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Effect of Grinded of Debris of Concrete on the Compressive Strength of Reactive Powder Concrete

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Abstract

This investigation is an attempt to increase the sensibility of sustainability in the construction industry through studying the influence of the replacement part of cement (C) or silica fume (SF) content with a Grinded Debris of Concrete (GDC) on the compressive strength (fcu) of Reactive Powder Concrete (RPC). Reference RPC mix without GDC and other six RPC mixes with GDC are designed, mixed, molded and tested. Three mixes are designed to show the effects of replacement 5%, 10% and 15% of C with GDC. While, the other three are designed to show the effects of replacement 10%, 20% and 30% of SF with GDC.

The results exhibited that high (fcu) can be achieved by involving the GDC in the mixes of RPC. However, a very little negative effect on (fcu) can be noticed. This effect differs according to the type of the replaced material, percentage of replacement and the age of concrete. The impact of replacing a part of C with GDC is clearer than that of replacing a part of SF with GDC. Increasing the percentage of replacement leads to decrease the values of (fcu). GDC has a very close action as SF especially at later ages.

Keyword: RPC, Sustainability, Grinded, Debris, Compressive, Strength, Concrete, Silica fume.

1. Introduction

The international production of concrete is about five billion tons by year [1]. Generally, the construction industry accounts for a massive environmental impact due to its high demand of energy. The cement industry and the production of ready-mixed concrete stands for a significant part of carbon footprints in the construction sector, mainly due to the high-energy consumption of the transportation of building materials [2].

Since the global warming has come into view as the most earnest environmental problem of present duration and since sustainability being the main affair of economic and political arguments, the following growth in the concrete industry will not be through producing new types of concrete made with costly constituents and special technique. The alternative method is to produce low cost and highly durable concrete types containing considerable possible quantities of made-up and urban byproducts, which are adequate for partial replacement of Portland cement and other ingredients of concrete. Due to the growth in concrete technology, mineral additives are used widely in concrete today. Many by-products and solid recyclable materials can be used in concrete mixtures as aggregates or cement replacement, depending on their chemical and physical characterization. The ability of concrete for mingling these additives is very extensive and the main limit is their availability [3].

2. Mineral Admixtures

Mineral admixtures, additions, or supplementary cementitious materials have long provided the means to improve the fresh and hardened properties of concrete and at the same time reduce the cost of concrete materials.

Mehta [4] defined mineral admixtures as "finely divided siliceous materials added to concrete in relatively large amounts, generally in the range 20 to 100 percent by weight of Portland cement, and classified them as:

* Cementitious like ground granulated blast furnace slag.

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* Cementitious and pozzolanic like high-calcium fly ash.

* Highly active pozzolanas like condensed silica fume & rice husk ash.

* Normal pozzolanas like low-calcium fly ash & natural materials.

* Weak pozzolanas are like slowly cooled blast-furnace slag & field burnt rice husk ash.

EFNARC [5] and the British Cement Association [6] defined additions as “Finely-divided inorganic materials used in concrete in order to improve certain properties or to achieve special properties”, and classified them into two categories:

* Type I (semi-inert) additions like finely crushed (lime stone, dolomite or granite), filler aggregate, pigments …etc.
* Type II (pozzolanic or latent hydraulic) like silica fume, metakaolin, rice husk ash, fly ash, ground granulated blast-furnace slag …etc.

Corinaldesi et al. [7] have found that the use of fine powder from recycled aggregates produced by grinding demolished concrete performs very well as fine filler in the Self Compacting Concrete SCC. The behavior of this powder in reducing segregation and increasing compressive strength is much better than fly ash and very close to that of silica fume.

Al-Jaberi Layth [8] evaluated the influence of types, dosages, and fineness of locally available mineral admixtures and the ternary blend of powders as a replacement for the weight of cement on the properties of SCC in fresh and hardened phases. One of those mineral admixtures was GDC. This study shows that the performance of GDC has the best effects on the hardened properties of SCC.

