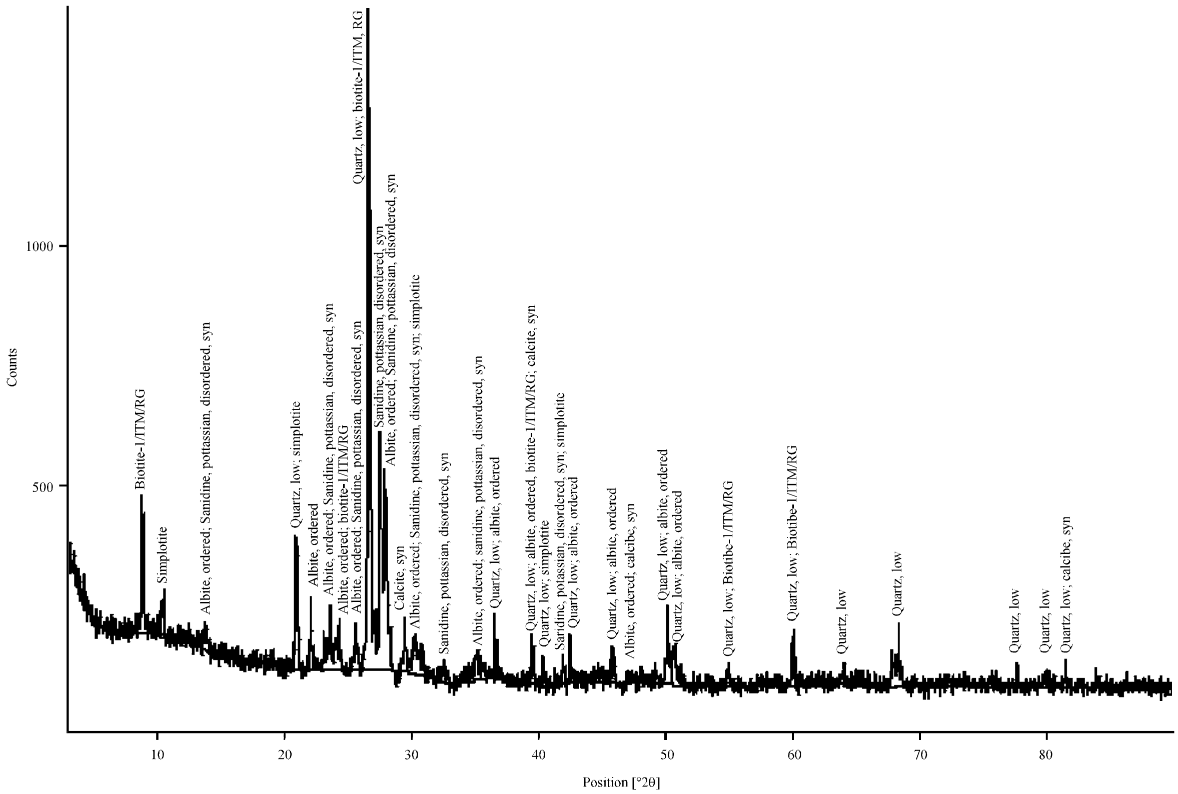

Fig. 1: X-ray Diffraction Patterns of 1111Granite Powder

Table 2: Chemical composition of mixtures when cement replaced by GP in different ratios

Cement replaced by GP%	SiO_2%	Al_2O_3%	Fe_2O_3%	CaO%	MgO%	SO_3%	K_2O%	Na_2O%
0	19.94	5.37	3.18	63.65	2.59	2.88	0.82	0.10
10	24.15	6.05	3.79	57.70	2.35	2.60	1.18	0.42
20	28.35	6.74	4.40	51.74	2.12	2.32	1.54	0.74
30	32.56	7.42	5.02	45.79	1.88	2.05	1.89	1.06

Table 3: Chemical composition of mixtures when GP added to cement in different ratios

Added GP, %	SiO_2%	Al_2O_3%	Fe_2O_3%	CaO%	MgO%	SO_3%	K_2O%	Na_2O%
10	23.73	5.98	3.73	58.29	2.38	2.63	1.14	0.39
20	26.96	6.51	4.20	53.71	2.20	2.42	1.42	0.63
30	29.61	6.94	4.59	49.95	2.05	2.24	1.64	1.15

