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The Effect of Different Curing Temperatures on Properties of Reactive Powder Concrete Reinforced by Micro Steel Fibers

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ABSTRACT

Reactive Powder Concrete (RPC) is a type of high-performance concrete that is known for its exceptional strength and durability also RPC is one of the new composite materials that allow for the most efficient use of materials, which benefits the concrete industry economically. Additionally, it improves environmental sensitivity. The main objective of this paper is the determine some characteristics of RPC, such as (compressive strength and fresh density) after exposure to different curing temperatures (60, 120, and 200) ^{o}C for 4 hours due two days. This study involves many variables such as micro steel fibers content with 1% by vol. of reactive powder concrete samples as well as elevated temperature. It was discovered that the optimum temperature that was used after conducting the tests was 60 Celsius, as it gave the best results for the mechanical properties of RPC, which were adopted in the rest of the tests. The value of fresh density increased by about (1.95%) and compressive strength increased by about (33.3%) at 60 ^{o}C for the age of 28 days in contrast to the reference mixture.

Keywords: Reactive Powder Concrete (RPC), Compressive strength, Fresh density, Micro steel fibers, Temperature.

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تأثير درجات حرارة المعالجة المختلفة على خصائص خرسانة المساحيق الفعالة المسلحة بألياف الحديد الدقيقة

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الخلاصة

خرسانة المساحيق الفعالة هي نوع من الخرسانة عالية الأداء معروفة بقوتها الاستثنائية ومتانتها ، كما أنها واحدة من المواد المركبة الجديدة التي تسمح بالاستخدام الأكثر كفاءة للمواد ، مما يفيد في صناعة الخرسانة بطرق اقتصادية . بالإضافة إلى ذلك فإنه يحسن من الظروف البيئية. إن تحديد بعض خصائص خرسانة المساحيق الفعالة هو الهدف الرئيسي لهذه البحث مثل (مقاومة الانضغاط ، الكثافة) بعد التعرض لدرجات حرارة معالجة مختلفة oC (60،120،200) لمدة 4 ساعات لمدة يومين. تتضمن هذه الدراسة العديد من المتغيرات مثل محتوى الألياف الفولاذية الدقيقة بنسبة 1٪ من حجم الخرسانة وكذلك درجات الحرارة المرتفعة. من خلال النتائج تم ملاحظة أن درجة الحرارة المثلى التي تم استخدامها بعد إجراء الاختبارات كانت 60 درجة مئوية، حيث أعطت أفضل النتائج للخصائص الميكانيكية لخرسانة المساحيق الفعالة والتي تم اعتمادها في باقي الفحوص.أن الكثافة ازادت بحوالي (1.95٪) ، ازادت مقاومة الانضغاط بحوالي (33.3٪) عند 60 درجة مئوية عند عمر 28 يوم مقارنة بالخلطة المرجعية.

الكلمات المفتاحية: خرسانة المساحيق الفعالة، مقاومة الانضغاط ، الكثافة، الياف الحديد الدقيقة ، الحرارة.

