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Study of torsional response of modified reactive powder concrete beams containing coarse recycled aggregates, and reactive powder concrete beams at different cross-sections

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Abstract

This paper examines the torsional behavior of Beams made from Reactive Powder Concrete (RPC) at different cross-sections. It also examines the torsional behavior of modified reactive powder concrete (MRPC) beams that contain coarse aggregate and recycled coarse aggregate (at different replacements) with a maximum particle size of 9.5mm. The study examines the mechanical properties of modified reactive powder concrete in the fresh and hard states and the effect of replacement.

All modified reactive powder concrete beam mixes are cured in standard curing treatment conditions, and RPC beams are placed under a hot water curing bath with different cross sections (Solid Square, hollow, and deep rectangular). The modified reactive powder concrete group, modified reactive powder concrete beam at 30% replacement of coarse recycled aggregate, gives the highest torsion moment among the three replacements. A solid square beam gives better results than hollow cross-sections or beams with rectangular cross-sections, and the result shows that RPC beams under heat curing conditions provide better structural torsional strength than standard curing conditions.

Keywords: *Modified reactive powder concrete, coarse recycled aggregate, torsion, ultra-high strength concrete, heat curing.*

1. Introduction

Torsional strength is important regarding structural stability, safety, and integrity. So, it directly affects structural members like beams and grids, which may be subject to complex loads. Standard concrete mixes worldwide are known to be weak in terms of tensile strength, which can directly affect the torsional performance, which insists on finding better concrete mixes that have higher strength, such as reactive powder concrete. Reactive powder concrete (RPC) is an emerging, unique composite Cementous material that will enable the mix with high-quality microstructures. It has lesser porosity and extremely high flexural and compressive strengths than high-performance concrete.

Many researchers have studied, investigated, and developed reactive powder mixes. In the year 2016, Sugathan [1] studied reactive powder concrete mixes with high workability as the RPC mixes achieved flowability comparable to self-compacted concrete mixes, examined the effect of micro steel fibers and the impact at various water-to-cement ratios and different cement content, and examined the properties of these mixes and their strengths. In 2023, Mounira et al. [2] examined the effect of using desert sand (dunes) on the hard mechanical properties of reactive powder concrete (RPC). The replacement for river silica sand is at (40%, 50%, and 60%) replacements. They found that adding desert sand (dunes) enhanced the reactive powder concrete mix. The addition of desert sand in the RPC mixture gives higher strength results than those with only river sand. It was found that the partial replacement with desert sand could significantly enhance the strength of the mix. Some researchers modified the reactive powder concrete mixes by adding coarse aggregate. In 2012, Khalil [3] examined the modified reactive powder concrete using coarse aggregate with 12.5 mm and tried it in different mixes until it reached 150 MPa and had good performance. The result shows that increased steel fiber dosage will enhance modified RPC's hard mechanical properties. In 2019, Mohammed, V. et al. [4] investigated the impact of Adding waste bricks on modified reactive powder concrete and saw the effects on the hard properties. The maximum particle size of waste bricks was 12 mm. When examined at different replacements, the results show increased overall mechanical strength properties when replacing brick waste at 25%.

Some researchers studied the effect of a concrete beam cross-section on torsional behavior. In 2015, Waryosh et al. (2015) [5] examined the torsional behavior of reinforced concrete beams with hollow and solid sections. The study also investigated the shape, location, and size of hollow beams done under pure torsion conditions. Results from the experimental investigation show that the magnitude of the torsion stiffness of the solid beam is higher than that of other hollow beams. Also, the twist angle increases in a hollow shape compared to a solid beam. The hollow-shaped beams behaved weaker than solid ones. The hollow core decreases significantly at the first crack and the ultimate torsional load capacity. Also, the failure mode has changed. More cracks have appeared in the hollow sections rather than solid sections. Furthermore, it has been cracking under pure torsion at an angle of around 45°, the circular-shaped hollow core has better crack resistance and ultimate failure torsion loads than that with a rectangular hollow-shaped beam core.

