University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 28 Number 10 October 2022

Civil and Architectural Engineering

Some properties of Reactive Powder Concrete Contain Recycled Glass Powder

Zainab Ali Hussain *	**Nada Mahdi Fawzi Aljalawi**
MSc student	Prof Dr.
College of Engineering	College of Engineering
University of Baghdad	University of Baghdad
Baghdad, Iraq	Baghdad, Iraq
Zainab.hussain2001m@coeng.uobaghdad.edu.iq	Nada.aljalawi@coeng.uobaghdad.edu.iq

ABSTRACT

Every year, millions of tons of waste glass are created across the globe. It is disposed of in landfills, which is unsustainable since it does not disintegrate into the environment. This study aims to produce reactive powder concrete by using recycled glass powder and determine the influence on the mechanical properties. This study investigated the effect of partial replacement of cement with recycled glass powder at two percentages (0, 20) % by weight of cement on some mechanical properties (Fresh density, Splitting tensile strength, Impact Strength, and voids%) of reactive powder concrete containing 1 % micro steel (MSRPC). Furthermore, using steam curing for (5 hours) at 90 degrees celsius after hardening the sample directly, RPC was produced using local cement, silica fume, and a super plasticizer, with a w/c (0.2). It was found the Fresh density increased by about (7.27%), splitting tensile strength increased by about (23.5%) at age 28day, energy that causes 1-st crack increased by about (77.7%), energy that causes ultimate failure increased by about (54.9%) at age 60 days, and a reduction in the voids % by about (12.5)% at age 28 day compared with the reference mixture.

Keywords: enhanced concrete, reactive powder concrete, Impact Strength, Splitting tensile strength, cement, recycled glass powder

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2022.10.04

Article received: 17/4/2022
Article accepted: 24/5/2022
Article published: 1/10/2022

بعض خصائص خرسانة المساحيق الفعالة الحاوية على مسحوق الزجاج المعاد تدويره

زينب علي حسين قسم الهندسة المدنية جامعة بغداد	**ا.د.ندى مهدي فوزي الجيلاوي** قسم الهندسة المدنية جامعة بغداد

الخلاصة

الهدف من هذه الدراسة هو إنتاج مسحوق خرساني تفاعلي باستخدام مسحوق زجاج معاد تدويره وتحديد التأثير على الخواص الميكانيكية. كل عام ، يتم إنشاء ملايين الأطنان من نفايات الزجاج في جميع أنحاء العالم. يتم التخلص منها في مكبات النفايات ، وهو أمر غير مستدام لأنه لا يتحلل في البيئة. بحثت هذه الدراسة في تأثير الاستبدال الجزئي للسمنت بمسحوق زجاج معاد تدويره بنسبتين (0 ، 20)٪ بالوزن من السمنت على بعض الخواص الميكانيكية (الكثافة ، مقاومة الشد ، مقاومة الصدم ، ونسبة الفراغات) لخرسانة المساحيق الفعالة التي تحتوي على 1٪ من الياف الفولاذ الدقيق (MSRPC). علاوة على ذلك ، أستخدم المعالجة بالبخار لمدة (5 ساعات) عند 90 درجة مئوية بعد تصلب العينة مباشرة ، تم تصميم RPC باستخدام السمنت المحلي ، ودخان السيليكا ، والملدنات الفائقة مع الماء / السمنت (0.2) ، الكثافة ازدادت بنسبة (7.27٪) ، و مقاومة الشد ازدادت بنسبة (23.5٪) في عمر 28 يومًا ، ازدادت الطاقة التي تسبب الشق الأول بنسبة (77.7٪) و الطاقة التي تسبب الشق النهائي ازدادت بنسبة (54.9٪) في عمر 60 يومًا مقارنة مع الخلطة المرجعية. وكما حصل انخفاض في نسبة الفراغات بمقدار (12.5)٪ بعمر 28 يوم مقارنة مع الخلطة المرجعية .