3. Research Significance

As illustrated above, concrete is being recognized for its powerful environmental advantages in support of creative and effective sustainable development. When considering the lifetime environmental action of a construction material—extraction, production, construction, operation, demolition and recycling, concrete is an excellent choice to meet these goals.

The present study is an attempt to increase the sensibility of sustainability in the construction industry through studying the influence of the replacement part of cement (C) or silica fume (SF) content with a Grinded Debris of Concrete (GDC) on the compressive strength (fcu) of Reactive Powder Concrete (RPC).

4. Experimental Program

4.1. Materials

4.1.1 Cement

The cement used in this study is Iraqi ordinary Portland cement (Taslogah) type (I). This cement is evaluated according to IOS 5:1984 [9]. Tables (1) and (2) show the chemical and physical properties of this cement and the criteria of IOS 5:1984 [9] for each one.

Table 1: Chemical Composition of Cement

Chemical Composition		
Oxides	Test Results	IOS 5:1984 Criteria
SiO_2	19.66	-
Fe_2O_3	3.44	-
Al_2O_3	4.66	-
CaO	62.23	-
MgO	2.83	< 5
SO_3	2.61	< 2.8
L.S.F	0.94	0.66 - 1.02
L.O.I	2.95	< 4
I.R	1.27	< 1.5
C_3A	6.53	-

Table 2: Physical Properties of Cement

Physical Properties			
Properties	Test Results		IOS 5:1984
Specific surface area (Blaine Method), m2/kg	327		> 230
Mortar Compressive strength (MPa) at	3 days	31.5	> 15
	7 days	40.5	> 23
Setting Time(min)	Initial	180 min.	≥ 45 min.
	Final	3.55 hr.	≤10 hours
Soundness: autoclave %	0.19		< 0.8

4.1.2 Fine Aggregate (Sand)

Extra Fine Sand (EFS), chemically inert, graded, hardwearing aggregate with size (300-600) µm is used in this study. Don Construction Products produce this extra fine sand. Table (3) shows that the physical properties of this extra fine sand are satisfactory to the requirements of the IOS No.45/1984 [10]. Figure (1) shows the grading curve of this extra fine sand.

Table (3): Grading of the Extra Fine Sand

Sieve size (mm)	% Passing by weight	Limits of the IOS No.45/1984 (zone 3)
10	100	100
4.75	100	95-100
2.36	100	95-100
1.18	100	90-100
0.60	100	80-100
0.30	42	15-50
0.15	8	0-15