Other researchers studied the effect of beams made from ultra-high strength concrete mixes (UHPC, RPC) under pure torsion. In 2010, Wameedh [6] examined the torsional performance of reactive powder concrete beams under pure torsion conditions. The study took 15 square beams at different percentages of steel fiber (0%, 0.5%, 1%, 1.5%, and 2%) and used different transverse and longitudinal steel bars ratios. The result shows that adding 1% of steel fibers to the reactive powder concrete mix seriously increases the torsional strength. In 2013, Yang. et al [7] investigated the beams made of (UHPC) mix with compressive strengths up to 150 MPa. The beams were under pure torsion conditions. Because the steel fibers bridged the cracks, their addition improved the UHPC beams' post-cracking behavior. The torsional strengths of the beams were enhanced by increasing the volume fraction percentage of steel fibers. As the stirrup ratio rose, so did the torsional strength. The twist angle at the final state increased as the longitudinal steel ratio increased, and the torsion moment at the ultimate state increased slightly. In 2016, Ahmed and Saad [8] investigated seven beams made of composite-modified RPC mix under pure torsion conditions. Two reference beams the first one was without a steel plate, and the second one was a solid with a steel plate, the other five were cast as composite-modified RPC beams with openings. The results show that using steel plates increases the ultimate torque of composite beams. The torsion behavior of the solid beam is better than the ones with an opening, and the circler opening shape is better than the square opening. In 2017, Ali et al [9] studied the torsional behavior of a T-shaped beam made of reactive powder concrete with an open web in shapes like rectangular and circles. They found that the ultimate torques decrease when the opening increases. In 2017 Ali and Sarmad [10] investigated the behavior of I-shaped beams made with reactive powder concrete with an opening under pure torsion. They studied nine RPC I beam shapes with different opening circles and squares, and the crack torques and ultimate torque decreased when the opening increased. Cracks density increased as the opening increased and became non-uniform. Increasing the hollow beam size reduces cracking torque and ultimate torque. In 2022, Abdullah and Aqeel [11] investigated the torsional performance of reinforced reactive powder concrete beams. The parameters are hollow (shape-location-dimension), transverse, and longitudinal reinforcements. The reinforced solid RPC beam's torsional cracking and pre-cracking torsional toughness values were enhanced with high values compared to beams without reinforcement (plain). Increasing the hollow area in the cross-section leads to more reduction in terms of cracking torque and ultimate torque moments. The hollow core beam with a circular shape performs better than the hollow square shape and rectangular hollow shape in the beam's cross-sections, and the hollow section was best located within the center of the cross-section. In 2023, Cao et al [12] studied the torsional behavior of beams with rectangular shapes. The nine (9) beams are made of a (UHPC) mixture. Under pure torsion load, the parameters are longitudinal and traverse steel reinforcement and steel fiber-steel ratio. Beams with longitudinal and stirrups reinforcement had a ductile failure mode; in contrast, beams with only main steel bars reinforcement had a collapse failure. If UHPC beams contain a high steel fiber percentage ratio, their cracking and ultimate torsion moments improve.

After multiple studies on reactive powder concrete (RPC) and modified reactive powder concrete (MRPC) there needed to be more gaps in understanding the beam torsion performance with complex mixes like modified RPC with coarse recycled aggregate. This study aims to investigate the torsional performance of beams made of modified reactive powder concrete (MRPC) focusing on the influence of recycled coarse aggregate replacement levels on torsion behavior. And the torsional performance of standard reactive powder concrete (RPC) beams at different curing conditions, and the impact of cross-sectional shapes (hollow and deep rectangular).

2. Experimental Program

2.1. Materials

The objectives of the experimental work were to investigate the torsional behavior of seven beams made from reactive powder concrete containing recycled aggregate; the experiment was worked and carried out in the Structure Lab of the Department of Civil Engineering, University of Basrah. For the RPC mix, Iraqi Portland cement was used in this experiment. It was stored in a dry place to preserve it from various weather conditions, complying with the requirements of the Iraqi standard specifications (IQ.S. No. 5/1984) [13]. For Aggregate: Three types of aggregates were used in this paper. Based on the limits of Iraqi Specification No.45/1984[14], a sieve analysis test of the aggregate's physical and chemical properties was performed.

Natural fine aggregate produced in mixes as Silica sand with a maximum particle size of 0.6 mm was used in all mixes. Natural Coarse aggregate with a maximum particle size of (9.5 mm) was used, especially for modified reactive powder concrete. Coarse recycled aggregate was made by crushing old concrete cubes with a crushing machine available at the laboratory. The crushed concrete was passed into a (9.5 mm) sieve to use on modified reactive powder the same size as the natural one. Densified silica fume, known commercially as MegaAdd MS (D) from CONMIX Company, was used in this

research. Super-Plasticizer (HRWR) named MasterGlenium 200 is an innovative third–generation super-plasticizer based on polycarboxylic ether (P.C) polymers. It is specially engineered for ready-mix concrete in hot weather conditions.
Steel Fibers with Straight, short brass coated gold-colored with lengths ranging from 12-13mm with a diameter of 0.2 mm manufactured by (Tianjin Hengfeng Xuxiang New Metal Material) complying with (ASTM A820/A820M standards, Type 1) [15]. For reinforcement, all beams in this paper had two types of reinforcement (transverse and longitudinal), which is very important for the torsional behavior of RPC beams. Two local steel bars of different sizes were used: the Ø16mm bars for longitudinal reinforcement and the Ø10mm bars for closed stirrups at 80 mm spacing. All the RPC beams were cast using plywood plates with a thickness of 18mm. All plywood plates were screwed to secure the mixture from leaking.

2.2. Beam identifications

The solid square cross-section beam shape was included (R0SS, MR0SS, MR30/9.5SS, MR60/9.5SS, and R0SH) a 200 mm by 200 mm cross-section and a length of 1200 mm. The hollow section beam (R0HH) consists of a hollow core inside the cross-section with a circular hollow 80 mm diameter. The length is the same as the solid section with 1200 mm, and the cross-section is also 200×200 mm. Rectangular cross-section (R0S1:2H) where the depth is double the width of the beam with the same length of 1200 mm and cross-section dimensions is 125×250 mm.