الكلمات الرئيسية: مسحوق خرساني تفاعلي، مقاومة الشد ، مقاومة الصدم مسحوق ،الزجاج المعاد تدويره

1. INTRODUCTION

The RPC, also referred to as UHPC, was developed initially by Richard P. and afterward in 1993 by Cheyrezy M. and Roux N., who worked for the French construction company Bouygues **(Richard and Cheyrezy, 1994)**. RPC development is founded on the idea that material with fewer interior voids would have a higher load-carrying capacity and better structural performance. As a result, the coarse aggregate was removed, and the RPC mix now consists of fine sand, a high cement percentage, silica fume, and a superplasticizer. The lack of coarse aggregate reduces variability between the cement matrix and the aggregate, improving microstructure and performance **(Collepardi et al., 1997)**. Sustainability problem has been considered as driving logic concept for the next materials innovation phase. Sustainable construction has gained considerable attention worldwide throughout the past years **(Yeheyis et al., 2013)**. Because the chemical components included in glass powder are almost identical to the chemical elements present in cement, it may be used as a partial substitute for cement in a concrete mixture **(Safarizki et al., 2020)**. Cracks in concrete construction are unavoidable during the course of its life. Structures

exposed to the external environment are more prone to cracking because they are impacted via shrinkage or expansion in weight and drying, as well as other environmental variables. These crack have an impact on mechanical characteristics, and durability of the structures are lowered as a result; fiber may be used to solve this issue **(Al Kareem, 2021)**. So RPC should include some steel micro-fibers and have a very low water cementitious material ratio to attain ultra-high strength **(Talebinejad, et al., 2004).** RPC has been demonstrated to have considerably higher tensile strength before and after breaking. RPC's tensile strength is produced by the interplay of randomly oriented steel fibers that function as reinforcement on a micro level, preventing fractures from developing. After breaking, the steel fibers may withstand further tensile stresses until the fibers are torn from the matrix, and the section is severed **(Spasojevic, 2008).**
Furthermore, the addition of silica fume reduces the permeability of concrete to chloride ions, which protects the reinforcing steel of concrete from corrosion, particularly in chloride-rich environments such as coastal regions, humid continental roadways, and runways (due to the use of deicing salts), and saltwater bridges **(Detwiler et al., 1994)**. And also, curing processes are defined as the series of actions or steps taken to achieve the hydraulic-cement concrete matures and grow or cause to grow and become more hardened concrete properties in the presence of sufficient water and heat with a specifically required time duration **(Gawad and Al-Jalawi, 2021).**

2. EXPERIMENTAL WORK

2.1 Materials

2.1.1Cement

Throughout the experiment, the OPC (Cem I- 42.5 R), and the physical and chemical requirement composition comply with the requirements of the **(IQS 5, 2019).**

2.1.2 Fine Aggregate

Fine aggregate with a good gradation must be selected and free from harmful substances, fine aggregates passing from sieve (0.6mm) and comply with requirements of the **(IQS 45, 1984)**.

2.1.3 Mixing water

The water used in this research should conform to **(IQS.No.1703/1992)**.

2.1.4 Silica fume (SF)

SF was utilized as a mineral admixture that is added to RPC mixtures of the present research. The chemical, physical properties, and strength activity index comply **(ASTM C1240, 2015)**.

2.1.5 Glass powder (GP)

In this research, the glass waste resulting from shops selling window glass was used, recycled, and ground to the required finesse according to the requirement of **(ASTM C311, 2016)**. The chemical, physical properties, and strength activity index comply **(ASTM C618, 2015)**, as shown in **Table 1**.