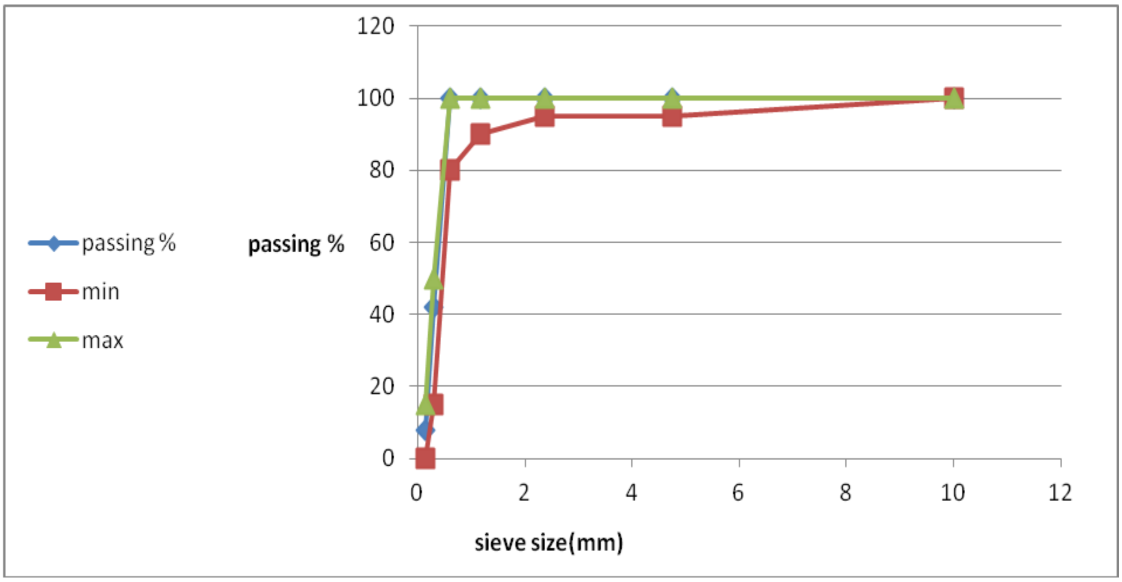

Figure (1): The Grading Curve of the Extra Fine Sand

4.1.3 Water

Tap water is used for both mixing and curing of concrete.

4.1.4 Silica Fume (SF)

MEYCO MS 610 is a mineral additive that is used in normal and sprayed concrete, which increases the engineer-ship properties of concrete such as pressure resistance, bending resistance, breaking mechanics and impermeability by improving the interface properties of concrete and the microstructure of the cement paste. It complies with ASTM C 618 and ASTM C 1240/95. Table (4) shows the chemical composition for this product.

Table (4): Chemical Composition of SF

Oxides	Content %	ASTM C 1240-05 Specification	
		Min.%	Max.%
SiO_2	87.00	85	-
Fe_2O_3	2.50	-	-
Al_2O_3	1.00	-	-
CaO	1.00	-	-
SO_3	0.50	-	-
K_2O+Na_2O	3.00	-	-
L.O.I	2.90	-	6
Moisture Content	1.00	3	-

4.1.4 Grinded Debris of Concrete (GDC)

Debris of concrete is collected from different samples, then grinded by locally special grinding machine by blowing technique. The cost of grinding is very low, and the fineness of the gained material is very high. Pozzolanic activity index (P.A.I) of GDC with Portland cement is determined according to ASTM C311-89 (11). GDC cement mortars that contain 10% GDC are tested, the w\p that satisfies flow 110±5mm is 0.40, and the dosage of superplasticizer is constant. The chemical and physical properties of GDC are listed in Table (5).

Table (5): Chemical and Physical Properties of GDC

Oxides	Content %
SiO2	50.74
Fe2O3	1.20
Al2O3	5.94
CaO	35.48
MgO	0.56
SO3	1.50
L.O.I	4.50
P.A.I	1.32
Fineness (Blain)	3550

4.1.5 High Range Water Reducing Admixture (HRWRA)

The high range water reducing admixture used in this study is a third generation super plasticizer for concrete and mortar, it is Aqueous solution of modified Polycarboxylates, which is known commercially as (Glenium 51). Glenium 51 has been primarily developed for applications where the highest durability and performance are required. Glenium 51 is free from chlorides and complies with ASTM C494-99type G and F.

4.1.6 Ultra-Fine Steel Fibers (Micro steel fiber)

Ultra-fine steel fibers are used throughout the experimental program as shown in Plate (1). The properties of the used steel fibers are presented in Table (6). Micro steel fiber is the material of ultra-high performance concrete (UHPC), Reactive powder concrete (RPC) and slurry infiltrated concrete(SIFCON), is well used in the project such as bank cash-box, strong-box, plant, water conservancy, foundation grouting, military project and blast protect panel and etc.