2.3. Test procedure for mechanical properties

The compressive strength test was conducted according to BS EN 12390-3:2019 [16]. The cube's size that was used was (100×100×100) mm, which was cured under hot water baths for seven days at 65°c by a large basin. Moreover, the Splitting tensile strength test was performed based on (ASTM, C496/C496M – 17) [17]. To determine Splitting tensile strength at cylinder test size (100×200) mm. at the same curing condition and for the flexural strength, 100x100x400 mm concrete prisms were prepared and tested according to the ASTM C78-84 specification [18] to determine the flexural strength of all concrete mixes in this work. The flexural strength of RPC mixes was measured with a Universal Testing Machine at the University of Basrah. Prisms were tested using two loading points with a clear span of 300 mm according to the ASTM specification [18], and all the prisms were cured in the same condition as testing cylinders and cubes. For workability assessment, the flow table test was done to measure the flowability of all the mixtures according to ASTM C1437 [19]. Where the reactive powder concrete mixes at fresh state but in small cones mold and then lifted to measure the diameter of spreading of the fresh mix which is the same principle as the slump flow test in self-compacted concrete [20] but in the flow table test done in smaller cones.

2.4. Mixing

All The beam mixes were mixed in a 350-litre capacity rotary tilting drum mixer. The mixer drum was cleaned and damped before every batch. The mixing steps first by adding all the dry ingredients (materials) in a drum mixer and mixing for more than 3 to 5 minutes by ensuring the drum mixer is at an angle of 15-25° for optimum performance, then adding ¾ of water gradually followed by all superplasticizer liquid and keep mixing for more than 5 minutes then add the remaining water while mixing to get a homogenous mixture. After that, test the workability of the RPC mix, add the steel fiber, and continue mixing for 3-5 min to ensure fiber disruption.

2.5. Test procedure for torsional

The beams were tested using a Universal Testing Machine at the University of Basrah with a maximum capacity of over 200 tons. Beams were placed on the testing machine with free-supported rollers at both ends and a clear span of 800 mm. The test setup of pure torsion reactive powder concrete beam was attached to the two steel I-sections reinforced by a tapered plate acting as lever arms, which provide an eccentricity load of 450 mm relative to the longitudinal axis of the beam, crucial to induce the desired torsional load.
The reaction arms were fixed with threaded rods to the frame of the testing machine. A steel box girder, fabricated from two-channel sections, was laid diagonally across the top of the lever arms and supported by hinged end supports. The mid-span of this box section girder was then loaded and this load applied the torsional force to the beam. Spherical seats were used at the end supports of the beam specimens to avoid any axial constraint. Such seats allow longitudinal movement and free rotation of the beams so that the applied torque can be the major force acting on the specimens. The Construction Laboratories and Research Center, Basrah University, College of Engineering, provided all the equipment and accessories for manufacturing and testing the beams under pure torsion as shown in Figure (1) and Figure (2). All mixed design components were mentioned in Tables (1).

Fig. 1: Reactive powder beam under pure torsion

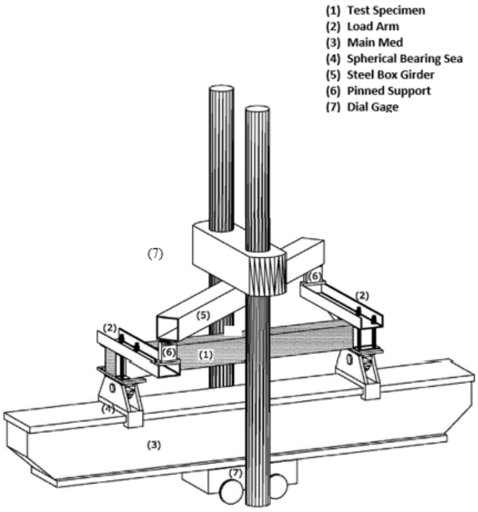

Fig. 2: Torsion beam test diagram

Table 1: Material portions modified reactive powder concrete

Mix RPC	Cement Content kg/m^3	Fine aggregate Kg/m^3 (600µm)	Coarse aggregate Kg/m^3 (9.5mm)	Coarse recycled aggregate Kg/m^3 (9.5mm)	Silica fume kg/m^3	HRWR liter/m^3	Total Water liter/m^3	Steel fiber kg/m^3
R0SS	900	1100	---------	---------	225	55	242	117
MR0SS	900	600	500	---------	225	55	247.5	117
MR30/9.5SS	900	600	350	150	225	55	252	117
MR60/9.5SS	900	600	150	350	225	55	256.5	117
R0SH	900	1100	--------	---------	225	55	242	117
R0HH								
R0S1:2H								

3. Experimental and result discussion

3.1. Workability and density

The effect of coarse recycled aggregate on workability in modified reactive concrete powder mix. A flow table test at the university lab was used to assess the workability (flow ability) of modified reactive powder concrete (RPC) with and without coarse recycled aggregate [21].

The desired flow characteristics of modified RPC depend on the specific application. The flow ability is often sufficient for Structural elements, thin-walled structures, and precast elements. However, a high flow ability is necessary to facilitate placement in confined spaces, achieve accurate dimensions, and avoid defects. To increase the flow to be suitable for these applications, the mix strength usually reduces. A gradual reduction in flow ability was observed in modified RPC mixes where coarse recycled aggregate was added in replacement to natural coarse aggregate at levels of 30% and 60%. However, the impact on workability could have been more substantial, even with increased replacement levels. Additionally, the modified reactive powder concrete mix gradually decreased density (Kg/m3) as the coarse recycled aggregate replacement level increased. A high dosage of superplasticizer (HRWR) in the mix maintained workability despite including coarse recycled aggregates, which reduced the effect on workability to a minimum. However, it remains within an acceptable range for fresh properties.

