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An Experimental Torsional Behavior of Normal Grade RCC Beams Containing Encased WWM Wrapping Patterns and the Future Outlook with Nanotechnology

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Abstract

A reinforced concrete structure may be subjected to four basic types of actions: bending, axial load, shear, and torsion. All these actions can, for the first time, be analyzed and designed by a single united theory based on the three fundamental principles of mechanics of materials: namely, the stress equilibrium condition, the strain compatibility condition, and the constitutive laws of concrete and steel. Because the compatibility condition is considered, this theory can be used to reliably predict the strength of a structure, as well as its load-deformation behavior. Pure torsion appears when exterior forces acting perpendicular to the reinforced axis produce only moments of torsion acting along the bar axis. Circulatory torsion induces shear stresses on all four sides and would be well resisted by closed form reinforcement. Therefore, strengthening either in the form of retrofitting techniques or in the form of closed encasement has the objective that completely enclosing the cross section will be more effective. An experimental study is concentrated on addressing the torsional capacity and twist of reinforced concrete beams with and without encased welded wire mesh utilized to enhance torsional capacities with their various concerned parameters. Test results were discussed based influence of welded wire mesh (WWM) on cracking, ultimate torsion capacity as well as pre-cracking and post-cracking stiffness with their failure modes. However, in the review of nanotechnology, the inherent properties, viz., homogeneity, compatibility, and bonding strength, of the composite materials in concrete composites are developed up to the micro-size level. But when the study progressed to a nano-sized level, it could be possible to enhance the chemical and ultimately physical properties of concrete composite materials.

Keywords

Strength and ductility parameters, Encased welded wire mesh, Nanomaterial, Nanotechnology

Introduction

The kinds of structural elements that are subject to a torsional moment are curved structural members, space frame members, eccentrically loaded beams, curved box girders in bridges, spandrel beams in buildings, and spiral staircases and torsion must be taken into consideration when designing these members. When a structural member is subjected to torsion, spiral-shaped cracks develop, and the member fails. Concrete is the most often used manmade building material in the world. It is durable and can withstand significant compression but not much tension consequently, strengthening is necessary to achieve a sufficient level of durability and serviceability. It has become necessary to develop effective practises to restore the load-bearing capacity of structural members damaged by wear and overloads. The use of fiber reinforced polymers (FRP) [1-8] are the best method for torsional strengthening among the several strengthening and upgrading processes that are accessible. In the most recent decades, research has been done on the use of epoxy-bonded material and laminates to strengthen reinforced concrete beams. Due to structural member construction constraints and de-bonding of FRP fabrics and laminates, the advantages of this FRP bonding process are reduced. There is use of ferro-cement jacketing [9-12] to prevent FRP retrofitting limitations such as fire hazard, need for additional adhesive with their specialised skilful tedious works, and chances of de-bonding effect, etc. However, the strengthening methods are beneficial for increasing the strength of existing structures. But using encased WWM [13-28] in the concrete body is one of the methods to increase the strength of the proposed structures by reducing the occurrence of brittle failure in plain and reinforced cement concrete (RCC) elements. Since WWM shows good composite behavior in concrete elements and has good tensile strength, it can be employed as an encasement to increase strength using its ductility effect.

Concrete jacketing by using polymer fiber materials and ferro-cement concept

It is a composite material that can be utilized to strengthen existing structural elements. It can be defined as the application of various materials, such as reinforced concrete jacketing, steel jacketing, FRP jacketing, and ferrocement jacketing, etc., to strengthen reinforced concrete structural components. Despite having a history dating back more than a century to 1905, this material has begun to be efficiently used for concrete structures in the last two to three decades. The fibers are often made of glass, carbon, and aramid. Likewise, fibers derived from wood, papers, and asbestos-containing sheets have been employed. But for each of the abovementioned fiber sheets to properly adhere to the concrete body at the surface, a high-quality adhesive was necessary. FRP [1-8] materials are significantly more tensile resistant than concrete, but they also have a considerably lower Young's modulus. They again have inadequate compressive stability [3], requiring their application in composite materials with concrete regarding the use of different types of materials, such as GFRP, CFRP [4], aramid [7], etc., FRP can be differentiated. The concept of ferro-cement has been brought up since the middle of the 19th century. Ferro translates as having iron. Thus, ferro-cement is created using wire mesh with small diameters and a cement to sand ratio of 1:3. Ferro-cement is used in the making of sewage manhole covers, boats, and planks for shelving in low-cost housing developments, among other things. However, ferro-cement is also used for structural components in full, U-shaped jacketing with full wrapping, or in strips. In civil engineering, all the aforementioned concrete jacketing can be applied depending on the availability of raw materials, precise needs, cost, appropriateness, etc.

WWM/ welded wire mesh fabric (WWMF)/weld mesh

It is built using a grid of previously produced parallel longitudinal wires that are evenly spaced apart. Machines generate precise, dimension-controlled meshes. The various varieties of WWM can be categorized based on their design, intended application, and other characteristics. High-strength, cold-drawn or cold-rolled wire that is forged at all intersections, joined in square or rectangular grids of equally spaced wires, and satisfies ASTM A185 and A497 requirements or other specified specifications is used to make weld mesh. To create the reinforcement bonds of welded wire to concrete, the junctions of each WWM play an important role in the form of mechanical anchorage. Due to the mechanical properties of the wire mesh described earlier, high-strength, evenly distributed wires are successfully used as reinforcement for concrete projects. Smaller diameter and closely spaced wires [24], resulting in more uniformly distributed stress in the concrete structures, improve the crack control mechanism. The presence of deformed welded wire material considerably improves the properties of concrete cracking. The wires meet the requirements of IS: 432-Pt. II/1982 due to their characteristic strength and ultimate tensile strength, which are 480 N/mm^2 and 570 N/mm^2, respectively. The wires used to create material typically have a diameter between 2 and 12 mm. WWM is manufactured with long and cross wire spacing ranging from 25 mm to 400 mm, per IS 1566-1982. Each firmly welded junction can withstand shear stresses of up to 210 N/mm^2 with the coordination of the longitudinal wire, according to IS: 4948/1974. To maintain best practises in the design and execution of structures, a variety of standard specifications/codes and manuals [14-18] are available.