Plate (1): Ultra Fine Steel Fiber MSF Used in This Investigation

Table (6): Properties of the Used Steel Fibers

Property	**Specifications**	**Property**	**Specifications**
Type	WSF 0213	Form	Straight
Surface	Brass coated	Average length	13 mm
Relative Density	7860 Kg/m^3	Diameter	0.2mm±0.05mm
Tensile Strength	Minimum 2300MPa	Aspect ratio (L_f/D_f)	65

4.2. Concrete Mixes

In order to fulfil the aim of this study, the work is divided into two groups of seven RPC mixes. One of these mixes is designed to be without GDC and considered to be the reference mix. Table (7) show the details of this reference mix. Three RPC mixes contain GDC as a replacement of the weight of C, while other three RPC mixes contain GDC as a replacement of the weight of SF. The percentages of replacement are shown in Table (8).

Table (7): Reference Mix Proportions

w/c ratio	C Kg/m^3	EFS Kg/m3	SF Kg/m^3	Super-Plasticizer % of cement mass	Micro Steel Fibers V_f %
0.18	933	1030	234	5	1

Table (8): Groups and Description of Other Mixes

Group No.	Mix Symbol	Percentage of GDC as a Replacement of C	Group No.	Mix Symbol	Percentage of GDC as a Replacement of SF
1	M1	5%	2	M4	10%
	M2	10%		M5	20%
	M3	15%		M6	30%

4.3 Experimental Procedure

In this study, compressive of RPC is compared by replacing a part of weight of C or SF by a weight of GDC and keeping everything else constant. The size of cubes (Compressive Strength Test) is casted by the 100 X 100 X 100 mm. Curing is performed in tap water at 23Co until the age test. Testing is carried out at ages 1 day, 7 days, 28 days, 56 days and 90 days. The tests are carried out by 3000 kN capacity machine (Plate (2)). The average value of the three specimens for each mix and age is determined and recorded.

Plate (2): Compressive Strength Test

5. Results and Discussion

The results indicate that high levels of (fcu) can be achieved through replacement a part of C or SF weights by a GDC. This indication confirms and encourages reducing the use of C and SF in RPC mixes. This in turn contributes to the reduction of the negative effects of the construction industry impacts on the environment. Table (9) shows the average results of the compressive strength (fcu) tests at 7, 14, 28, 56 and 90 days gained from tests.

Table (9): Results of Compressive Strength (fcu)

	7 days	14 days	28 days	56 days	90 days
Reference Mix					
R	38.5	100.0	145.0	157.2	166.0
Group 1					
M1	36.0	94.5	138.2	151.7	160.5
M2	32.3	85.4	130.6	146.3	156.8
M3	29.0	78.5	122.6	139.2	153.5
Group 2					
M4	38.3	99.2	144.4	157.1	165.9
M5	38.0	97.5	141.6	154.8	163.4
M6	37.5	96.3	140.0	152.5	160.8

5.1 Group (1)

The values of (fcu) for mixes of group (1) and the value of (fcu) for mix (R) are graphed in Figure (2).

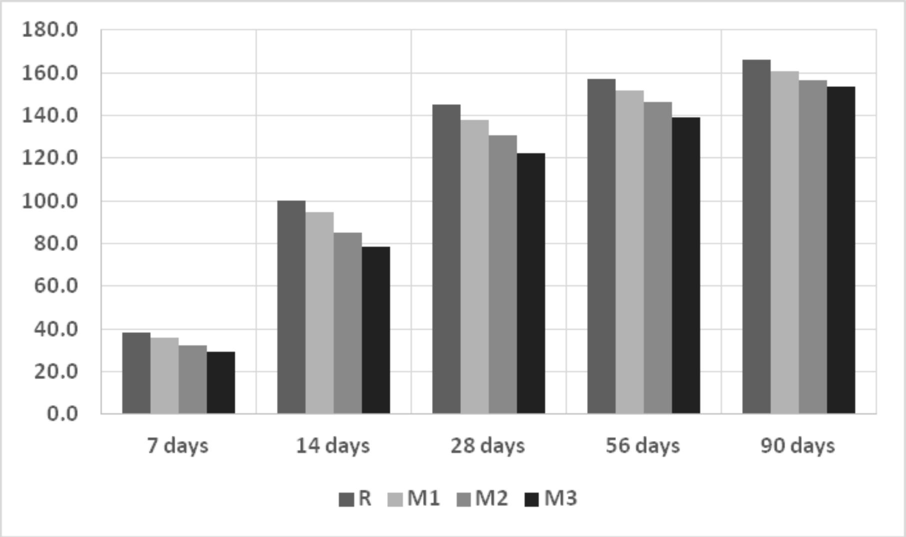

Figure (2): Results of (fcu) for Mixes of Group (1) and Mix (R)