1. INTRODUCTION

Reactive Powder Concrete (RPC) is indeed considered a special kind of cementitious material, it is a high-performance concrete (HPC) that is engineered to have exceptional strength, durability, and resistance to a range of environmental and chemical factors compared to traditional concrete due to its unique composition and production process. RPC has water to cement ratio that is almost less than 0.2, which makes it highly dense and impermeable, as well as an extremely high cement content. Additionally, RPC contains very fine quartz powder, which enhances its workability and reduces bleeding and segregation. The coarse aggregates used in traditional concrete are completely exchanged in RPC by crushed quartz and fine quartz sand. RPC is known for its exceptional compressive strength, which can range from 50 to 100 MPa, depending on the mix design and curing conditions **(Gamal et al., 2019; Fawzi et al., 2010; Collepardi et al., 1997)**. Researchers led by Richard and Cherezy at Bouygues in Paris, France, created RPC for the first time in the early 1990s. The Sherbrook Bridge, the country's first RPC structure, was built in July 1997 **(Richard and Cheyrezy, 1994; Gawad et al., 2021)**. RPC is only used in confined locations because of a high production cost. RPC is being used more and more frequently on a worldwide scale, especially in Europe, where various researches have been done. RPC is employed in nuclear power reactors, the defense sector, and the production of weapons **(Canbaz, 2014; Dhundasi et al., 2021)**. However, the rising cost of natural resources has prompted a quest for substitutes, including recycled materials like sawdust ash, fly ash, coal bottom ash, rice husk ash, silica fume, limestone dust, marble powder, tile powder, millet husk ash, crumb rubber, etc. **(Ali et al., 2021)**. Because of its great strength, durability, and performance. RPC is a potential material for unique pre-stressed and precast concrete components. In particular, RPC is suitable for applications where high strength and durability are essential, the facilities that are often mapped to such applications are industrial facilities and nuclear waste storage facilities. While the production costs of RPC are generally higher than those of traditional concrete, there are some economic advantages to using RPC in certain applications. For example, RPC can reduce or eliminate the need for passive reinforcement using steel fibers, which can result in cost savings. Additionally, Cause of the ultra-high mechanical performance of RPC may allow for the thickness of concrete elements to be lower than traditional concrete, resulting in good material and lower cost **(Yazıcı et al., 2009; Hussain and Aljalawi, 2022)**. When compared to conventional concrete, RPC has been found to have much greater tensile strength, both before and after breaking. This is because of the interaction of randomly oriented steel fibers that serve as micro-reinforcement, preventing fractures from forming. Steel fibers in RPC also offer a variety of other advantages. Firstly, it strengthens the concrete's tensile strength, increasing its resistance to breaking and cracking. Second, they increase the concrete's resilience to environmental deterioration by strengthening its durability. **(Hussian and Fawzi, 2022; Aljalawi, 2021**). Additionally, silica fume is added to concrete to reduce its permeability to chloride ions, which prevents corrosion of the concrete's reinforcing steel, especially in chloride-rich environments like coastal areas, humid continental roads, and runways (caused by the use of deicing salts), and saltwater bridges **(Detwiler et al., 1994; Muhsin et al, 2021)**. To achieve ultra-high strength, RPC should have a very low water cementitious material ratio and some micro steel fibers **(Talebinejad et al., 2004; Najib et al., 2020)**. Some investigators have examined the effect of including various volume fractions of steel fibers. They studied the characteristics of concrete utilizing volume fractions (0.5, 0.75, and 1) with substantial volume fractions and an aspect ratio of 100. Specimens (prisms and cubes) of hard concrete and fiber-reinforced concrete were checked **(Fawzi and AL-Ameer, 2013; Hussian and Aljalawi, 2022).** Environmentally friendly materials can be used in civil engineering projects to reduce the effects of negative environmental construction and to advance sustainable development. By reducing the demand for cement and promoting recycling and reuse of industrial waste, we can help reduce carbon emissions and conserve natural resources **(Alsaedy et al., 2021; Amouri and Fawzi, 2022).** The RPC's mechanical attributes, including its flexural and compressive strengths, are reinforced with steel fibers. In comparison to concrete without steel fibers, the results demonstrate that the inclusion of steel fibers significantly improved the concrete's bending and compressive strength **(Smith, 2015)**. The results of the researchers showed that the sample with the highest density and 1.5% fiber content is the best for protection. Additionally, it was stated that reactive powder concrete was made utilizing micro steel fibers at a ratio of (1-1.5%) and by water treatment. At the age of 28 days, a compressive strength of 70 MPa was attained **(Muhsin and Fawzi, 2021).**

This work aims to determine some fresh and hardened characteristics of RPC mixtures, considering (M0) the reference mixture without fibers, and (M1) the mixture contains micro steel fibers, after exposure to different curing temperatures (60,120, and 200) ^{o}C.

2. EMPIRICAL STUDY

2.1 Materials

2.1.1 Cement

Ordinary Portland Cement (OPC) (Cem I- 42.5 R) was involved in this study and matches the physical and chemical requirements of the **(IQS. 5, 2019).**

2.1.2 Fine aggregate (FA)

The aggregate used is fine aggregates, free from harmful substances, passed through a (0.6 mm) sieve, fell within zone 4, and complies with the specification **(IQS. 45, 1984).**

2.1.3 Silica Fume (SF)

SF was employed as a mineral addition, SF replaced 10% of cement weight in the RPC mixes, and the physical characteristics and strength activity index (110.3) met the requirements of **(ASTM C1240, 2015).**