The mineralogical analyses Fig. 1, illustrate that GP is formed basically from Quartz, Albite, Sanidine and Biotite, [SiO_2, Na Al Si_3, and (Na , K) (Si_3 Al) O_8]. The iron filings from sawing and polishing of granite rocks caused the high Fe_2O_3 content of GP and the use of flocculants for dewatering of GP sludge are the cause of Al_2O_3 high content. The chemical composition of cement mixes containing different ratios of GP are shown in Table 2 and 3. The normal consistency of mixes when the cement was replaced by GP in mass ratios of 10, 20 and 30% increased by 7, 13 and 13 mL, respectively, compared to the control sample Fig. 2. This increase represent the difference between the amount of water absorbed by the added GP and the amount necessary for the hydration of the replaced cement. The addition of GP to cement in the same amounts increased normal consistency by 23, 47 and 64 mL, respectively. This amount represents the water absorbed by the added GP Fig. 2. The data presented in Fig. 3 indicate that 10% replacement of cement by GP and 10% addition of GP to cement increased the setting time. This increase is not significant when GP replace cement, indicating that the amount of water absorbed or held on the surface of the added10% GP is close to that required for hydration of the replaced cement. However, the addition of GP to cement in ratio up to 10% increased the setting time by 35 min due to increase of water content of the paste. In both cases increasing the GP ratio beyond 10% caused uniform

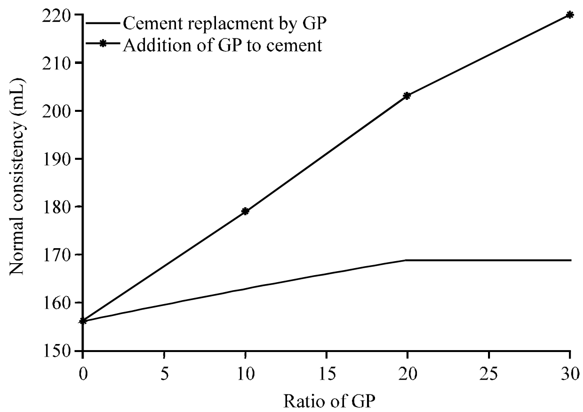

Fig. 2: Effect of replacing cement by GP and adding GP to cement on the consistency of cement paste

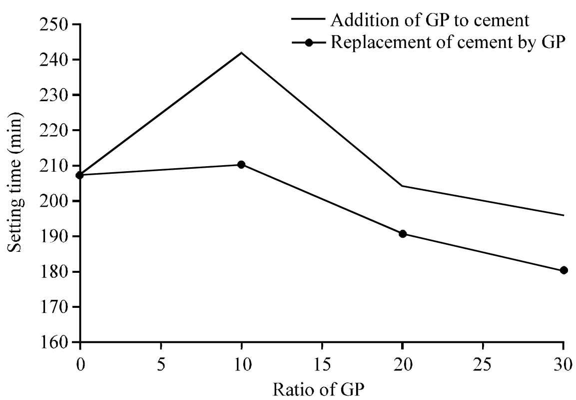

Fig. 3: Effect of partial replacement of cement by GP and GP addition to cement on the final setting time of cement paste

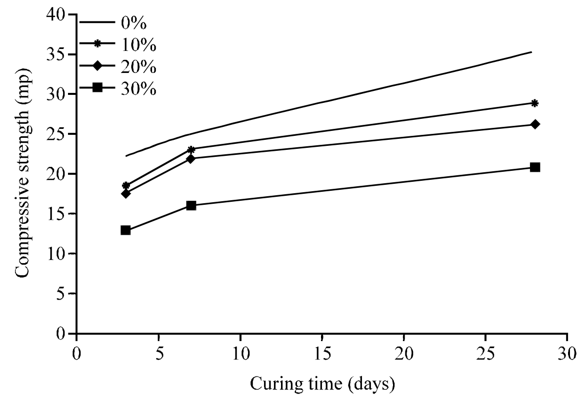

Fig. 4: Effect of cement replacement by GP and curing time on the compressive strength of mortar