Nanotechnology in construction

According to their size and appearance, nanomaterials can be categorized. Nanoparticles, graphite sheets, and quantum dots are examples of three-dimensional nanomaterials; thin films, layers, and surfaces are considered one-dimensional; nanowires and nanotubes are considered two-dimensional. Nanotechnology has the potential to be used to design and build processes in a wide range of fields since the products it produces have many unique properties. Furthermore, these attributes possess the capacity to significantly tackle current construction challenges and can influence the design and specifications of the construction process. Four main areas of development [29, 30] for the use of nanomaterials in construction include structural concrete, real-time structural monitoring, coatings and paints, and thermal insulation. Concrete as a macro-material [31] is strongly impacted by the properties of nanoparticles. Nano-silica [32] (SiO_2) can be added to cement-based products to increase durability and prevent water penetration by reducing the degradation of the calcium-silicate-hydrate (C-S-H) reaction caused by calcium leaching in water.

Significance of present study

Due to the inherent characteristics of the torsion-induced-shear flow stresses, it is well known that closed systems of reinforcement might effectively withstand torsion phenomena. The major objective of this study is to evaluate the experimental behavior of test specimens of RCC beams with encased WWM to control specimens of plain and RCC beams. The strength of plain and RCC beam specimens is increased by using the four-sided wrapping patterns. A total of 18 beam specimens were used in the experiment, six of which served as control specimens. The remaining twelve beam specimens contained specimens of four-sided encased WWM, both in the form of continuous type wrap and specimens wrapped in four-sided strip wrapping. Experimental characteristics like cracking torque, ultimate toque, pre-cracking stiffness, post-cracking stiffness, and crack propagation behavior has been examined. Furthermore, in the enhancement of concrete's properties, the optimum addition of appropriate nanomaterials to the concrete can improve its mechanical properties, such as tensile strength, compressive strength, flexural strength, durability, etc.

Literature review and future outlook with nanotechnology

Considering the significance of the study, it is essential to employ composite materials in the concrete body to enhance the torsion capacity, improve the brittle failure mechanism, provide uniformity in crack propagation, etc. The additional composite wrapping material, available in sheet form, can be used to enhance the concrete mechanical properties. The literature provides a variety of retrofitting materials [1-12] with their specific procedures for strengthening existing components. However, using encased WWM wrapping patterns in the concrete body [13-28] is also probable to enhance the ductility effect and strengthen the mechanical property of the new proposed concrete component. In addition to improving the composite material's strength properties at the nanoscale, the reviews [29-35] offered considerable information.

Polymer and ferro-cement concrete jacketing

Retrofitting methods can be divided into two types after considering the literature review. (1) Retrofitting using jackets made of polymer fibers [1-8] and (2) Retrofitting using steel mesh [9-12]. The first group includes a variety of materials such as carbon-reinforced polymers, fiber-reinforced plastics and polymers, glass-reinforced fibers polymers [4], aramid fibers [7], etc. Ferro-cement wire meshes can be found in a range of diameters. Researchers from both groups have done considerable research, and some of them offered theoretical analyses in the form of FEM models [2]. Another researcher has created a soft truss model [3] that is based on the Hsu model with changes to the material parameters. Equations for equilibrium and compatibility based on elastic theory were produced by the remaining researchers. Fiber polymer jacketing materials demonstrated their good effects in cracking arresting mechanism, ductility, and contribution of torque carrying capacity. However, several specimens de-bond [2, 3] before undergoing maximum loads. It has been revealed that ferro-cement jacketing [9-12] can be used in place of polymer fibers jacketing to avoid the drawbacks of such materials. The use of a single layer of wire mesh [11], however, cannot achieve ferro-cement jacketing. Several wire mesh layers can be necessary to significantly increase the torque capacity of the beam specimen. Also, the ratio of the percentage increase in torque carrying capacity to the number of wire mesh layers is not exactly correlated.

Influence on shear capacity with flexural behavior by utilization of WWM in RCC beams