3.2. Mechanical properties of modified reactive powder concrete

3.2.1. Compressive strength

The compressive strengths of all test specimens were determined using (100×100×100) mm cubes treated using heat treatment, with hot water bath curing type at 65°C for 7 days. The compressive strengths of various modified RPC mixes are used to investigate the influence of coarse recycled concrete aggregate (at a maximum size of 9.5 mm) at different replacement levels (0%, 30%, and 60%). The control mix of standard reactive powder concrete (R0SS) mix gave (79.14 MPa) while the reference mix of modified reactive powder concrete (MR0SS) reached 76.7 MPa, while at 30% replacement (MR30/9.5SS) gave 84.33 MPa, and at 60% replacement (MR60/9.5SS) yielded to 86.7 MPa. The (MR30/9.5SS) mix showed a 9% increase in compressive strength and the compressive strength of the (MR60/9.5SS) mix showed a 13% increase in strength. When compared to the reference modified reactive powder concrete mix at 0% replacement (MR0SS) as shown in Table (2). the reason for the increase in compressive strength recycled aggregate exhibit an internal curing effect. Water initially absorbed within pores becomes available later to hydrate cementitious materials. The second reason was the Un-hydrated cement particles in recycled materials participate in pozzolanic reactions, resulting in higher strength. The third one which was the most important one was the roughness and more irregular and angular shapes of recycled aggregate particles reinforce the recycled concrete's transition zone, leading to a stronger bond with the cement paste [22-26].

3.2.2. Tensile strength

The standard RPC mix (R0SS) gives 10.9 MPa while the control modified reactive concrete powder 0% replacement (MR0SS) reaches 11.16 MPa, and for replacements at (30%, 60%) with coarse recycled aggregate gives a higher result than the reference modified RPC mix the result reach to (11.458 MPa, and 11.8 MPa) respectively, as shown in Table (2). Improvement in tensile strength can be attributed to the improved aggregate interlock between the cementitious paste and all sizes and types of aggregate with and with improved steel fiber distribution in the mix at a variety of sizes and shapes of components in the modified RPC mix plus the three reasons mentioned in paragraph of compressive strength of modified reactive powder concrete [21-24, 26].

3.2.3. Flexural strength of modified reactive powder concrete

The control reactive powder concrete (R0SS) gives 17.58 MPa. The reference mix of modified reactive powder concrete at 0% replacement (MR0SS) showed a flexural strength of about 16.5 MPa and flexural strengths for replacement at levels 30% and 60% reached up to 26.5 MPa and 20.5 MPa, respectively; however, as mentioned the effect of reactive powder concrete mix strongly affected the aggregate size, especially in flexural strength when it increased in replacements by 60% with a coarse recycled aggregate at maximum size (9.5 mm) leads to drop in flexural strength as shown in Table (2) unlike the compressive and tensile strength of modified-RPC, the optimum result of flexural strength settled at 30 % replacement then the flexural strength drop at the 60% replacement but still higher than the modified reactive powder concrete at 0% replacement the enhancing in flexural was due to same reasons of enhancement of tensile strength and compressive strength of modified RPC [22-26].

Table 2: Fresh and hard mechanical properties of mixes

Beam mix design	Density (kg/m^3)	Flow (mm)	compressive strength (MPa)	split tensile strength (MPa)	flexural strength (MPa)
R0SS	2315.74	235	79.14	10.9	17.58
MR0SS	2338	230	76.7	11.16	16.5
MR30/9.5SS	2321	225	84.33	11.4588	26.5
MR60/9.5SS	2311	220	86.71	11.8	20.5
R0SH	2319	235	81.1	10.5	16.5
R0HH					
R0S1:2H					

3.3. Torsion behavior results

The experimental results of beams tested under pure torsion revealed distinct behaviors based on curing methods and mix compositions. For beams under normal curing with a solid square shape, the first cracking torque moments as in Table (3) were as follows: R0SS, MR0SS, MR30/9.5SS, and MR60/9.5SS exhibited values of 27 kN·m, 27 kN·m, 31.5 kN·m, and 27 kN·m, respectively. The second group of normal RPC Beams without recycled aggregate under hot water bath curing, with different cross sections (solid square, hollow section, solid rectangular 1:2) names with R0SH, R0HH, and R0S1:2H, showed first crack torsion moments of 36 kN·m, 31.5 kN·m, and 29.3 kN·m, respectively. At the ultimate torsion stage, the standard curing beams (R0SS, MR0SS, MR30/9.5SS, and MR60/9.5SS) recorded torsion moments of 58.5 kN·m, 58.5 kN·m, 63 kN·m, and 60.75 kN·m respectively. While the hot water bath cured beams (R0SH, R0HH, and R0S1:2H) achieved ultimate torsion values of 69.75 kN·m, 63 kN·m, and 51.15 kN·m, respectively.

