Behavior of Modified Reactive Powder Concrete Containing Sustainable Materials and Reinforced with Micro-Steel Fibers

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ABSTRACT

Reusing and recycling construction debris offers intriguing opportunities for resource conservation and waste disposal site economies. This study investigates the feasibility of using 10 mm crushed brick as coarse aggregate in Modified Reactive Powder Concrete. Natural sand was substituted with crushed brick aggregate by 25, 50, and 100%. Up to 7 and 28 days of age, the tensile strength, absorption, and void content of the mixtures were compared with those of a mixture without coarse aggregate. According to the test results, it is feasible to produce Modified Reactive Powder Concrete (MRPC) with coarse aggregate or shattered bricks. Compared to the reference mixture, the tensile strength of MRPC decreased as the replacement ratio of broken bricks increased. At 7 and 28 days of testing, the tensile strength increased by 10.2 and 12.06 with 25% crushed bricks compared to normal reactive powder concrete. Tensile strength decreased by 7.2% and 6.27% at 7 days and by 9.89% and 8.87% at 28 days when replacing fine sand with crushed brick aggregate at rates of 50% and 100%, respectively. Compared to the reference mixture, the absorption and void content of MRPC with 25, 50, and 100% crushed brick increased by 13.6, 61.2, and 116% and 15.9, 62.1, and 136%, respectively.

Keywords-modified reactive powder concrete; silica fume; crushed brick; micro steel fibers; absorption; tensile strength test

I. INTRODUCTION

Concrete is a composite material made up of particles chemically bound by hydrated Portland cement. These aggregates significantly affect the characteristics of concrete, the mix quantities, and its overall cost-effectiveness [1-2]. The requirement for high-strength and high-performance concrete is the main reason for producing Reactive Powder Concrete (RPC) [3]. A lot of cement is used to manufacture reactive RPC. Unlike other binder materials, such as cement and silica fume, RPC contains a large amount of superplasticizers in addition to extremely finely ground quartz and silica fume [4-5]. Conventional RPC does not contain coarse aggregate. However, some studies included coarse aggregate to produce Modified Reactive Powder Concrete (MRPC). Contemporary societies face pollution and global warming as the most pressing issues [6]. Crushed concrete, crushed clay bricks, and crushed thermo-stone are among the massive amounts of debris in landfills due to building demolitions worldwide. Other common types of waste include plastic and scrap tires. These materials can have less impact on the environment through recycling and industrial use, thus reducing resource consumption and pollution [7-8]. The main objective of this study is to make more environmentally friendly RPC by utilizing recycled materials, specifically crushed bricks with a particle size limit of 600 µm. This study also examines how adding coarse aggregate affects the mechanical properties of MRPC, such as tensile strength, absorption, and void content, filling a knowledge gap in this area.

In [9], a 1:2:4 proportion of concrete mixture with a characteristic strength of 3000 psi was experimentally studied. A concrete mix with 50% brick aggregate replacement of coarse aggregate and silica fume was tested at 7, 14, and 21 days of age, showing that its compressive and tensile strengths were nearly identical to regular concrete. In [10], an MRPC was produced, incorporating crushed and graded natural aggregates with a maximum size of 12.5 mm, achieving a high compressive strength of 150 MPa, despite the notion that the high compressive strength of RPC is associated with its lack of coarse aggregates. Compressive strength, splitting tensile strength, modulus of rupture, impact strength, and static modulus of elasticity were impressive, and MRPC reinforced with different types and volume fractions of crimped and hooked steel fibers showed excellent performance. In [11], vibrations were used to cast the original and modified RPC with a plastic-fluid viscosity. The curing process took place under room temperature, steam curing at 90°C, and high-pressure steam curing at 160°C. The compressive strength was unaffected by the addition of graded aggregate, as long as the water-cement ratio of the matrix was kept constant. This discovery was in contrast to the proposed model, which links the absence of coarse aggregate to the RPC's high compressive strength level of 200 MPa. Curing the original and modified RPC (containing coarse aggregate) in steam produced better results than room-temperature curing in terms of improved strength and reduced drying shrinkage or creep strain. An increase in particle concentration in the cement matrix was shown to be responsible for the improvement, particularly in RPC samples that were steam-cured at 160°C.