Many authors [13, 19-28] have done well-informed studies on the use of WWM in concrete beams. Some of them use cold-drawn steel wire mesh [20], while others [23] use deformed main and cross wires that are the same size or different diameters, etc. Due to its high tensile strength, welded wire mesh obviously desires on good anchoring for its shear capacity. Thus, the 90° bend in Mansur et al. [19] examination revealed an improvement in the anchorage over 45° and 135°, respectively. Additionally, research [21] demonstrated that the use of wire mesh has a substantial impact on the crack pattern of reinforced concrete beams by prolonging the formation of cracks, increasing the number of cracks, and decreasing the width of cracks, among other effects. Again, some studies [20] found that the decreased ductility of the cold-drawn wires and the stress concentration resulting from tack-welds had no effect on the performance of WWM as shear reinforcement. To increase the beam's ductility and overall shear strength, an additional horizontal wire must be used at the middle of the WWM. Based on his [20] own experimentation, one of the authors [22] found that shear capacity increased to some extent for beams reinforced with wire mesh for shear and for beams reinforced with wire mesh and stirrups combined, in comparison to beams reinforced with stirrups alone. As a result, after considering the research, it appears that welded wire mesh contributes significantly to the reinforced concrete beam's capacity to carry shear loads. Additionally, WWMF encased and served as a crack arrester on the reinforced beam's surface, which causes micro-crack behavior in the concrete. Previously noted, the use of WWM as shear reinforcement can also demonstrate the flexural behavior [24-28] of RCC beams in a beneficial way. The studies on that topic confirmed that, in addition to conventional stirrups, a WWMF system can be employed as a shear reinforcement alternative. With excellent outcomes [24], WWMF shear reinforcement demonstrates aspects such as deflection behaviour, initial cracking load and its position, kind of failure, load vs deflection behavior, ductility effect, and stiffness. One researcher [26] found that when shear stirrups are totally replaced with welded mesh, the behavior of the beam in distributing load over the span is superior to that of the beam with traditional stirrups. After looking at this review, it can conclude that the WWM performs as well when it comes to the flexural behavior of RCC beams that include WWM as shear reinforcement.

A future outlook to enhance the concrete and steel constitives property by using nanomaterials and nanotechnology

As mentioned above concrete is one type of macro-materials [31] are mostly impacted by the properties of nanoparticles nanomaterial which is the "glue" that keeps concrete together [33]. Concrete is a mixture of molecular assemblages, surfaces (aggregates, fibers), and chemical bonds that interact through intra-phase diffusion, local chemical reactions, and intermolecular forces when observed from the bottom up. This scale is characterized by the following properties: surface functional groups; bond length, strength (energy), and density; and molecular structure. This scale is the source of the structure of the interphase borders as well as the crystalline and amorphous phases. The macroscale influences of working loads and the surrounding environment are determined by the characteristics and processes at the nanoscale, whereas the microscale interactions between phases and particles are determined by these qualities and processes. The engineering properties and performance [34] of the bulk material are eventually impacted by processes occurring on at the nanoscale. The study of concrete at the nanoscale [35] led to several advances, one of which is the use of nano-silica to improve particle packing in concrete, resulting to a densification of the micro- and nano-structure and therefore improved mechanical properties; the addition of nano-silica to cement-based materials can also control the degradation of the fundamental C-S-H reaction of concrete caused by calcium leaching in water as well as block water penetration and therefore lead to improvements in durability; in relation to improved particle packing, high energy milling of ordinary Portland cement (OPC) clinker and standard sand produces a greater particle size diminution in comparison to conventional OPC and, as a result, the refined material is also 3 to 6 times higher. Titanium dioxide is a different kind of nanoparticle that can be added to concrete to enhance its characteristics. Titanium dioxide, a white pigment, is an efficient reflective coating substance. Self-compacting concrete does not require vibration to level up and achieve consolidation, according to Balaguru [29]. This is a sustainability concern because it signifies a major advancement in the reduction of energy required to construct concrete structures. Furthermore, Self-compacting concrete can save labor expenditures by up to 50% because it can pour up to 80% faster and requires less formwork wear and tear. The usage of polycarboxylates, a substance comparable to plastic created utilizing nanotechnology, allows the material to behave like a thick fluid. Today, it is rather usual to wrap concrete with fiber to strengthen existing concrete structural parts. Incorporating a fiber sheet (matrix) which includes hardeners and nano-silica particles is an advancement in the method. In strengthening applications, the matrices provide a solid connection between the concrete's surface and the fiber reinforcement, while the nanoparticles fill up minute surface cracks. Steel is an essential part of construction materials. Its properties [31], including as strength, corrosion resistance, and weldability, are essential for the building and design. It is possible to produce new low-carbon, high-performance steel. It was possible to generate a unique steel with enhanced corrosion resistance and weldability by incorporating copper nanoparticles from the steel grain boundaries. In construction projects that are subject to fatigue issues, this reduces the quantity of stress risers and fatigue cracking, strengthening safety, minimizing the requirement for observation, and optimizing the use of materials. However, this research has the scope to study the overall torsional behavior of normal-grade RCC beams containing encased WWM wrapping patterns. So, it is necessary to focus on said thing, but in view of the further outlook regarding the use of well-developed structural properties of concrete composite material, there will be a need to see the involvement of nanomaterials with respect to nanotechnology in the concrete composite materials.

Experimentation

In the experimental program, the three main and total six possible states of tested specimens are considered in the control as well as beams containing WWM wrapping under torsion. The three main possible states are plain beam specimens, beams that contained only longitudinal conventional reinforcement, and specimens that were fully reinforced, i.e., having longitudinal as well as transverse reinforcement. Again, for specimens in the fully reinforced category, there are four possible cases considered: nominal top and bottom longitudinal reinforcement with stirrups, flexural under reinforced beams, flexural balanced reinforced beams, and flexural partially over reinforced beams. The objective of the present experimental study is to evaluate the effectiveness of the use of encased WWM patterns in plain and RCC-tested specimens under states of torsion. There are two types of wrapping patterns considered: WWM four-sided wrapping strips, just like stirrups, and continuous fully or four-sided wrapped WWM. So, this research work aimed to enhance the torsion capacity of conventional concrete specimens with the utilization of encased WWM patterns that can be used in the proposed new construction of the various structures. In figure 1 to figure 3 and table 1, specifics such as the geometry and

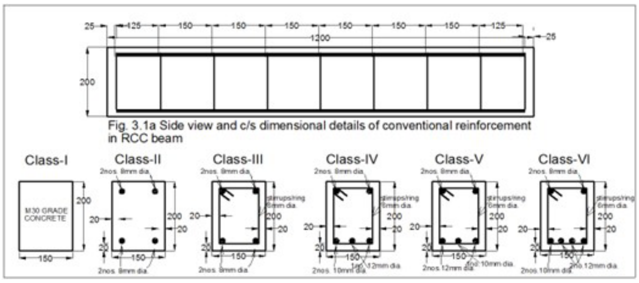

Figure 1: Side view and cross-section dimensional details of conventional reinforcement in RCC beam.