Table 3: torsional strengths of the beams testing results

Beam mix		Beam shape	Cracking Torque moment (kN.m)	The angle of twist at the first crack (Radians/m)	Ultimate torque moment (kN.m)	The angle of twist at ultimate torsion (Radians/m)
R0SS	Standard curing	Solid square	27	0.0045	58.5	0.008
MR0SS		Solid square	27	0.0045	58.5	0.0105
MR30/9.5SS		Solid square	31.5	0.005	63	0.0116
MR60/9.5SS		Solid square	27	0.007	60.75	0.0128
R0SH	Heat curing	Solid square	36	0.004	69.75	0.0075
R0HH		Square with hollow	31.5	0.006	63	0.0108
R0S1:2H		Solid deep rectangular	29.3	0.008	51.15	0.011

3.3.1. Effect of replacement of recycled aggregate of MRPC beams on torsional behavior

For group beams made from modified reactive powder concrete (MR0SS, MR30/9.5SS, MR60/9.5SS) with a maximum coarse aggregate particle size of 9.5 mm, the first crack torsional moment the control of modified reactive powder concrete (MR0SS) gives (27 kN.m.), and the other beam (MR30/9.5SS, MR60/9.5SS) gives results (31.5 kN.m., 27 kN.m.), respectively, as shown in the Figure (3). So, the MR0SS as the control for the first crack twist crack angle gives (0.0045) radians and (MR30/9.5SS, and MR60/9.5SS) give (0.005, 0.007) radians, respectively, as shown in Figure (4). The ultimate torsional moment of the control modified reactive powder concrete beam (MR0SS) is 58.5 kN.m, and for beams that had replacements (MR30/9.5SS, MR60/9.5SS), results are (63 kN.m, 60.75 kN.m). Modified reactive powder concrete has a negligible impact and a slight increase compared to the beam with 0% replacement; the increasing percentage was (7.7% and 3.8%), respectively, at (30% and 60%) replacements. For the twist angle at ultimate torsion, the MR0SS gives (0.0105) radians, and for these beams (MR30/9.5SS, MR60/9.5SS) gives (0.0116, 0.0128) radians. There was an enhancement at 30% replacement, the reason for that was to improve practical packing and mixture matrix optimization with recycled aggregate, and the reasons for the enhancements of hard mechanical properties of modified-RPC were mentioned before. However, at 60% replacement, the torsion strength at both states dropped due to a high portion of recycled aggregate, which contains high porosity in the concrete mixture and made it easy for micro cracks formation. The figures below represent the effects of replacement percentage as shown in Figure (3), which shows the effect of the replacement percentage of coarse recycled aggregate for modified-RPC on torsion moment at both state cracking torque and ultimate torque and as shown in Figure (4) which the effect of the replacement percentage for modified RPC on the angle of twist while the Figure (5) Torsion behavior of modified reactive powder concrete mix beams. The result showed that a partial 30% replacement provides an optimum result in terms of torsional moment at both state [26].

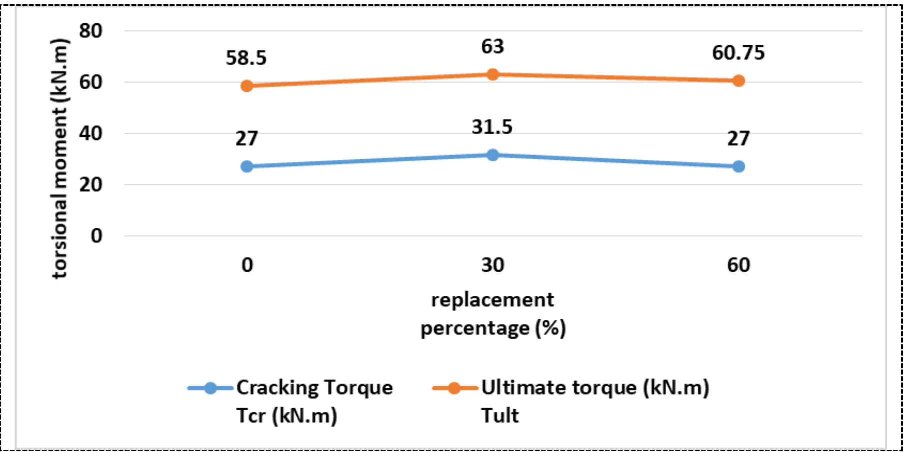

Fig. 3: Effect of replacement percentage of coarse recycled aggregate for modified RPC on torsion moment

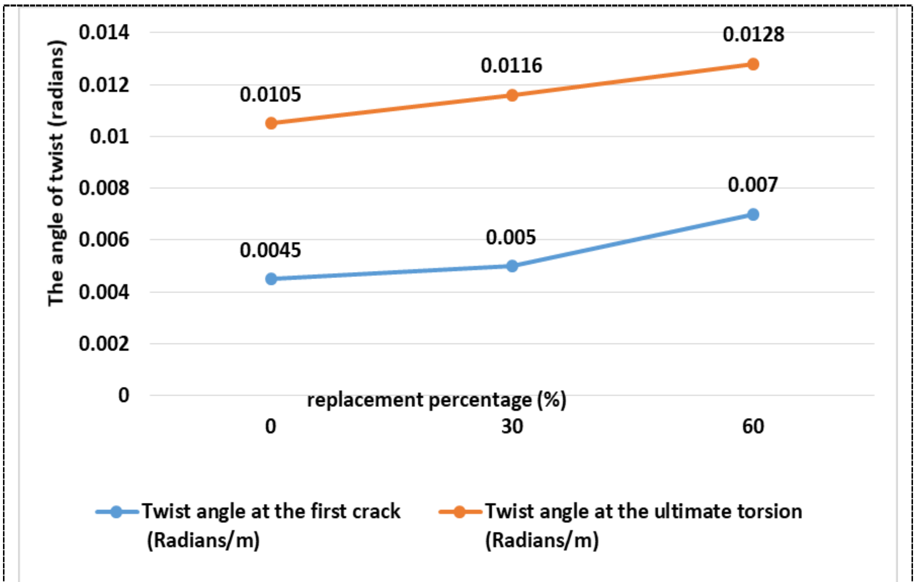

Fig. 4: Effect of replacement percentage of coarse recycled aggregate for modified RPC on the angle of twist