Table 1. Physical and Chemical characteristics of GP

Composition of the Oxide	Test Result%	Limit of Specification Requirement ASTM C618 class N
SiO_2	64.22	Min(70)
AL_2O_3	9.6 (79.02)	
Fe_2O_3	5.2	
SO_3	2.1	Max(4)
CaO	4.26	-----
MgO	1.65	-----
Loss of Ignition	3.21	Max(10)
Percentage retained on 45µm (NO325), maximum variation, percentage point from avg.	32%	34%
Index of the Strength Activity With the Portland Cement at 7 days (%).	101.4	Minimal (75)

2.1.6 Steel Fibers (MSF)

Steel fibers used were a straight type, have an average tensile strength of 2600MPa, and the utilized percentage was 1% by volume of Concrete.

2.1.7 Superplasticizer (SP)

A superplasticizer has been added to the mixture. The recommended dose by the manufacturer ranged between (0.5-2.5) liters per 100kg of cement, and hyperplastic PC600 complies with **(ASTM C-494, 2005**) type (G).

2.2 Concrete Mixes

Design Reactive powder concrete containing (1%) By vol. of concrete micro steel fiber group and used dosage superplasticizer (1.8) L/100Kg of Cement and SF (25%) by cement weight and replacement (0, 20)% glass powder by weight of cement. To obtain Reactive powder concrete with desirable and appropriate properties, a group of experimental mixtures was prepared based on a group of previous studies and research, such as (Sarika S., Elson J, 2015). The concrete mix is shown in **Table 2.**

Table 2. concrete mix for MRPC.

Mix	OPC kg/m^3	FA kg/m^3	SF kg/m^3	GP kg/m^3	Weight Water kg/m^3	w/cm
M.0%	950	1045	237.5	----	208	0.175
M.20%	760	1045	237.5	190	208	0.175

2.3 Curing Concrete

After the samples were removed from the molds, they were placed in the steam curing device for five hours at a temperature of 90°C. The sample was then taken out from the steam curing device and placed in the normal treatment tank for the age of the test.

2.4 Testing

2.4.1Fresh density test

The fresh density of RPC was checked according to **(ASTM C138 / C138M, 2017)** using a known mass and volume cylinder.

2.4.2 Splitting tensile strength

A cylinder specimen with dimensions (100×200) mm was used according to **(ASTM C496/C496M, 2017)**, the cylinders were tested at age (7, 28, and 90) days, respectively, and the mean of two cylinders was calculated by using the Eq. (1)

$$T = \frac{2p}{\pi l d} \tag{1}$$

Where:

T: represents Splitting tensile strength (MPa).

l: represents length of the sample (mm).

P: represents Maximum Applied load (N).

d: represents Diameter (mm).

3.4.2 Impact Strength

Using tiles samples with dimensions of (500x500x50) mm in size, the impact strength was calculated procedure according **(ACI 544.2R, 2008)** and **(Aljalawi, 2006)**. The shock energy of blows may be estimated using Eq. (2) and agree with **(Chyad, 2021)**.

$$U = N \times m \times g \times h \tag{2}$$

Where:

U: represents energy of the strike (KN.m).

m: represents mass of falling body (kg).

N: represents number of hits.

h: represents height of the falling body (m).

g: represents ground acceleration (m/Sec2).

3.4.3 Voids test

The voids test is determined based on **(ASTM C-642, 2013);** the voids had been estimated as in Eq. (3):

Vol. of the permeable pore space or voids% = [(C-A)/(C-D)] x100 (3)

Where:

A: represents oven-dried sample mass, g

C: represents the surface-dry sample's mass in the air post immersion and the boiling, g

D: represents apparent sample mass in the water after the immersions and the boiling, g

4. RESULTS AND DISCUSSION

4.1 Fresh density test

The density is (3480 kg/m^3) at replacement 0% and (3733 kg/m^3) at replacement 20% .The percentage of increase when replacement of 20% percentage of recycled glass powder is about 7.27%, as shown in **Table 3** and **Fig. 1**. That improvement due to fine particles for recycled glass powder cause filling within the void. The reasons for the increase are consistent with a study **(Raju and Kumar, 2014)**.