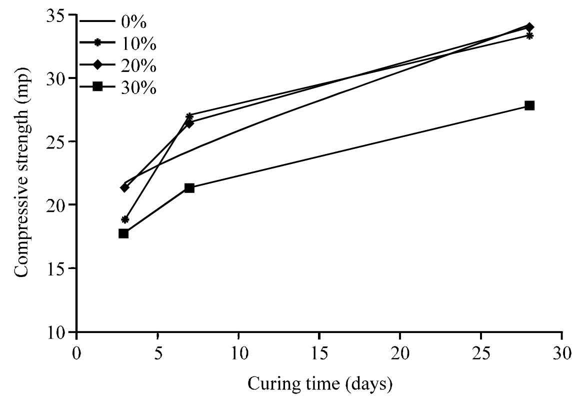

Fig. 5: Effect of adding GP to cement and curing time on the compressive strength of the mortar

decrease of the setting time due to the large surface area of GP which increases water absorption this is more noticeable when GP added to cement. The details of mortar mixes where cement replaced by GP and when GP added to cement in different ratios are shown in Table 4. The effect of partial replacement of cement by GP on the compressive strength of mortar is presented in Fig. 4. The strength proportionally increases with curing time due to continuous hydration of cement and decreases with the increase of GP in the binder. The strength of mortar cubes with 10, 20 and 30% cement replacement by GP decreased by 18, 25.9 and 41.2%, respectively after 28-day compared to the strength of reference cubes (Fig. 4). Low CaO and high SiO_2 and Al_2O_3 contents of GP affect the chemical composition of mixtures when GP replaced cement (Table 2). Replacement of cement by GP adversely affects the amount of C_2S, C_3S and C_3A which are responsible for cementing and strength properties of mortar. These results are in consistence with the results obtained by Al-Hamaiedeh *et al.* (2010), El-Hasan and Al-Hamaideh (2012), Al-Hasan (2006), Oymael (2007) and Yeginobali *et al.* (1993) when oil shale ash and tripoli were used to partially replace cement in mortar. The compressive strength of mortar cubes when GP was added to cement in ratios up to 20% is very close to that of the reference cubes (Fig. 5). However, increasing the ratio of GP up to 30% increased GP/cement which resulted in the decrease of mortar compressive strength by 19%. The results illustrated in Fig. 6, indicate that cement replacement by GP in ratios up to 10% increased the workability of concrete. Despite of the small decrease in mix water which absorbed by GP, the workability increased because the too fine GP particles were acted as lubricant between the coarse aggregate. However, when the ratio of the replaced cement increased beyond 10% the workability decreased due to the significant reduction of mix water which absorbed by GP. The added GP to the mix replaced part of fine aggregate

Table 4: Constituents of mortar mixes containing different granite powder ratios

Mix	GP mass (%)	GP mass (g)	Cement (g)	Water (g)	Fine aggregate (g)
Replacing cement by GP					
1	0	0	7000	3727	19396
2	10	700	6300	3727	19396
3	20	1400	5600	3727	19396
4	30	2100	4900	3727	19396
Addition of GP to cement					
1	10	700	7000	3727	19396
2	20	1400	7000	3727	19396
3	30	2100	7000	3727	19396

Table 5: Constituents of concrete mixes containing different granite powder ratios

Mix	GP mass (%)	GP mass (kg m^{-3})	Cement (kg m^{-3})	Water (kg m^{-3})	Fine Aggregate (kg m^{-3})	Coarse aggregate (kg m^{-3})
Replacing cement by GP						
1	0	0.0	427.1	220	614.3	1074.3
2	10	42.7	384.4	220	604.8	1074.3
3	20	85.4	341.7	220	604.5	1074.3
4	30	128.1	299	220	599.7	1074.3
Addition of GP to cement						
1	10	42.7	427.1	220	574.4	1074.3
2	20	85.4	427.1	220	534.5	1074.3
3	30	128.1	427.1	220	494.6	1074.3