2.1.4 Water

The water used in this work should conform to the **(IQS. 1703, 1992).**

2.1.5 Chemical admixture

A superplasticizer (SP) is added to the mixture. The typical dosage given by the manufacturer ranged between (0.5-1) liters per 100kg of cement and conformed to the **(ASTM C494, 2005).**

2.1.6 Micro Steel Fibers (MSF)

The MSF used in this paper was straight with a tensile strength of 2600 MPa and aspect ratio (L/d=65). The percentage used in this study is 1% by vol. of concrete as shown in **Fig 1.** and given in **Table 1.**

Figure 1. Micro steel fibers utilized in this work

Table 1. Features of micro steel fibers

Description	Specification
Surface	Brass coated
Tensile strength	2600 MPa
Density	7860 kg/m^3
Melting point	1500 ^{o}C
Diameter	0.20 mm±0.05 mm
Average length	13mm

2.2 Concrete Mixtures

Reactive Powder Concrete (RPC) is designed to meet the requirements and recommendations which containing (1%) by vol. of concrete micro steel fibers and dosage of superplasticizer (1) L/100kg of Cement and SF with (10%) replacement by weight of cement. To obtain the desirable and appropriate properties of RPC a group of experiments were conducted based on previous research such as **(Abid et al., 2019)**. The concrete mixture contents are illustrated in **Table 2**.

2.3 Curing of Concrete

After being removed from the molds, the samples were placed in a temperature-controlled oven set at (60, 120, or 200) ^{o}C for four hours over the course of two days. Following this, the samples were moved to another oven to maintain the same temperature until the test day.

Table 2. Design for MSRPC

Mix Number	Ordinary Portland Cement kg/m^3	Fine Aggregate kg/m^3	Silica Fume kg/m^3	Water kg/m^3	w/cm	percentage of Fiber %
M0	720	950	80	185	0.23	-
M1	720	950	80	185	0.23	1%

2.4 Testing

2.4.1 Fresh 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 Compressive Strength Test

The compressive strength is calculated based on the requirements of **(ASTM C109/C109M, 2016)** using cubes with dimensions of (50x50x50) mm. This test is implemented at ages (7, 28, and 90) days. Each cube's compressive strength is estimated according to:

$$F=\frac{P}{A} \quad (1)$$

where: F is the compressive strength in (MPa), A is the loaded surface area in (mm^2), *and* P is the total maximum load in (N).

3. RESULTS AND DISCUSSIONS

3.1 Fresh Density Test

The fresh density of RPC increased with the embedding of MSF. The high density and specific gravity of MS fiber increase the density of mixtures as shown in **Fig. 2** and this reason complied with **(Sathawane et al., 2013; Momtazi and Zanoosh, 2011).**

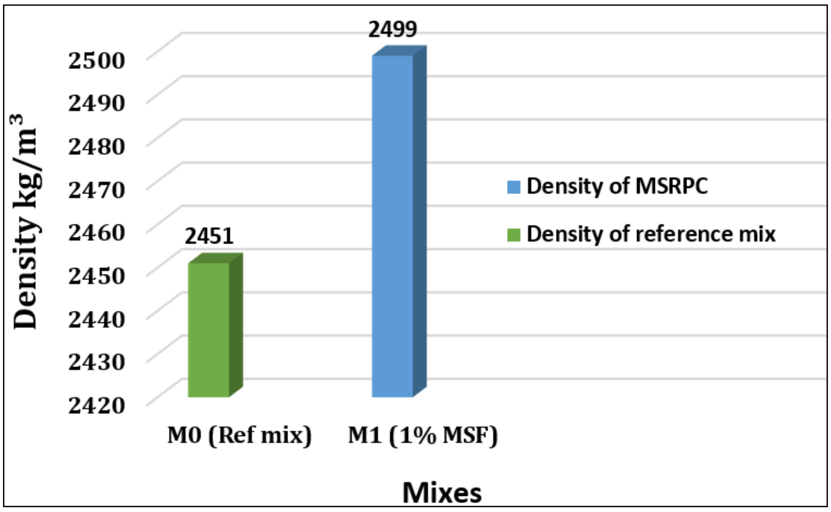

Figure 2. Fresh Density values for RPC with Micro steel fiber

3.2 Compressive Strength Test

Fig. 3 and **Table 3** summarize the results of the three cubic samples that were formed for this study's average compressive strength.