Table 3. Effect micro steel fiber for density

Mix type	MSF%	Density(kg/m^3)
M. 0%	1	3480
M.20%	1	3733

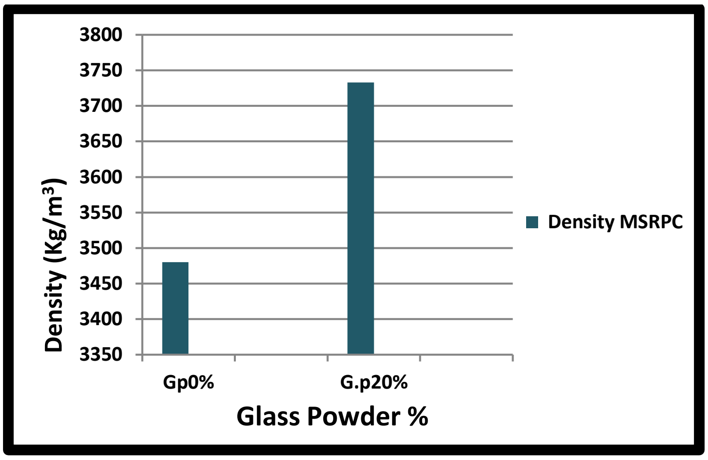

Figure 1. Relationship between the density and glass powder %for (MSRPC).

4.2 Splitting tensile strength

The tensile strength was tested for the samples that included the replacement percentage (0,20)%, and the results are shown in **Table 4** and **Fig. 2.** The apparent improvement in the values of the tensile strength when comparing the values of the 20% replacement ratio of cement with recycled glass powder with values of reference mix. Percentage of increase about (23.4,23.5.24.1)% at age(7,28,90)days. That improvement is due to microstructural properties of RPC containing finely dispersed recycled glass powder and silica fume with steam curing at high temperatures, will be a sufficient Pozzolanic additives that may be playing micro filler role in concrete matrix because of interaction with the product of $Ca(OH)_2$ result from hydration of cement, and produce more C-S-H binding the repair material with substrate concrete (enhance bonding between the fibers and concrete). And that has resulted in the improvement and strengthening of concrete material structure, thereby decreasing porosity and increasing RPC strength. The reasons for the increase are consistent with a study **(Iqbal, et al., 2015) and (Aljalawi, 2018) and (Abed et al., 2018).** The failure pattern is shown in **Fig. 3.**

Table 4. Splitting tensile strength for MSRPC mixes

Mix type	Splitting tensile strength (MPa)		
	7day	28 day	90 day
M.0%	9.6	10.2	10.8
M.20%	11.9	12.6	13.4

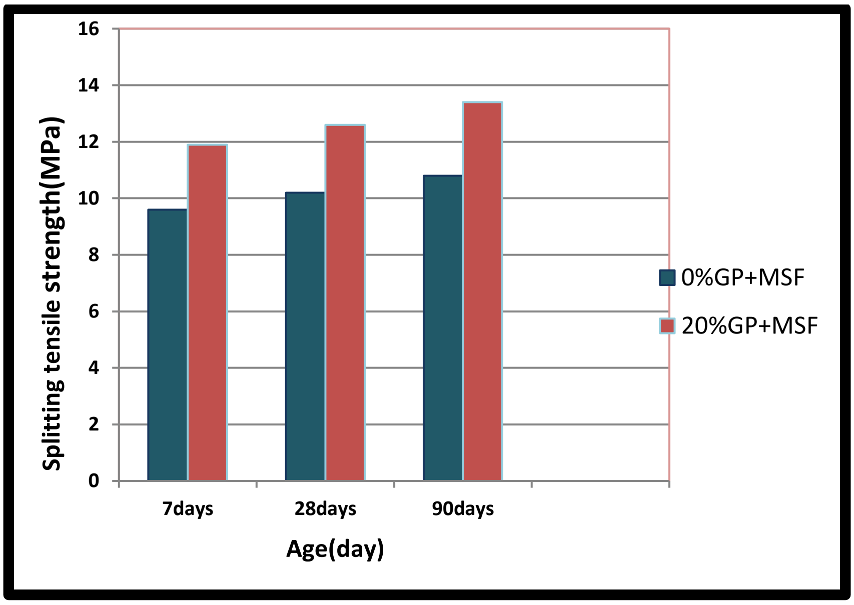

Figure 2. The relationship between splitting tensile strength and age for (MSRPC).