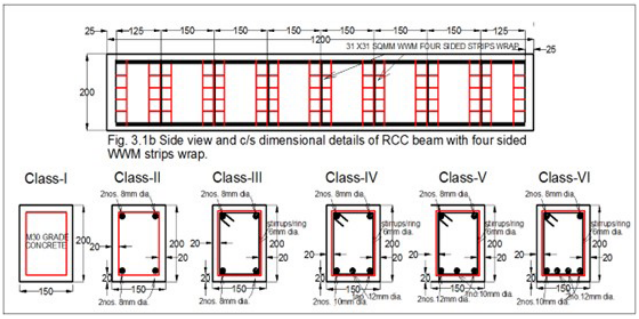

Figure 2: Side view and cross-section dimensional details of RCC beam with four sided WWM strips wrap.

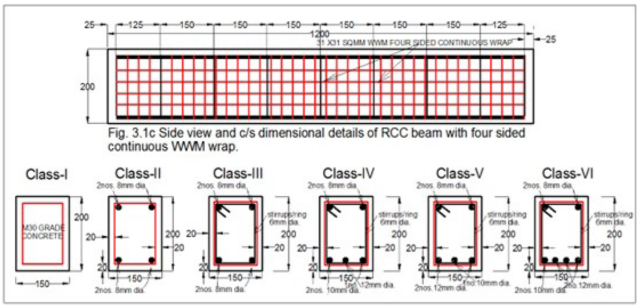

Figure 3: Side view and cross-section dimensional details of RCC beam with four sided continuous WWM wrap.

Table 1: Details of control test beam specimens and specimens contained encased WWM wrapping.

Class	Beam titles	Grade of concrete (N/mm^2)	Overall, of size of test specimens (mm)	Yield strength of longitudinal, stirrups and WWM steel (N/mm^2)			Encased four-sided shaped WWM patterns
				Longitudinal	Stirrup	WWM	
Class I	R/Pc	30	150 x 200 x 1200	-	-	-	-
	R/Pc/Fsw	30	150 x 200 x 1200	-	-	405	Four-sided strip
	R/Pc/Fcw	30	150 x 200 x 1200	-	-	405	Four-sided continuous wrap
Class II	R/Lc	30	150 x 200 x 1200	500	-	-	-
	R/Lc/Fsw	30	150 x 200 x 1200	500	-	405	Four-sided strip
	R-Lc/Fcw	30	150 x 200 x 1200	500	-	405	Four-sided continuous wrap
Class III	R/Rc/Nr	30	150 x 200 x 1200	500	415	-	-
	R/Rc/Nr/Fsw	30	150 x 200 x 1200	500	415	405	Four-sided strip
	R/Rc/Nr/Fcw	30	150 x 200 x 1200	500	415	405	Four-sided continuous wrap
Class IV	R/Rc/Ur	30	150 x 200 x 1200	500	415	-	-
	R/Rc/Ur/Fsw	30	150 x 200 x 1200	500	415	405	Four-sided strip
	R/Rc/Ur/Fcw	30	150 x 200 x 1200	500	415	405	Four-sided continuous wrap
Class V	R/Rc/Br	30	150 x 200 x 1200	500	415	-	-
	R/Rc/Br/Fsw	30	150 x 200 x 1200	500	415	405	Four-sided strip
	R/Rc/Br/Fcw	30	150 x 200 x 1200	500	415	405	Four-sided continuous wrap
Class VI	R/Rc/Por	30	150 x 200 x 1200	500	415	-	-
	R/Rc/Por/Fsw	30	150 x 200 x 1200	500	415	405	Four-sided strip
	R/Rc/Por/Fcw	30	150 x 200 x 1200	500	415	405	Four-sided continuous wrap

arrangement of the reinforcements of the beam specimens are presented.

Designation of tested beams

Based on practical convenience, the test specimen size for each prototype is 150 mm x 200 mm x 1200 mm overall. To avoid local failure, the effective length is kept at 1000 mm with a 100 mm grip on either side. Six of the eighteen numbers consist of control beam specimens, while the remaining 12 numbers use a usual form with welded wire mesh patterns wrapped around them. The following abbreviations laid in table 2 are used in their designations to indicate the characteristics of the specimen from the name.

Table 2: Abbreviations used in beam designations.

S.No.	Abbreviations
1	R: Rectangular beam
2	Lr: Beam with only longitudinal reinforcement
3	Rc: RCC beams
4	Nr: Nominal longitudinal reinforcement with stirrups
5	Ur: Under reinforced longitudinal reinforcement with stirrups
6	Br: Balanced reinforced longitudinal reinforcement with stirrups
7	Por: Partially over reinforced longitudinal reinforcement with stirrups
8	Fsw: Beam containing encased four sided/fully wrapped strips
9	Fcw: Beam containing encased continuous four sided/fully wrapped strips