In order to compare between the values of (fcu) for the Reference mix and the mixes in group (1) and to figure out the influence of GDC on the (fcu) values, the Percentage Ratios of Variation (PRV) between these results are listed in Table (10) and represented in Figure (3).

Where at the same age;

Table (10): PRV values for Mixes in Group (1)

	7 days	**14 days**	**28 days**	**56 days**	**90 days**
M1	-6.49%	-5.50%	-4.69%	-3.50%	-3.34%
M2	-16.10%	-14.60%	-9.93%	-6.96%	-5.57%
M3	-24.68%	-21.50%	-15.45%	-11.47%	-7.56%

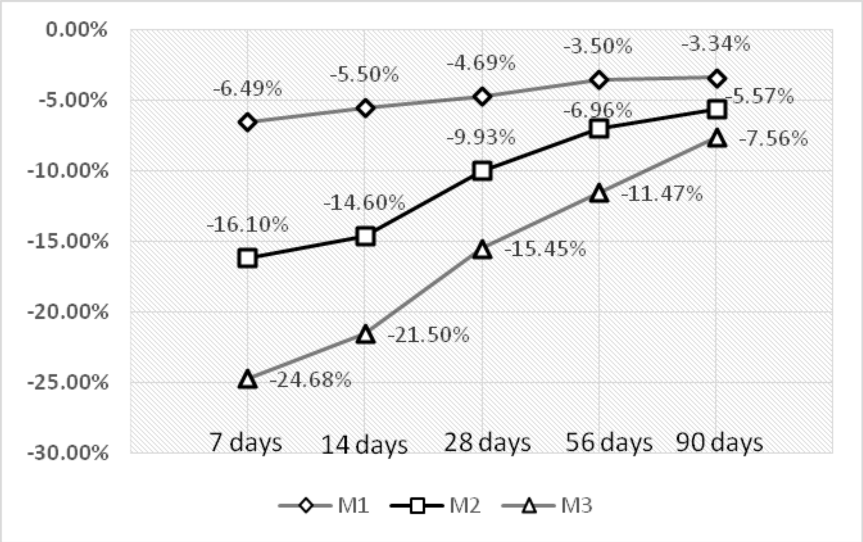

Figure (3): PRV values for Mixes of Group (1)

- According to the percentage of replacement: It can be noticed from the data in Tables (9 & 10) and Figures (2 & 3), that the values of (fcu) are decreased when the percentage of replacement of C with GDC is increased especially at early ages. There is no admixture material has the binder effect of cement, thus, any decrement in the amount of (C) leads to decrease (fcu). Thus, PRV values are increased with the decrement of weight of C.
- According to the age of concrete: The values of (fcu) are directly functioned with age of concrete. In addition, the long-term pozzolanic action, which continues to combine with free lime, results in increasing structural strength over time. This behavior explains the distant of the values of (fcu) at early ages and the convergent of them at later ages. Consequently, the values of PRV at early ages are higher than those at later ages. It is very clear that the best value of (fcu) is at 90 days age.

5.2 Group (2)

Figure (4) shows the values of (fcu) for mixes of group (2) and the value of (fcu) for mix (R). Table (11) and Figure (5) illustrated the values of PRV for this group.