Figure 3. The pattern of failure for MSRPC

4.3 Impact strength

Enhanced impact resistance is a very significant RPC attribute. Where the number of blows to cause 1-st crack increases about (43.7) % when replacing, and the number of blows that will cause ultimate failure increases about (35.4) % when replacing 20% of recycled glass powder at ages60 day. The number of blows that are needed, which causes the first crack and ultimate failure, and the energy causing initial cracking and ultimate failure for the MSRPC have been summarized in **Table 5** and **Fig. 4** and **5**. Test results explain clearly that the value of the impact strength or numbers of the blows that cause the 1rst crack and ultimate failure values are considerably increased when replacement (20%) compared to reference Mix (0%). The improvement is due to using recycled glass powder and silica fume into the cementitious composites, which enhances the strength of the interface bond between fine aggregate and hardened cement paste. As a result, it plays a role in improving the strength of cement paste because of pozzolanic reaction and affects the steam curing. The reasons for the increase are consistent with a study **(Roslan et al., 2016), (Muhsin and Aljalawi, 2021) and (Tong, 2020).**

Table 5. Impact strength for MSRPC mixtures.

Mix type	No. of blows to cause 1-st crack	No. of blows that will cause ultimate failure	Energy up to 1-st crack (J)	Energy up to ultimate failure (J)
M.0%	27	58	1350.8	2551.5
M.20%	48	79	2401.4	3952.4

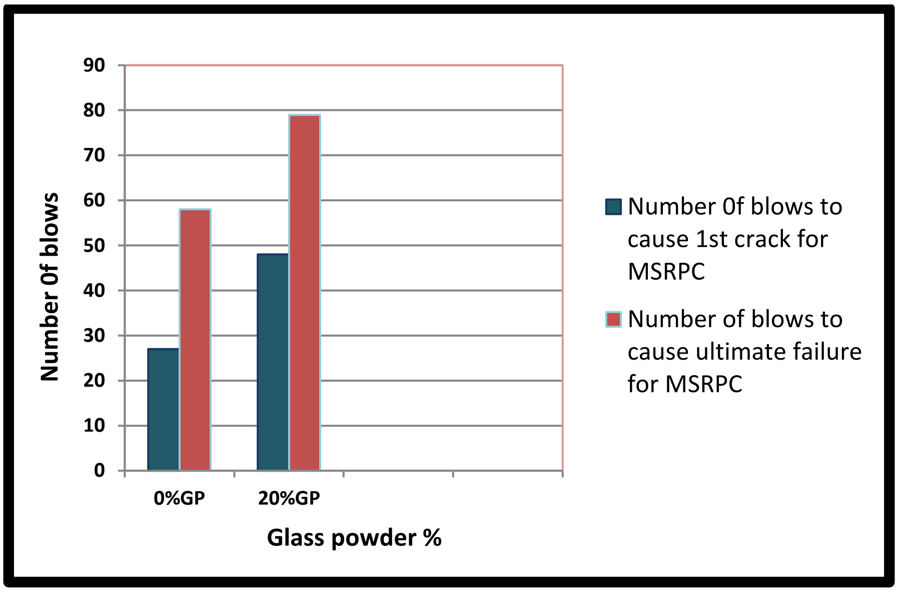

Figure 4. Relationship between the number of the blows that cause initial cracking and ultimate failure for (MSRPC)