In [12], diverse methodologies were followed to improve RPC by including naturally graded coarse aggregate. The experiments monitored the development of strength, complete absorption, and the ability to penetrate RPC after exposure to kerosene and petrol oil for 6 months. Substituting fine particles with larger particles in RPC yielded superior results, and the optimal ratio of fine to coarse particles was between 0 and 25% by weight. In [13], the use of waste-crushed bricks obtained from structural applications in MRPC was investigated. Waste-crushed bricks with a maximum size of 10 mm were used as a replacement for silica sand. The results showed that by adding 25% crushed waste brick to the mix, the mechanical qualities of the MRPC improved, but these characteristics gradually degraded when the substitution level approached 50%.

II. EXPERIMENTAL WORK

A. Cement

This study used CEMI 42.5R OPC that complies with the chemical and physical requirements of IQS No.5, 2019 [14].

B. Sand

The study used fine aggregate that passed a 600 μm sieve and complied with IQS No.45, 1984 [15].

C. Silica Fume

The physical features and strength activity index of silica fume conformed with ASTM C1240-15 [16].

D. Water

Water mixing met IQS 1703, 2018 [17].

E. Superplasticizer

A chemical additive was used to improve the flow and workability of concrete. The Fosroc Structuro W420-EB superplasticizer was used to improve the workability and facilitate the addition of fibers. F and G superplasticizers were specifically used. The typical superplasticizer dosage ranged from 0.2 to 2 liters per 100 kg of cementitious material, following ASTM C494-15 [18].

F. Fiber

The aspect ratio (L/D) for microsteel fibers was equal to 60, with L = 12 mm and D = 0.2 mm.

G. Crushed Bricks

Crushed bricks up to 10 mm were collected from demolished buildings in Baghdad. The bricks were sorted and divided into coarse aggregate fractions for the MRPC mixtures. Their density was 958 kg/m³, having an absorption of 11%. The crushed brick aggregate was sieved according to Iraqi requirement No.45/1984 [15], as shown in Table I.

TABLE I. SIEVE ANALYSIS OF CRUSHED BRICK

Sieve opening size (mm)	**Passing %**	**Iraqi specification No.45/1984**
10	100	85-100
4.75	24	0-25
2.36	4.3	0-5

III. MRPC DESIGN

All mixtures in Table II contained 11% silica fume by weight of cement. The cement content was 720 kg/m³, with microsteel fibers comprising 1% of the concrete volume. Two liters of superplasticizer were used per 100 kg of cementitious material. The water-to-cement ratio was 0.24. For MRPC, the required design strength was 82 MPa. The mix design's MRPC is shown in Table II.

TABLE II. MIX DESIGN OF MRPC

Mixes	**Sand (kg/m³)**	**Crushed concrete aggregate (kg/m³)**
MRPCb0	950	0
MRPCb25	712.5	237.5
MRPCb50	475	475
MRPCb100	0	950

A. Mixing

The procedure of creating concrete mixes involved the following steps:

- The dry components were blended for 6 min.
- The water and superplasticizer were combined separately and then added to the dry ingredients. The mixture was blended for 3 min.
- Fibers were uniformly dispersed by scattering them onto the concrete surface for 2 min with rotation, and then further mixed for another 3 min. The overall duration of the mixing process was 14 min.

B. Curing Samples

The curing process requires a constant water supply to hydrate the cement. Curing conventional concrete externally keeps the mixture warm and damp rather than drying on the surface [19-20]. Following the removal of molds after 24 hours, the samples were submerged in a water bath device for curing at 35°C until the examination day.

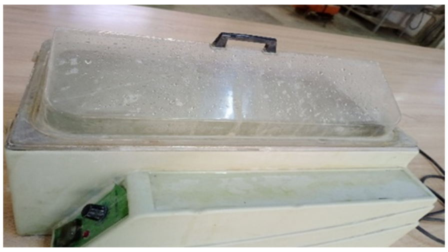

Fig. 1. Curing bath device.

C. Testing

1) Tensile Strength

Two cylinder specimens (100 × 200 mm) were used to measure the average tensile strength of each MRPC combination after 7 and 28 days of curing. The tests followed the ASTM C496-17 guidelines [21].

Fig. 2. Shape of failure in tensile strength.

2) Water Absorption Test

Water absorption was tested following ASTM C642-13 [22] to evaluate the surface permeability of concrete. The specimens were tested immediately after removing the molds.

3) Voids Content Test

The determination procedure of void content followed the guidelines outlined in ASTM C642-13 [22].