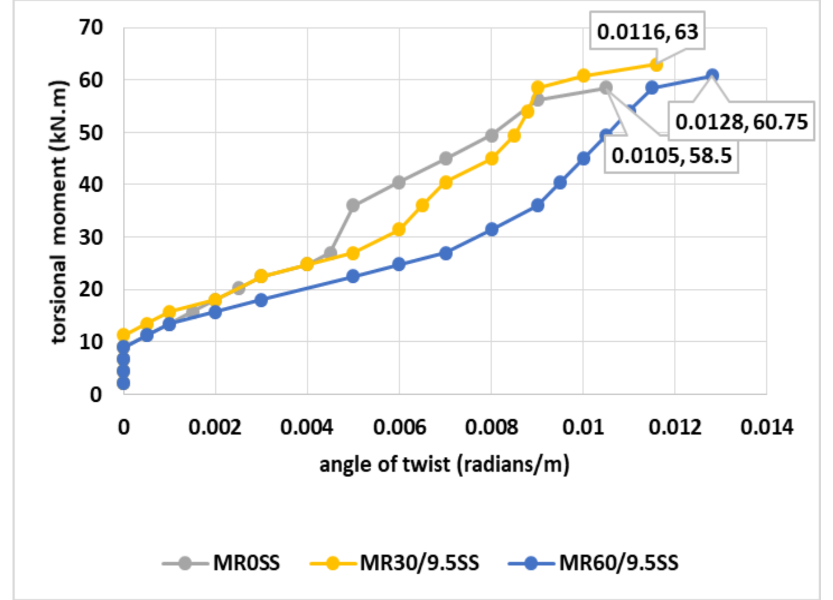

Fig. 5: Torsion behavior of the effect of coarse recycled aggregate replacement on modified reactive powder concrete

3.3.2. Effect of heat curing on torsional behavior

The Effect of curing type on torsion behavior when comparing beam (R0SS) treated under normal curing with (R0SH) beam has the same control mix. However, the beam treated under hot curing using a big water basin filled with hot water at 65° c for 7 days gave better results than the one cured under normal conditions as the first crack torsional moment for (R0SS) is 27 kN.m while the (R0SH) is 36 kN.m.as shown in Figure (6). The enhancement of (R0SH) is about 33.33% over (R0SS) in the first crack moment. The beam (R0SS) gives an angle of twist at (first crack), giving (0.0045) radian, and for (R0SH) gives (0.004) radian, and for ultimate torsional moment, the (R0SS) gives 58.5 kN.m and the (R0SH) beam 69.75 kN.m the increase is 19.23% in ultimate moment torsion for beams cured with heat curing. However, the angle of twist at ultimate (R0SS) gives (0.008) radian, and for (R0SH) gives (0.0075) radian as shown in Figure (7). The reason for the increase in torsional strength is the higher formation of calcium silicate hydrate (C-S-H) in hot water bath treatment through the pozzolanic reaction of micro-silica and calcium hydroxide; more consumption of portlandite leads to a higher amount of hydration formulation.[27][28]. Figure (8) represents a torsion behavior at different curing types.