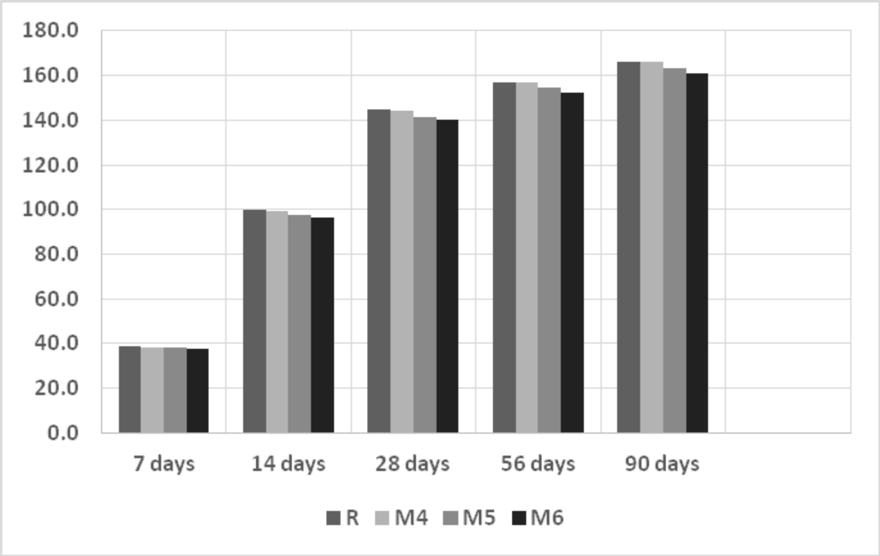

Figure (4): Results of (fcu) for Mixes of Group (2) and Mix (R)

Table (11): PRV values for Mixes in Group (1)

	7 days	14 days	28 days	56 days	90 days
M4	-0.52%	-0.80%	-0.41%	-0.04%	-0.06%
M5	-1.30%	-2.50%	-2.34%	-1.54%	-1.60%
M6	-2.60%	-3.75%	-3.45%	-2.98%	-3.12%

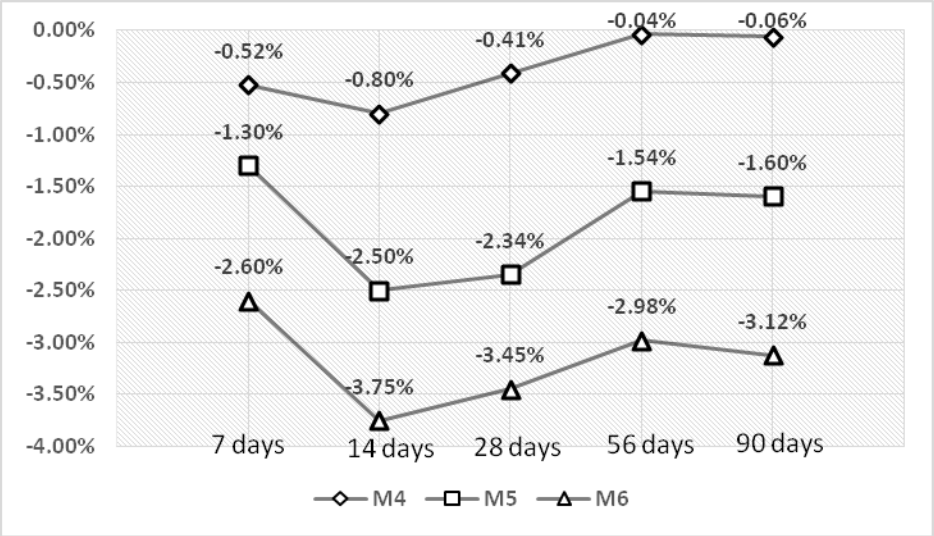

Figure (5): PRV values for Mixes of Group (2)