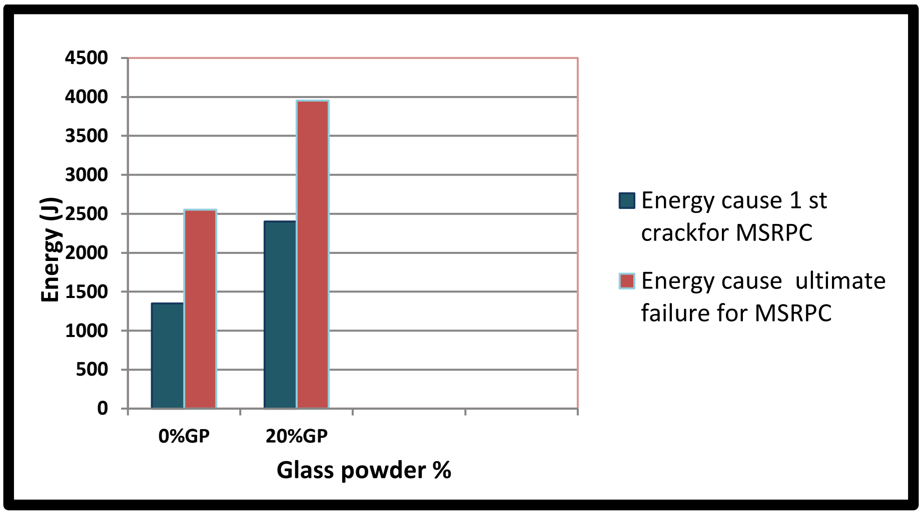

Figure 5. Relationship between the energy causing initial cracking and ultimate failure for (MSRPC)

4.4 Permeable pore space volume (voids%)

It was noted that replacing cement with recycled glass powder in a ratio of 20% reduces the porosity of the RPC by about (10.7, 6.85, and 5.35) % at the age of (7, 28, and 90) days compared to the reference samples. Recycled glass powder plays the role of filler and fills the voids through pozzolanic interactions **(Aljalawi, 2009) and (Gawad and Al-Jalawi, 2021).** Also, the RPC micro-structure is modified considerably by the heat treatment steam curing. The reasons for the increase are consistent with a study **(Aljalawi and AL-Awadi, 2017) and (Salim at el., 2019)**. The results are shown in **Table 6** and **Fig. 6**

Table 6. Voids for RPC mixtures with micro steel fiber

Mix type	Voids (%)		
	7 day	28 day	90 day
M.0%	9.1	7.83	6.67
M.20%	8.12	6.85	5.35