IV. RESULTS AND DISCUSSION

A. Tensile Strength

Tensile strength was tested after 7 and 28 days of curing. One sample did not include any crushed brick at all, while the other three samples contained 25, 50, and 100% crushed bricks, respectively. Figure 3 and Table III show the test results. Tensile strength was improved by adding crushed brick up to 25%. However, replacing 50% and 100% of the sand with crushed brick decreased the tensile strength. The low density of crushed brick increased air voids and water absorption, decreasing concrete density and tensile strength.

B. Absorption

Table IV and Figure 4 show the absorption ratios of the different samples of MRPC.

C. Void Content

The formation of voids in concrete is a complex phenomenon influenced by various factors. Incomplete hydration of cement is one of the potential causes of voids in concrete, but it is not the only factor. Other factors, such as improper mixing, inadequate compaction, excessive water content, or poor curing, can also contribute to the formation of voids [23]. The test results of void content are shown in Table V and Figure 5. In all the mixtures tested, the void content increased as the percentage of fine aggregate replaced with crushed bricks increased. This effect is similar to absorption, and both of these measures indicate the durability of the mixtures.

TABLE III. TENSILE STRENGTH TEST RESULTS

Mix	Tensile strength (MPa)	
	7 days	28 days
MRPCb0%	9.26	11.86
MRPCb25%	10.2	12.06
MRPCb50%	7.2	9.89
MRPC100%	6.27	8.87

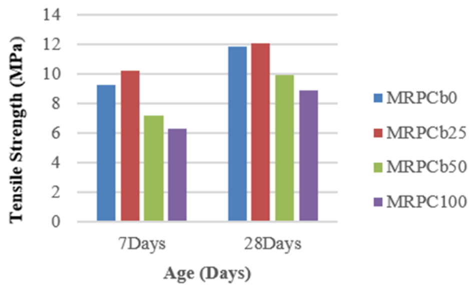

Fig. 3. Tensile strength of MRPC at 7 and 28 days of curing.

TABLE IV. ABSORPTION RATIO OF MRPC

Mix	Absorption %
MRPCb0%	2.5
MRPCb25%	2.84
MRPCb50%	4.03
MRPCb100%	5.4

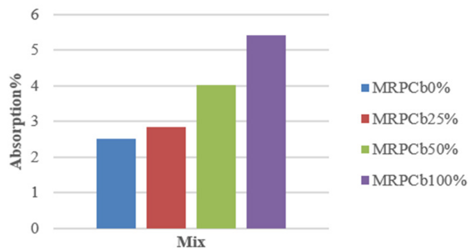

Fig. 4. Absorption test results of MRPC.

TABLE V. VOID CONTENT RESULTS

Mix	Void content %
MRPCb0%	4.83
MRPCb25%	5.6
MRPCb50%	7.83
MRPCb100%	11.4

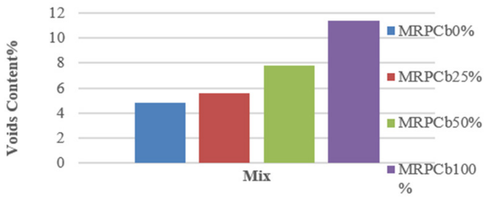

Fig. 5. Void content % of MRPC.

V. CONCLUSIONS

This study produced and examined a novel MRPC using 11% silica fume, 2% superplasticizer, and 1% microsteel fibers as reinforcement, where natural sand was replaced with crushed brick coarse aggregate in varying proportions of 0, 25, 50, and 100%. The samples were exposed to a curing process at a heat of 35°C in a water bath until they reached the testing age. MRPC is appropriate and environmentally friendly because it uses sustainable and waste components. The following findings were reached:

- Replacing 25% of the sand by weight with crushed brick as a coarse aggregate resulted in an improvement in the mechanical strength of the MRPC.
- The tensile strength of the MRPC was reduced when increasing the crushed brick content. The increased surface area and non-uniform shape of recycled crushed brick resulted in a 10.2 and 12.06% increase in the tensile strength of the MRPC containing 25% crushed bricks, compared to conventional RPC, after 7 and 28 days of curing, respectively. When fine sand was replaced with crushed brick aggregate at rates of 50 and 100%, the tensile strength was reduced by 7.2 and 6.27% after 7 days and by 9.89 and 8.87% after 28 days, respectively, related to the reference mixture.
- As the proportion of crushed brick coarse aggregate used to replace fine natural aggregate increased, the absorption rate and void content increased.

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