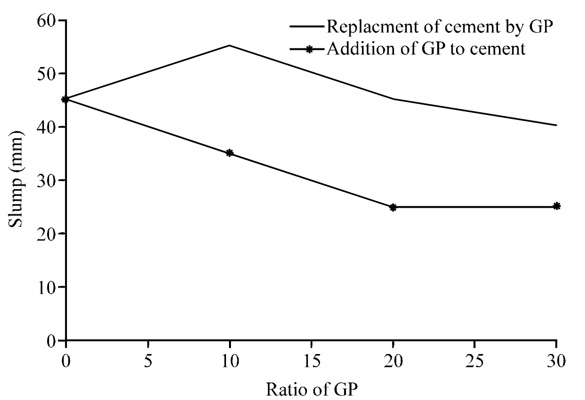

Fig. 6: Effect of adding GP to cement and replacement of cement by GP on the workability of concrete

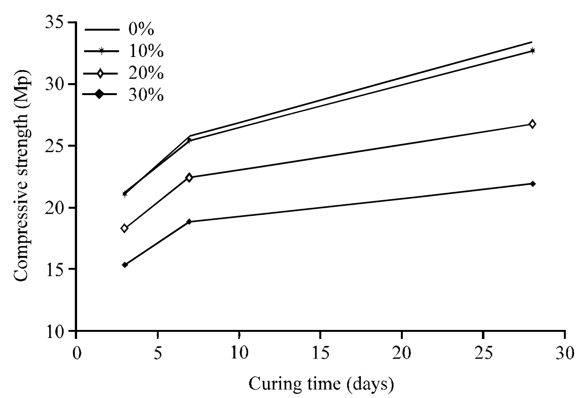

Fig. 7: Effect of cement replacement by GP and curing time on the compressive strength of concrete

(Table 5). Replacement part of fine aggregate by the too many fine GP decreases the fineness modulus of aggregate and increases its surface area. Workability decreases also due to consumption of more mix water to wet the large surface area of aggregate. The effect of replacing cement by GP in different ratios on the compressive strength of concrete is shown in Fig. 7. The compressive strength of concrete cylinders with 10% cement replacement by GP is very close to the strength of the reference cylinders it decreased by only 2% after 28 day curing. Presence of low ratios of fine GP in concrete reduces the voids ratio and as a result increases the strength. Therefore, the addition of GP in ratios of 10% and 20% of the cement mass increased the 28 day compressive strength of concrete by 5 and 3%, respectively (Fig. 8). However, adding

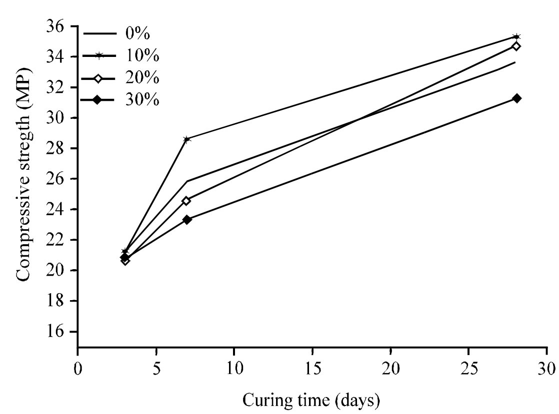

Fig. 8: Effect of adding GP to cement and curing time on the compressive strength of concrete

GP in ratios more than 25% adversely affected concrete strength, due to reduction in mix water necessary for cement hydration and decrease of cement content necessary to coat the large surface area of the added GP.

CONCLUSION

From the results of the conducted experiments it is concluded that:

- Replacement of cement by GP or adding GP to cement did not cause unsoundness of cement paste
- The addition of GP to cement in ratios up to 10% increased the setting time, which enable the transport of mortar and concrete for long distance before casting
- Replacement of concrete cement by GP in ratios up to 10% did not affect the compressive strength of concrete
- Cement replacement by GP which is a solid waste have two benefits; first, reduce the amount of cement required and as result the stress on the raw materials used for cement manufacturing, second reduce the environmental pollution which combined with both cement manufacturing and GP disposal
- Adding GP in mass ratios up to 20% of cement to concrete increased its compressive strength. The added GP replaces fine aggregate in concrete mixes which also reduces the stress on fine aggregate natural sources and reduce the cost of the produced concrete

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