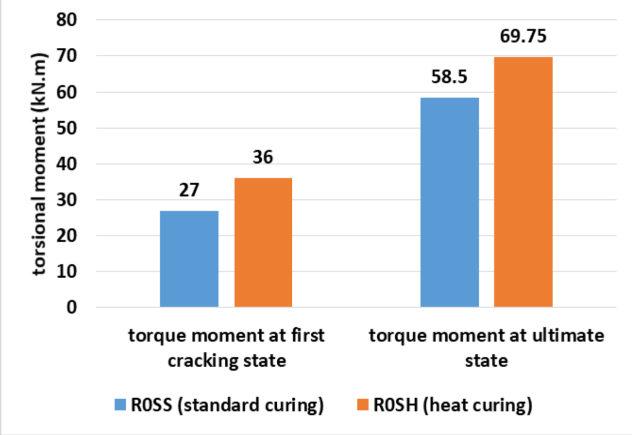

Fig. 6: Comparison of torsion moment at different curing types

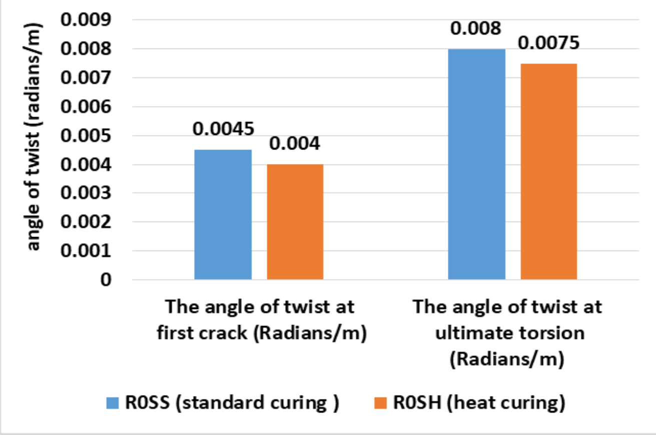

Fig. 7: Comparison of an angle of twist at different curing regimes

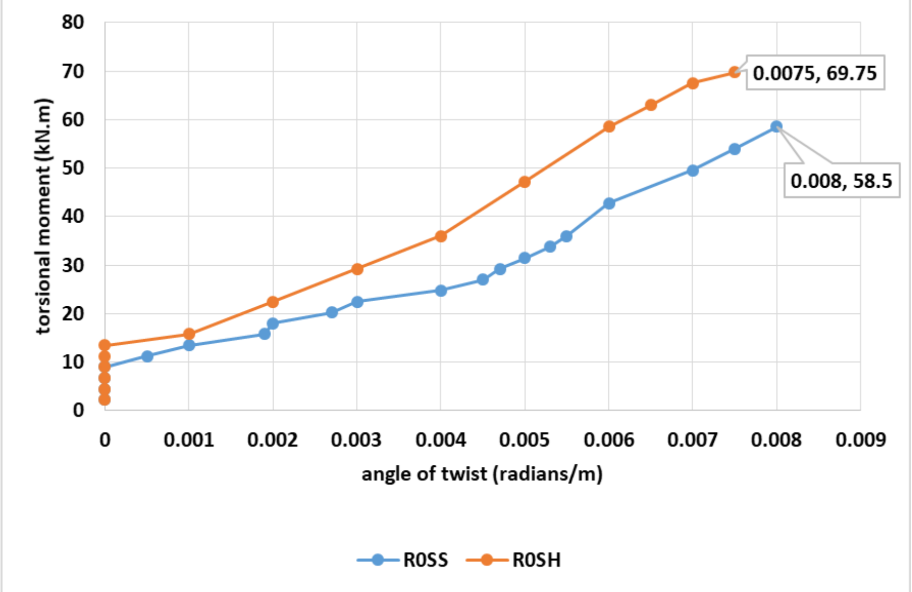

Fig. 8: Torsion behavior for the effect of heat curing

3.3.3. Effect of cross-sectional shape on torsional capacity

Three beams were cured in the hot water bath at 65 c for 7 days with the same reactive powder concrete mix without recycled aggregate solid cross-section and hollow and rectangular beams with deep double the width size (1:2) which beams named (R0SH, R0HH, R0S1:2H) respectively. Take the (R0SH) beam as a control because it is treated by hot water curing, and the R0SS beam is treated by normal curing, but both had the same mixture without recycled aggregate concrete. The first crack torsion moment of ((R0SH) gives 36 kN.m, but for hollow and rectangular cross-sections (R0HH, R0S1:2H) gives (31.5 kN.m, 29.7 kN.m) respectively, and for an angle of twist at the first crack stage, the hot control gives (0.004) radian. For the hollow beam, (R0HH) gives 0.006 radians, and for the (R0S1:2H) beam gives (0.008) radians. For an ultimate torsional moment, a square solid beam (R0SH) gives 69.75 kN.m, and for (R0HH, R0S1:2H) it gives (63 kN.m, 51.15 kN.m) respectively. As shown in the Figures (9). For an angle of twist at (the ultimate torsional state) (the R0SH) beam gives (0.0075 radians) and for (R0HH, R0S1:2H) beams (0.0108 radians, 0.01 radians) respectively, as shown in the Figures (10). In contrast, the Figure (11) represents the torsion behavior at different cross-sections. The result proves that the square solid section gives better results in terms of torsion moment and angle of twist than rectangular sections (R0S1:2H) and hollow section beams (R0HH). The reduction is about 10%, and for beam (R0S1:2H), the reduction is 27% compared to (R0SH). The causes of that reduction when comparing the hollow and solid beams to the reduced polar moment of inertia plus the material that is removed from the section of the beam that resists the torsion forces and the solid beam (R0SH) has more stiffness than the hollow beam [11], that gives good predict why has higher result in torsion behavior (torsion moment, angle of twist) and comparing the rectangular deep beam to the solid square beam there is a decrease in torsion moment cause of the increase in depth of cross-section to double leading to a decrease in the torque moment and an increase in the twist angle the reduction in torsion is about 27% of a square beam.