- ❖ According to the percentage of replacement: In this group, a part of the weight of SF is replaced with GDC, while the weight of C is keept constant. As C is constant, the binder effect is not affected. However, it is very clear that the values of (fcu) are slightly affected by the replacement of SF with GDC. This can be explained by the very high fineness of SF, which is higher than the fineness of C or GDC. The ultra-fine particles of SF filled the ultra-fine voids in the microstructure of concrete, which lead to more dense structure and better strength. However, it can be noticed from the data in Tables (9 & 11) and Figures (4 & 5), that the values of (fcu) are little bit decreased when the percentage of replacement of SF with GDC is increased especially at early ages. This behavior indicates that the influence of GDC is very close to that of SF. According to this, PRV values are so small increased with the decrement of weight of SF.

- According to the age of concrete: The long-term pozzolanic action is clearer in the behavior of the mixes in this group. This pozzolanic action enhance the strength of concrete as the age increased. However, it can be noticed that value of (fcu) at 56 days age is the best.

These indications confirm that C or SF can be successfully partially replaced by GDC, which has a very close behavior to that of the SF.

6. Conclusions

According to the results of this research, the following conclusions can be drawn:

1- Inclusion of GDC as a replacement of C or SF in the model of RPC is satisfactory and the produced concrete can achieve high level of (fcu).

2- Increasing the percentage of replacement of C with GDC leads to decrease the values of (fcu). However, the strength is enhanced with the age of concrete.

3- The best value of (fcu) for mixes in-group (1) is at 90 days age.

4- Increasing the percentage of replacement of SF with GDC leads to a very slight decrease of the values of (fcu). In addition, the strength is improved with the age of concrete.

5- The best value of (fcu) for mixes in group (2) is at 56 days age.

6- C or SF can be successfully partially replaced by GDC.

7- GDC has a very close behavior to that of the SF.

CONFLICT OF INTERESTS.

There are no conflicts of interest.

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تأثير مسحوق أنقاض الخرسانة على مقاومة انضغاط خرسانة المساحيق الفعالة

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الخلاصة

إن هذا البحث هو محاولة لزيادة الوعي بمفاهيم الاستدامة في الصناعة الانشائية، من خلال دراسة تأثير استبدال جزء من وزن السمنت (C) أو جزء من وزن مسحوق غبار السيليكا (SF) بمسحوق أنقاض الخرسانة (GDC) على مقاومة انضغاط خرسانة المساحيق الفعالة (RPC). تم تصميم وتنفيذ خلطة مرجعية من (RPC) خالية من (GDC)، وستة خلطات من نفس نوع الخرسانة تحتوي على (GDC). ثلاثة من الخلطات الخرسانية تم تصميمها لبيان تأثير استبدال 5%، 10% و15% من وزن (C) بـــ (GDC). بينما تم تصميم الخلطات الثلاثة الأخرى لبيان تأثير استبدال 10%، 20% و30% من وزن (SF) بـــ (GDC).

أظهرت النتائج إمكانية الحصول على مستويات عالية من مقاومة الانضغاط (fcu) لخلطات (RPC) الحاوية على (GDC). تم ملاحظة حدوث تأثيرات سلبية طفيفة على مستويات (fcu) بسبب استخدام (GDC). بينت النتائج ان هذه التأثيرات ليست على مستوى واحد وتتباين استنادا الى نوع المادة المستبدلة، نسبة الاستبدال وعمر الخرسانة. كان تأثير استبدال جزء من وزن الـــ (C) بـــ (GDC) أكثر وضوحا من تأثير استبدال جزء من وزن الـــ (SF) بـــ (GDC). أدت زيادة نسبة الاستبدال الى تقليل قيم (fcu). أكدت النتائج ان فعالية وتأثير الـــ (GDC) قريب جدا من فعالية وتأثير الـــ (SF) خاصة في الأعمار المتقدمة للخرسانة.

الكلمات المفتاحية: RPC، الاستدامة، مطحون، الحطام، والضغط، والقوة، وملموسة، غبار السيليك.