To better understand let explain one of them, like 'R-Rc-Ur means RCC under reinforced rectangular beam with spacing transverse reinforcement. Similarly, 'R-Rc-Br-Fsw means RCC balanced reinforced rectangular beam including stirrups containing encased four sided/fully wrapped strips. In this experiment, the OPC 43 cement grade conforming to IS-8112(2013) was utilized. The use of well-graded coarse aggregates with a maximum size of 20 mm along with natural Zone II River sand that complies with IS 383-2016. The proportions of cement, sand, and crushed aggregates in the concrete mixture were 1:2.30:3.85, respectively. The w/c ratio was maintained 0.42. To improve the workability without increasing w/c ratio, the "Conplast SP430" titled super plasticizer was employed. Cementitious material admixture was added to concrete grade M30 at a mass 1% dose in accordance with IS 10262:2019. According to IS:1566 (2007), a practical dimension of 31 mm x 31 mm with a 2.8 mm diameter and an average ultimate strength of 480 N/mm^2 and average yield strength 405 N/mm^2 of WWM was chosen from the market. The steel grades Fe 500 and Fe 415 used for the longitudinal and transverse reinforcement of various diameters specified in table 1 have been taken into consideration.

Test setup

To conduct a pure torsion test in the universal testing machine, the experimental setup has been carried out as shown in figure 4. The action-reaction phenomenon of load was performed between the middle and lower jaws of the universal testing machine. The middle jaw acted in the form of a central load cell and provided eccentric loads other than bending planes by using a diagonally placed spreader beam made of steel channel section. The pair of two numbers of steel arms placed on opposite sides of the longitudinal axis of the specimen was subjected to eccentric loads by the spreader steel beam, forming the pure torsion test as shown in figure 4. The effective length of the testing setup is kept at 1000 mm in the form of a simple support with free rotation to ease measuring the angle of twist per meter. However, to avoid local failure during testing of specimens, the overall beam length was cast at 1200 mm with 100 mm grips at the ends of the specimens. The load was applied gradually and recorded by a computerized load cell. A pair of dial gauges with least count of 0.01 mm set 750 mm apart from the longitudinal axis of a beam specimen beneath loading steel arms were employed to determine the average angle of twist per unit length.

Figure 4: Torsion test setup.

Results and Discussion

In the experimental program, there are a total of six possible states in the form of class I to VI that are considered to observe the overall behavior of tested specimens wrapped with encased WWM over their control beam specimens. As above mentioned, the tested beam specimens are categorized into plain beam specimens, beams that contained only longitudinal conventional reinforcement, and specimens that were fully reinforced in four types of varieties. To check the effectiveness of newly composed beams, two types of WWM wrapping patterns are introduced. To observe the improved behaviour, parameters like cracking and ultimate torques, pre-cracking and post-cracking stiffness, and lastly, observed failure torques just before collapse of tested specimens were considered. Figure 5 and figure 6 are allotted the torque-twist behavior curves from class I to VI. Table 3 showed an average increase in all mentioned parameters with the introduction of WWM wrapping patterns over control beam specimens in their respective classes.

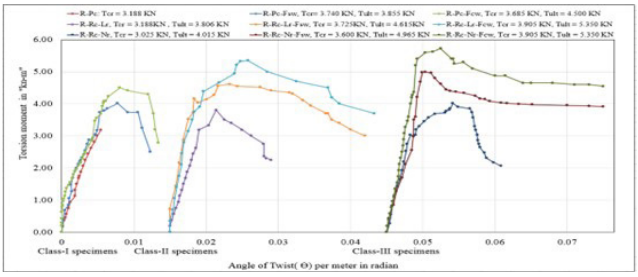

Figure 5: Torque-Twist curves of class I to III beam specimens with WWM wrapping patterns over their control beam specimens.

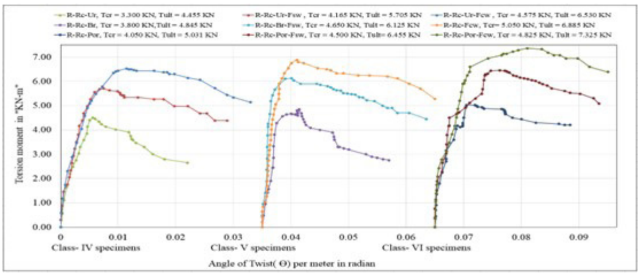

Figure 6: Torque-Twist curves of class IV to VI beam specimens with WWM wrapping patterns over their control beam specimens.

Torque-twist behavioral curves including their parameters

Tested specimens of all classes had torque twist curves that nearly followed a linear pattern up to their cracking torques and then increased in profile until their maximal torques. In class I plain beam did not exhibit increasing post-cracking response and failed abruptly i.e., their maximum torque would become the torque moment at cracking: $T_{max} = T_{cr}$. For the other specimens are made up of WWM wrapped patterns showed their performance with cracking and ultimate torques distinctly. Due to four side wrapping patterns of WWM, it showed ductile behaviour also in class I group of beams. Class II, single type longitudinal reinforcement in control beams showed somewhat ductility after cracking but not enhancing post-cracking behavior up its failure torque. However, in that class beams having WWM wrapping showed good in cracking, ultimate, failure torque and their stiffness with their control beam specimens. The beams from class III to IV were tested and observed in monotonically increasing torque moment up to their ultimate torque strength and subsequently in increasing twist until the total failure of the specimen. Except R-Rc-Nr the beams of above-mentioned classes showed the improved twist capacity of the test apparatus. Such improvement causes because of utilization of fully conventional reinforcement with and without WWM wraps. However, with the introduction of WWM wrapped patterns which showed the better cracked resisting capacity in the form of cracking, ultimate torque and failure torque just before collapse over control bema specimens. Also, effectiveness of utilization of four sided

Table 3: Observation of tested RCC beam specimens containing four sided /fully wrapping patterns over control beam specimens.