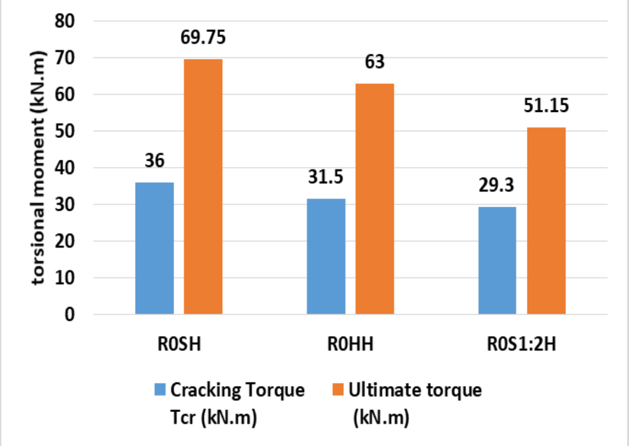

Fig. 9: Effect of cross-section on torsion moment

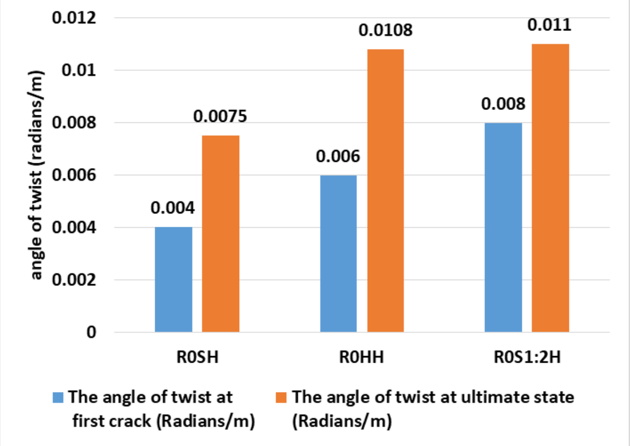

Fig. 10: Effect of cross-section on the angle of twist

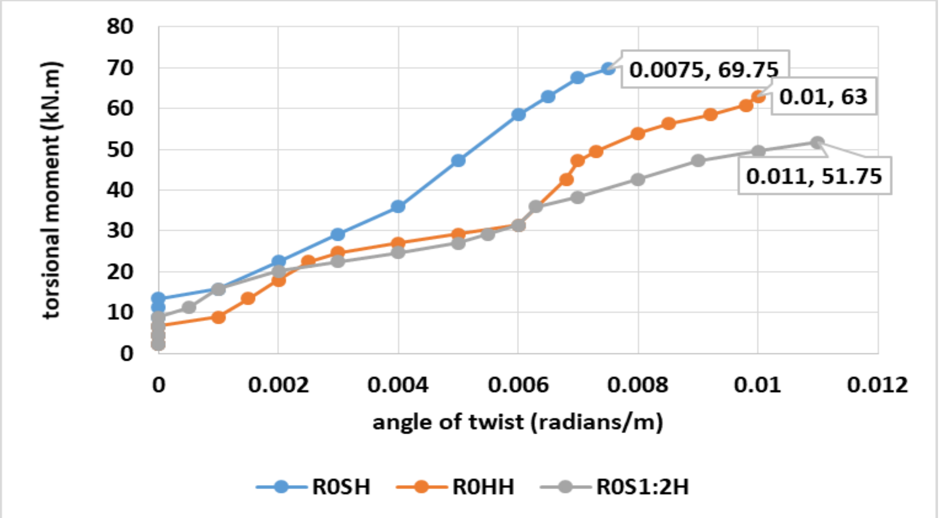

Fig. 11: Effect of cross-section on torsion behavior

3.3.4. Crack patterns and failure modes

Several diagonal cracks were shown in all beams with an acceptable percentage of steel fibers, thus indicating the redistribution of stresses beyond the first cracking stage. The microsteel fibers became more effective after the crack appeared, and the fibers continued to resist the principal stresses until the total pullout of microfibers happened simultaneously. However, for the group of modified reactive powder concrete (MR0SS, MR30/9.5SS, MR60/9.5SS), Modified RPC that mention is a reactive powder concrete mix containing a coarse aggregate of 9.5 mm. The effect of adding coarse aggregate and coarse recycled aggregate gives obvious and clear failure cracks when compared to standard control reactive powder concrete (R0SS) when coarse aggregate (natural and recycled) is 45% of the total aggregate, and that leads to more transparent and wider cracks at the same torsion crack pattern along the beam length. For groups that are cured by heat, which is (under a hot water bath in a basin) (R0SH, R0S1:2H, R0HH), with the same control reactive powder concrete mix, the effect of hollow at the beam (R0HH) leads to more clarity and wider compared to solid square beam (R0SH) because of the missing material of reactive powder concrete that creates a larger crack through the hollow beam. There is no significant difference between a solid beam (R0SH) and a deep (R0S1:2H) one, but the deep beam leads to more angle and less torsion moment at both states first crack and ultimate torsion.

4. Conclusion

1. In the modified reactive powder concrete (MRPC) mix, when adding coarse recycled aggregate, the flow diameter decreases when increasing the replacement percentages.
2. Density decreases when the replacement percentage of coarse recycled aggregates is increased in modified reactive powder concrete (MRPC).
3. Compressive and tensile strength gradually improves when the replacement of coarse recycled aggregate is increased. The optimum result is at 60% replacement, but for flexural strength, the optimum result is at 30% replacement in modified reactive powder concrete.
4. The torsional moment for modified reactive powder concrete beams gives the optimum result at a 30% replacement beam (MR30/9.5SS) for a group of modified RPC beams at the first cracking and ultimate torsion moment states.
5. For modified reactive powder concrete beams, the twist angle is higher than that of standard reactive powder concrete.
6. At the same curing regime, the control-modified reactive powder concrete beam gives a higher angle of twist than the control reactive powder concrete beam.
7. A reactive powder concrete beam (R0SH) treated under heat curing (under a hot water bath) gives a higher torsion moment than an RPC beam treated under normal curing (R0SS).
8. In terms of the effect of cross-section on torsion behavior, the solid square beam shows better torsion behavior (torsion moment and angle of twist) than the deep rectangle beam (R0S1:2H) and the hollow section beam (R0HH).
9. Using coarse recycled aggregate made from old concrete can enhance the strength of modified-reactive powder concrete as a partial replacement at the same time can reduce the pollution of the environment and improve the sustainability of natural resources.

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