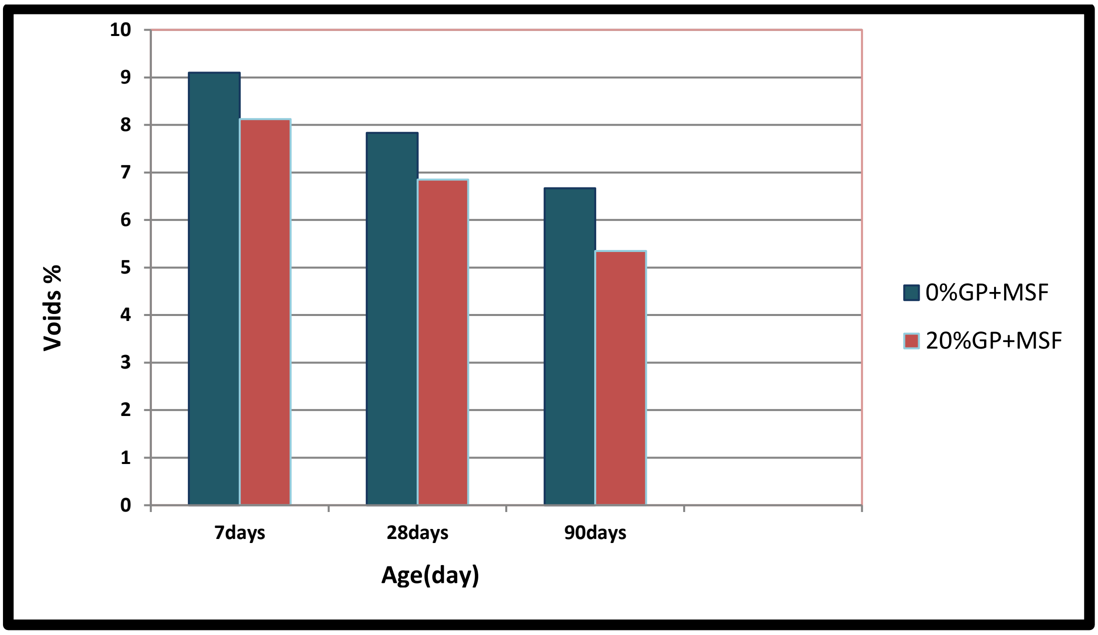

Figure 6. Relationship between the porosity (%) and age for (MSRPC)

5. CONCLUSIONS

After experiments in the laboratory, it was concluded that:

- The Fresh density increases with an increase in the substitution ratios of recycled glass powder
- When replacing 20% recycled glass powder, the splitting tensile strength of RPC increases about (23.4,23.5.24.1) % at all ages compared to the reference sample.
- The number of blows to cause 1-st crack and the number of blows that will cause ultimate failure for RPC with micro steel fiber increases about (43.7,35.4) %, respectively when replacing 20% recycled glass powder at ages 60 days compared to the reference samples.
- The voids% for RPC was minimized by replacing 20% recycled glass powder by about (10.7, 6.85, and 5.35) % at 7, 28, and 90 days compared to the reference samples.

REFERENCES

Abd Al Kareem, S., and Ahmed, I. F., 2021. Impact Resistance of Bendable Concrete Reinforced with Grids and Containing PVA Solution, *Engineering, Technology & Applied Science Research*, 11(5), 7709-7713.

Abed, M., Mohammed. N., and Zaid, H., 2018. Effect of silica fume/binder ratio on compressive strength development of reactive powder concrete under two curing systems. MATEC Web of Conferences. 162. 02022. 10.1051/ matecconf/ 201816202022.

ACI PRC-544.3, 2008 Guide for Specifying, Proportioning, and Production of Fiber-Reinforced Concrete.

Aggregate from Natural Sources for Concrete and Construction, Iraqi Specification, No.45/1984.

ASTM C 1240., 2015. Standard Specification for Silica Fume Used in Cementitious, Mixture Annual Book of ASTM Standards.

ASTM C 496/C496M, 2011. Standard Test Method for Splitting Tensile Strength of cylindrical Concrete Specimens.

ASTM C 618, 2015. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.

Chyad, A., 2021. Flexural Strength and Impact Behavior of Ferro cement Members Containing Waste Materials, A Thesis Submitted to Civil Engineering Department, University of Anbar.

Collepardi, S., Coppola, L., Troli, R., and Collepardi, M., 1997. Mechanical properties of modified reactive powder concrete, *ACI Special Publications*, 173, 1-22.

Detwiler, R. J., Fapohunda, C. A., and Natale, J., 1994. Use of supplementary cementing materials to increase the resistance to chloride ion penetration of concretes cured at elevated temperatures, *Materials*, 91(1), 63-66.

Gawad, M. A., and Fawzi, N. M., 2021. Use of Thermostone Waste Aggregates for Internal Curing of Reactive Powder Concrete, In IOP Conference Series: Earth and Environmental Science (Vol. 877, No. 1, p. 012043), IOP Publishing.

Gawad, M. A., and Al-Jalawi, N. M., 2021. Effect of Internal Curing On Some Properties of Reactive Powder Concrete, A Thesis for the Degree of Master of Science in Civil Engineering. Civil Engineering Department, College of Engineering, University of Baghdad.