S. No.	Name of specimen	Cracking torque (T_{cr}) (KN-m)	Percentage increase in T_{cr}	Ultimate torque (T_{ult}) (KN-m)	Percentage increase in T_{ult}	Angle of twist/m at T_{cr}	Stiffness at T_{cr}	Percentage increase in stiffness at T_{cr}	Angle of twist/m at T_{ult}	Stiffness at T_{ult}	Percentage increase in stiffness at T_{ult}	Failure torque in post-cracking zone ($T_{failure}$) (KN-m)	Percentage increase in $T_{failure}$
1	R-Pc	3.188	-	3.188	-	0.0108	292.82	-	0.0108	271.88	-	0	-
2	R-Lc	3.188	-	3.806	-	0.0094	336.71	-	0.014	219.16	-	2.5	-
3	R-Rc-Nr	3.025	-	4.015	-	0.0072	415.52	-	0.0183	371.25	-	2.78	-
4	R-Rc-Ur	3.3	-	4.455	-	0.0068	219.16	-	0.012	378.52	-	2.25	-
5	R-Rc-Br	3.8	-	4.845	-	0.0082	371.25	-	0.0128	460.15	-	3	-
6	R-Rc-Por	4.05	-	5.031	-	0.0073	378.52	-	0.0109	271.88	-	3.7	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	R-Pc-Fsw	3.74	17.33	3.855	20.94	0.0126	280.84	-4.09	0.0126	140.14	-48.45	2.5	-
8	R-Lc- Fsw	3.725	16.86	4.615	21.25	0.0092	404.53	20.14	0.0309	471.48	115.13	3	20
9	R-Rc-Nr- Fsw	3.6	19.01	4.965	23.66	0.0064	547.85	31.85	0.0096	355.92	-4.13	3.91	40.65
10	R-Rc-Ur- Fsw	4.165	26.21	5.705	28.06	0.008	471.48	115.13	0.0149	824.93	117.94	4.39	95.02
11	R-Rc-Br- Fsw	4.65	22.37	6.125	26.42	0.0025	867.69	133.72	0.0066	274.12	-40.43	4.45	48.33
12	R-Rc-Por- Fsw	4.5	11.11	6.455	28.31	0.005	274.12	-27.58	0.0225	140.14	-48.45	5.08	37.3
Avg % increase in parameters			18.82%	-	24.77%	-	-	44.86%	-	-	28.01%	-	48.26%
13	R-Pc-Fcw	3.685	15.61	4.5	41.18	0.0124	287.29	-1.88	-	910.87	549.97	2.78	-
14	R-Lc- Fcw	3.905	22.51	5.35	40.56	0.0028	1285.71	281.85	-	487.07	3.31	3.7	48
15	R-Rc-Nr- Fcw	3.595	18.84	5.725	42.59	0.0048	910.87	119.21	-	367.19	3.17	4.55	63.67
16	R-Rc-Ur- Fcw	4.575	38.64	6.53	46.58	0.0093	487.07	122.25	-	504.77	-38.81	5.02	123.3
17	R-Rc-Br- Fcw	5.05	32.9	6.885	42.11	0.009	367.19	-1.09	-	292.97	6.87	5.28	75.93
18	R-Rc-Por- Fcw	4.825	19.14	7.325	45.6	0.008	504.77	33.35	-	910.87	549.97	6.39	72.59
Avg % increase in parameters			24.60%	-	43.10%	-	-	92.28%	-	-	104.90%	-	76.70%

WWM wrapping in the form of the rate of increasing crack resisting capacity were observed in class IV to VI groups than remaining one.

Influenced on strength parameters with the utilization of encased WWM wrapping patterns

For control beam specimens, the cracking torques range from 74% to 84%, for beam specimens with encased WWM wrapping strips, from 69% to 80%, and for specimens with a continuous wrapped WWM pattern, from 63% to 82%. The torsional resistance in comparison to control beam specimens, the beam specimens with WWM wrapping patterns demonstrated better load resistance in the form of a substantial torque with increasing rotation. With the addition of enclosed WWM strips and continuous four-sided warping patterns over control beam specimens, there is an average increase in cracking torque of 18.82% and 24.60%, as well as an average rise in ultimate torque of 24.77% and 43.10%. Despite the introduction of WWM wrapping patterns, they do not rapidly impact the tested specimens' linear pre-cracking zone. However, there is an enhancement of the average pre-cracking as well as average post-cracking stiffness by 44.86% and 28.01% with the utilization of WWM encased strip patterns and by 92.28% and 104.90% with the use of WWM continuous fully wrapped patterns over control beams. The failure torques in the post-cracking zone range from 62% to 73% in control beam specimens, from 62% to 87% in beams wrapped with WWM strips, and from 64% to 79% in beams wrapped continuously with WWM. In comparison to control beam specimens, there is also an improvement in the load at failure in the post-cracking zone of WWM wrapping beams. The tested beams, with the exception of plain concrete control specimens, exhibit post-cracking zones as a result of the conventional and WWM reinforcements yielding in. Due to the use of encased continuous fully wrapping patterns and enclosed WWM strip, respectively, there is an average improvement in failure torques of 48.26% and 76.70% in relation to measured rotation capabilities. In comparison to plain and RCC control beam specimens, the strengthened beams in the form of encased WWM patterns such as four-sided strips and continuous fully wrapped beams exhibited overall improved torsional resistance performance.