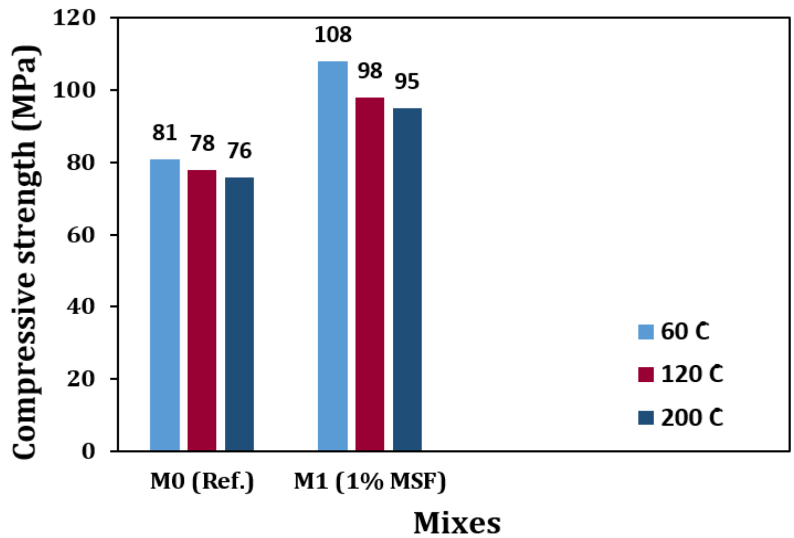

Figure 3. 28-day RPC Compressive Strength at Curing Temperatures

Table 3. Compressive strength of RPC with different curing temperatures

Mix No.	Compressive Strength Results (MPa)								
	Curing age of Testing (days)								
	7 days			28 days			90 days		
	60 °C	120 °C	200 °C	60 °C	120 °C	200 °C	60 °C	120 °C	200 °C
M0	70	69	65	81	78	76	90	86	80
M1	99.8	87	85.3	108	98	95	114	100	98

Outcomes indicated that the compressive strength of RPC increased when temperatures from 60 up to 120 and 200 °C then the compressive strength began to decrease when temperatures increased, the loss of water from the hydrated cement paste and possible interior collapse are the causes of this. Considering the existence of numerous pores and the production of various C-H bonds, therefore, it does not offer an influence on the matrix bonding, leading to low compressive strength and this complied with the researcher **(Chadli et al., 2021; Hanafiah and Agistin, 2019; Taha, 2013)**. When adding MSF the compressive strength increases and reason is that the MSF in reinforced concrete plays an important role in enhancing the mechanical properties of the concrete matrix ,the strength of the bond between the micro steel fibers and the cementitious matrix is one of the main factors that contribute to the development of strength in reinforced concrete also because the embedding of micro steel fibers to cement-based matrices in the hardened situation can improve the strength of the bond between the MSF and the cementitious matrix, improving its strength, and durability, and give the capacity to postpone the development of micro cracks. These reasons agree with **(Aljalawi and Faleh, 2009; Ramli et al., 2011; Kushartomo et al., 2015).** The failure pattern is shown in **Fig. 4.**

Figure 4. Failure pattern for MSRPC

4. **CONCLUSIONS**

The results of an experimental program to examine the properties of reactive powder concrete (RPC) reinforced with micro steel fibers at high curing temperatures (60–200 °C) were presented and discussed in this work. It has been determined through laboratory testing and comparison of the reference RPC mixture's findings with combinations including 1% by volume of concrete MSF that the fresh density increases with the addition of MSF. The compressive strength decreases when temperature increases and the ideal temperature is

60 °C which is adopted for all tests. When MSF was added, the compressive strength of RPC increased by about (42.5%, 33.3%, and 26.6%) for 7, 28, and 90 days respectively at a curing temperature of 60 °C.

NOMENCLATURE

Symbol	Description	Symbol	Description
RPC	Reactive Powder Concrete	F	Compressive strength in (MPa).
OPC	Ordinary Portland Cement	A	Loaded surface area in (mm^2).
FA	Fine aggregate	P	Total maximum load in (N).
SF	Silica Fume	M0	Mixture number 0
SP	superplasticizer	M1	Mixture number 1
MSF	Micro Steel Fibers	HPC	High-performance concrete

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Credit Authorship Contribution Statement

Rafal Mohanad Qasim: Writing – original draft, Validation, Methodology.
Nada Mahdi Fawzi: Review & editing, Validation, Proofreading.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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