Iqbal, S., Ali, A., Holschemacher, K., and Bier, T. A., 2015. Effect of change in micro steel fiber content on properties of High strength Steel fiber reinforced Lightweight Self-Compacting Concrete (HSLSCC), *Procedia Engineering*, 122, 88-94.

Muhsin, Z. F., and Fawzi, N. M., 2021. Effect of Fly Ash on Some Properties of Reactive Powder Concrete, *Journal of Engineering*, 27(11), 32-46.

N. M. Al-Jalawi, and AL-Awadi, A. Y. E., 2017. Enhancing Performance of Self–Compacting Concrete with Internal Curing Using Thermostone Chips, *Journal of Engineering*, 23(7), 1-13.

N. M. Al-Jalawi, 2018. Effect of steel fiber on properties of high performance no fine concrete, *International Journal of Engineering and Technology*, vol 7, 4.37.

N. M. Al-Jalawi, 2006. Properties of compacted lightweight ferrocement plates, Ph. D. thesis, University of Baghdad. p142.

N. M. Al-Jalawi., 2009. Production of high-performance concrete using different types of local pozzolana, *Journal of engineering*, vol.15 - No.1.

Portland cement, Iraqi Standard Specification No.5, 2019.

Raju, S., and Kumar, P. R., 2014. Effect of using glass powder in concrete. International Journal of Innovative Research in Science, *Engineering and Technology*, 31, 21-427.

Richard, P., and Cheyrezy, M. H., 1994. Reactive powder concretes with high ductility and 200-800 MPa compressive strength, *Special Publication*, 144, 507-518.

Roslan, N. H., Ismail, M., Abdul-Majid, Z., Ghoreishiamiri, S., and Muhammad, B., 2016. Performance of steel slag and steel sludge in concrete, *Construction and Building Materials*, 104, 16-24.

Safarizki, H. A., and Gunawan, L. I., 2020. Effectiveness of Glass Powder as a Partial Replacement of Sand in Concrete Mixtures, *In Journal of Physics: Conference Series* (Vol. 1625, No. 1, p. 012025), IOP Publishing.

Salim, L. Gh., Al-Baghdadi, H. M., and Muteb, H. H., Reactive powder concrete with steel, glass and polypropylene fibers as a repair material, *Civil Engineering Journal*, 5.11: 2441-2449, 2019.

Sarika, S., 2015. A study on properties of reactive powder concrete, Literatures, 3, 5.

Spasojevic, A., Burdet, O., and Muttoni, A., 2008. Applications structurales du béton fibré à hautes performances aux ponts (No. REP_WORK), Rapport OFROU.

Specification, I., 1992. No. 1703: Water used in concrete, Baghdad, Iraq: Central Organization for Standardization and Quality Control.

Standard specification for chemical admixtures for concrete, ASTM C494, 2005.

Standard Test Method for Density (Unit Weight), ASTM C138/ C138M, 2017.

Standard Test Method for density, absorption, and voids hardened concrete ,2013 ASTM C642.

Standard Test Methods for Sampling And Testing Fly Ash Or Natural Pozzolans For Use In Portland-Cement Concrete, ASTM C311,2016.

Talebinejad, I., Bassam, S. A., Iranmanesh, A., and Shekarchizadeh, M., 2004. Optimizing mix proportions of normal weight reactive powder concrete with strengths of 200–350 MPa, *In Proceedings of the International Symposium on UHPC*, Kassel, Germany (pp. 133-141).

Tong, K., 2020. Application of New Concrete Materials in Civil Engineering, *Insight - Material Science* - PiscoMed Publishing Pte Ltd, Volume 3, Issue 2.

Yeheyis, M., Hewage, K., Alam, M. S., Eskicioglu, C., and Sadiq, R., 2013. An overview of construction and demolition waste management in Canada: a lifecycle analysis approach to sustainability, *Clean Technologies and Environmental Policy*, 15(1), 81-91.