Observation of cracks and cracking pattern

Crack propagations of control and strengthened beams by encased WWM wrapping patterns subjected to pure torsion are shown in figure 7. Crack propagation in all tested specimens has started at the middle of one of the vertical faces in the form of inclined diagonal tension cracks. The crack generation and propagation are in spiral patterns. The

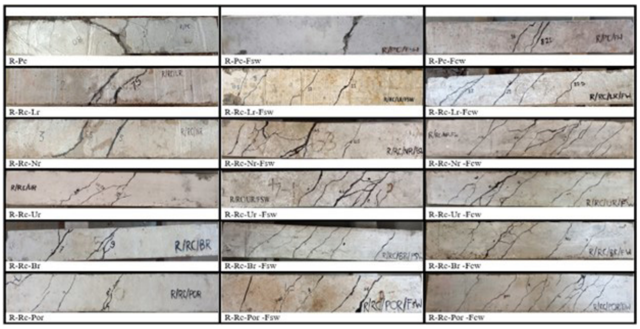

Figure 7: Cracks propagations of tested control beams specimens and specimens contained encased WWM wrapping patterns.

cracks gradually widened as load increased, with the two beam segments rotating relative to one another about the centroid longitudinal axis of the tested beams. The control specimen of plain concrete is cracked into two pieces after reaching cracking torque. Due to WWM-encased wrapping with sufficient clear cover, WWM acted as a good composite component material, so chances of debonding of WWM wrapping were not present in the testing programme. The diagonal cracks were observed on both vertical faces (depth faces) of beam specimens, and inclined cracks on both shorter sides, i.e., on the width of beam specimens, tried to join the cracks on the longer vertical faces. R-Pc-Fsw means plain beam contained WWM only strips behave like plain beams but do not collapse into two distinct pieces. In control beam specimens, the micro-crack formations increase with increasing conventional reinforcement in the concrete beams. However, the uniformity and percentage of enhancement of the micro-crack formations and propagations have been well observed in the specimens containing WWM wrapping over the control beams in all specified classes. Single major cracks with 2-3 to 4-5 numbers of minor cracks with small range lengths were observed in control beams, and on the other hand, 3-4 major cracks with 'N' numbers of minor cracks with small to long range lengths were observed in specimens having WWM wrapping patterns. The beams of all classes possess the same cracking patterns. The major cracks make a near 45° cracking angle with a horizontal axis on two opposite vertical faces. The minor crack propagation on two opposite vertical faces makes cracking angles vary from 32° to 67° with the horizontal axis.

Conclusions

The aim of this research is to evaluate the effectiveness of using encased WWM as additional transverse reinforcement in normal-grade concrete beams and the future outlook for enhancing the concrete composite material with nanotechnology. Based on the test results presented herein, the following concluding remarks are drawn:

- The WWM demonstrated ductile behavior in all classes of beams because of its four side wrapping patterns. Although class I group did not enhance post-cracking behavior up to its failure torque, class II, single type longitudinal reinforcement in control beams showed small ductility after cracking.
- In class III to VI, i.e., fully reinforced beams having WWM wrapping showed good cracking, ultimate, failure torque, and stiffness with their control beam specimens.
- The beam specimens with WWM wrapping patterns showed better load resistance in the form of a significant torque with increasing rotation when compared to the control beam specimens.
- WWM served as a good composite component material since it was fully encased with sufficient clear concrete cover and had no chance of debonding.
- The specimens with WWM wrapping over the control beams in all specified classes have well-observed uniformity and percentage enhancement of the micro-crack forms and propagations.

Expected outcomes by using nanotechnology in concrete and steel:

- It is anticipated to increase soon, and nanoparticles will become increasingly significant as a foundation for the industry's design, development, and manufacturing of building materials.
- The mechanical properties of concrete, such as its tensile strength, compressive strength, flexural strength, durability, etc., can be enhanced by the optimal inclusion of the right nanomaterial.
- It could be possible to extend the normal grade concrete up to either self-compacted concrete or high performance of concrete.
- Utilization of nanomaterials in the form of nanotechnology could enhance the bonding properties of conventional steel, WWM steel, and concrete to become a newly improved concrete composite material.

Acknowledgments

None.

Conflict of Interest

None.

References

1. Zojaji AR, Kabir MZ. 2012. Analytical approach for predicting full torsional behavior of reinforced concrete beams strengthened with FRP materials. *Scientia Iran* 19(1): 51-63. https://doi.org/10.1016/j.scient.2011.12.004
2. Chalioris CE. 2007. Analytical model for the torsional behaviour of reinforced concrete beams retrofitted with FRP materials. *Eng Struct* 29(12): 3263-3276. https://doi.org/10.1016/j.engstruct.2007.09.009
3. Chalioris CE. 2008. Torsional strengthening of rectangular and flanged beams using carbon fibre-reinforced-polymers – experimental study. *Constr Build Mater* 22(1): 21-29. https://doi.org/10.1016/j.conbuildmat.2006.09.003
4. Tibhe SB, Rathi VR. 2016. Comparative experimental study on torsional behavior of RC beam using CFRP and GFRP fabric wrapping. *Procedia Technol* 24: 140-147. https://doi.org/10.1016/j.protcy.2016.05.020
5. Matthys S, Fib Working Group. 2019. Externally Applied FRP Reinforcement for Concrete Structures. International Federation for Structural Concrete.

6. Deifalla A, Ghobarah A. 2010. Full torsional behavior of RC beams wrapped with FRP: analytical model. *J Compos Constr* 14(3): 289-300. https://doi.org/10.1061/(ASCE)CC.1943-5614.0000085
7. Kandekar SB, Talikoti RS. 2019. Torsional behaviour of reinforced concrete beam wrapped with aramid fiber. *J King Saud Univ Eng Sci* 31(4): 340-344. https://doi.org/10.1016/j.jksues.2018.02.001
8. Deifalla A, Ghobarah A. 2010. Strengthening RC T-beams subjected to combined torsion and shear using FRP fabrics: experimental study. *J Compos Constr* 14(3): 301-311. https://doi.org/10.1061/(ASCE)CC.1943-5614.0000091
9. Behera GC, Dhal MR. 2016. Prediction of twist at ultimate torque of ferrocement U wrapped RCC beams. *Int J Eng Appl Sci* 3(6): 257651.
10. Behera GC, Gunneswar RT, Rao CB. 2013. Torsional strength of ferrocement “U” wrapped normal strength beams with only transverse reinforcement. *Procedia Eng* 54: 752-763. https://doi.org/10.1016/j.proeng.2013.03.069
11. Behera GC, Rao TG, Rao CB. 2016. Torsional behaviour of reinforced concrete beams with ferrocement U-jacketing-experimental study. *Case Stud Constr Mater* 4: 15-31. https://doi.org/10.1016/j.cscm.2015.10.003
12. Behera GC. 2016. Ultimate torque calculation of RCC beams with ferrocement “U” wraps: experimental and analytical study. *Int J Innov Sci Eng Technol* 3(5).
13. Mansur MA, Leong TW, Lee SL, Tink RK. 1984. Welded wire fabric as stirrups in beams. In Proceedings of the International Conference on Tall Buildings, The Institution of Engineers, Singapore.
14. BS 4449: Steel for the Reinforcement of Concrete. [https://standardsdevelopment.bsigroup.com/projects/9022-06656#/section] [Accessed on March 21, 2024]
15. AS 1303-1991. Steel Reinforcing Wire for Concrete. [https://store.standards.org.au/product/as-1303-1991] [Accessed on March 21, 2024]
16. IS:1566. Specification for hard-drawn steel wire fabric for concrete reinforcement.
17. IS: 4948. Welded steel wire fabric for general use - Specification.
18. Wire Reinforcement Institute. [www.wirereinforcementinstitute.org] [Accessed on March 21, 2024]
19. Mansur MA, Lee CK, Lee SL. 1986. Anchorage of welded wire fabric used as shear reinforcement in beams. *Mag Concr Res* 38(134): 36-46. https://doi.org/10.1680/macr.1986.38.134.36
20. Xuan X, Rizkalia S, Maruyama K. 1988. Effectiveness of welded wire fabric as shear reinforcement in pre-tensioned prestressed concrete T beams. *ACI Struct J* 85-S41: 429-436.
21. Sridhar MP, Senthilnathan KP, Priyaadharashini M. 2016. Shear behaviour of RC composite beams. *Int J Chem Tech Res* 9(3): 342-349.
22. Elavarasi D, Sumathi A. 2019. Behaviour of reinforced concrete beams with wire mesh as shear reinforcement. *Int J Innov Technol Expl Eng* 1-6.
23. Cui M, Nie X, Fan J, Li S, Liufu J, et al. 2019. Experimental study on the shear performance of RC beams reinforced with welded reinforcement grids. *Constr Build Mater* 203: 377-391. https://doi.org/10.1016/j.conbuildmat.2019.01.064
24. Radhakrishnan B. 2016. Numerical analysis of structural behavior of welded wire reinforcement in reinforced concrete beams. University of Alaska. (Doctoral Disseration)
25. Soundhirarajan K, Sathieshkumar MT, Karthikeyan S. 2018. Flexural behaviour of RC beam with welded mesh as shear reinforcement. *Int Res J Eng Technol* 5(05): 4281-4284.
26. Nithin KR, Kumar NS. 2016. Flexural behaviour of self-compacting concrete beam using welded wire mesh as shear reinforcement. *Int J Sci Res* 1-4.
27. Ajin M, Gokulram H. Flexural behaviour of RC beam with welded mess as shear reinforcement. *Int J Eng Sci Res Technol* 4(3): 242-246.
28. Alexander D, Ramakrishnan S. 2016. Design of RC beam with and without welded mesh as shear reinforcement in flexural and shear behaviour. *Int J Adv Eng Res Technol* 4(6): 1-4.
29. Balaguru PN, Dhir RK, Newlands MD, Csetenyi LJ. 2005. Nanotechnology and Concrete: Background, Opportunities and Challenges. In Dhir RK, Newlands MD, Csetenyi LJ (eds) Applications of Nanotechnology in Concrete Design. ICE Publishing.
30. Khandve P. 2014. Nanotechnology for building material. *Int J Basic Appl Res* 4: 146-151.
31. Kuda A, Yadav M. 2022. Opportunities and challenges of using nanomaterials and nanotechnology in architecture: an overview. *Mater Today Proc* 65: 2102-2111. https://doi.org/10.1016/j.matpr.2022.07.052
32. Kargozar S, Mozafari M. 2018. Nanotechnology and nanomedicine: start small, think big. *Mater Today Proc* 5(7): 15492-1500. https://doi.org/10.1016/j.matpr.2018.04.155
33. Chong KP, Garboczi EJ. 2002. Smart and designer structural material systems. *Prog Struct Eng Mater* 4(4): 417-430. https://doi.org/10.1002/pse.134
34. Sanchez F, Sobolev K. 2010. Nanotechnology in concrete – a review. *Constr Build Mater* 24(11): 2060-2071. https://doi.org/10.1016/j.conbuildmat.2010.03.014
35. Zhu W, Bartos PJ, Porro A. 2004. Application of nanotechnology in construction: summary of a state-of-the-art report. *Mater Struct* 37: 649-658. https://doi.org/10.1007/BF02483294