Torsional Behavior of Reinforced Concrete Hollow Core Beams

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Abstract:

The aim of this work is to study the behavior of reinforced concrete hollow beams under torsion load. The experimental work includes investigation of eight reinforced concrete rectangular beams of dimension (length 2000 x height 240 x width170 mm) with the same reinforcing ratios, tested under pure torsion. Two beam sections are provided: solid and hollow section with varied shape and percentage (circular 18%, rectangular 18% & 27% of total cross section area of beam). Variables considered in the test program include; effect of hollow shape & area and concrete type (normal and high strength). Test results were discussed based on torque - twist behavior, beam elongations, behavior and influence of hollow core on cracking torque, ultimate torque and failure modes. Test results indicate that the ultimate torque for hollow sections is about 89% for Circular (hollow ratio 18%) and 83% and 60% for rectangular, of hollow ratio 18% & 27% respectively of solid beam. The high strength concrete type in solid beam gave an increase in the cracking and ultimate torque by about 100% and 66% respectively and an increase in the ultimate torque was observed by about (63%, 60%, 62%) for circular (18% ratio), rectangular (18% ratio) and rectangular (27% ratio) respectively.

Keywords: Torsion, Reinforced Concrete, Rectangular Beams, Hollow Core.

سلوك اللي للأعتاب الخرسانية المسلحة المجوفة

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الخلاصة

ان الهدف من هذا البحث هو لدراسة تصرف الأعتاب الخرسانية المسلحة المجوفة المقطع تحت حمل اللي . البرنامج العملي يشمل تحري وسلوك ثماني أعتاب خرسانيه مسلحه مستطيله وبأبعاد (طول 2000 ملم وارتفاع 240 ملم وعرض 170 ملم) بنفس نسبه حديد التسليح، فحصت تحت حمل اللي . الأعتاب كانت بمقطعين صلدة ومجوفة (بأشكال ومساحات مختلفة الدائرية 18% و مستطيلة 18 % و 27 % نسبه إلى مساحة المقطع العرضي للعتبة). شملت

المتغيرات التي أخذت بنظر الاعتبار في بـرنامج الفحص : مساحة وشكل التجويف ونوع الخرسانة (اعتيادية آو عاليه المقاومة). اعتمدت النتائج على مناقشة سلوك عزم الدوران – الالتواء واستطالة العتبات وسلوك وتأثير اللب المجوف على تشقق عزم الدوران وعزم الدوران الأقصى وأنماط الفشل . بينت نتائج الفحص أن عزم ال دوران الأقصى للمقاطع المجوفة كانت تقريبا 89% للمقطع الدائري(وبنسبه تجويف 18%) و 83% و 60 % للمقاطع ألمستطيله (وبنسبه تجويف 18% و 27 %) على التوالي من المقطع الصلد . ان الخرسانة عاليه المقاومة في الأعتاب الصلدة تزيد من عزم الدوران التشقق والأقصى بمقدار (100% و 66 %) على التوالي وتزيد عزم الدوران الأقصى بمقدار (63% و 60% و 62%) للمقاطع المجوفة (الدائرية (18%) ،المستطيلة (18%) والمستطيلة (27%) على التوالي.

1. Introduction:-

Structural trends today show an increase in the use of Hollow Cross Section (HCS) members, for both building and bridge structures. This is primarily due to their advantageous characteristics for structural as well as aesthetic aspects of design as compared to conventional open-section members. Much advancement was made [1,2,3,4], but there are still areas which need some improvements. Hollow cross sections are most widely known for providing economical light weight and long span members. A longitudinal opening is used to construct hollow core beam as cast in site, precast and pre-stressed concrete member with continuous voids provided to reduce weight and, therefore, cost. The applications of structural hollow sections nearly cover all fields. Sometime, hollow sections are used because of the beauty of their shape, to express lightness or in other cases their geometrical properties determine their use. These sections are used for the various fields such that in buildings, halls, bridges, offshore structure and towers. In the first part of the previous century Hollow cross sections are most widely known for providing economical solutions.

2. Objective of the Research:

The proposed study is an attempt to investigate the behavior and load carrying capacity in torsion for reinforced concrete hollow beams to show the effect of different hollow shape, hollow area, and type of concrete that influence the torsional strength capacity and also behavior of the beam. During the tests, the following variables will be measured for each beam:

- Torque versus angle of twist values at two locations (end and quarter span).
- Torque versus longitudinal elongation values at two locations of the beam ends.

3. Experimental Program:

The experimental program was conducted in the laboratory of the Civil Engineering Department at College of Engineering at the University of AL-Mustansiriya. The experimental program involves eight reinforced concrete beams under torsion load, two of these beams were solid section and six with hollow sections. The beams were divided into two groups depending on hollow shape and hollow area and concrete type. Each group contains one solid and three hollow sections. The cross section of the beams (b x h), was (170 x 240 mm) and length 2000 mm as shown in Fig. (1). To avoid failure of the specimen at cracking, minimum steel reinforcement in both longitudinal and transverse directions was provided for torsion requirements. The total ratio of volume of stirrups and longitudinal reinforcement to the volume of the concrete was taken as 1.96% to avoid failure of the beams at torsion cracking load [5,6]. All beams had the same cross section & reinforcing and the length of the hollow part was 1400 mm in the longitudinal direction of the beam. The details of the beams are listed in Table (1, 2 and 3).

Table (1): Details of R.C. Beams Specimens.

Groups No.	Beam Symbol	Type of Section	Hollow Shape	Hollow* area %	Type of concrete
Group 1	+STN	Solid	-	-	Normal Strength
	$HTNC_1$	Hollow	Circular	18	
	$HTNR_1$	Hollow	Rectangular	18	
	$HTNR_2$	Hollow	Rectangular	27	
Group 2	+STh	Solid	-	-	High Strength
	$HThC_1$	Hollow	Circular	18	
	$HThR_1$	Hollow	Rectangular	18	
	$HThR_2$	Hollow	Rectangular	27	

+ Reference of all Beams.
* Percentage of the total cross section area of beam.

STN : Solid Torsion Normal Strength.

HTNC1: Hollow Section Torsion Normal Circular of 18%.

HTNR1: Hollow Section Torsion Normal Rectangular of 18%.

STH : Solid Torsion High Strength.

The other symbols are the same as above but contain high strength concrete.

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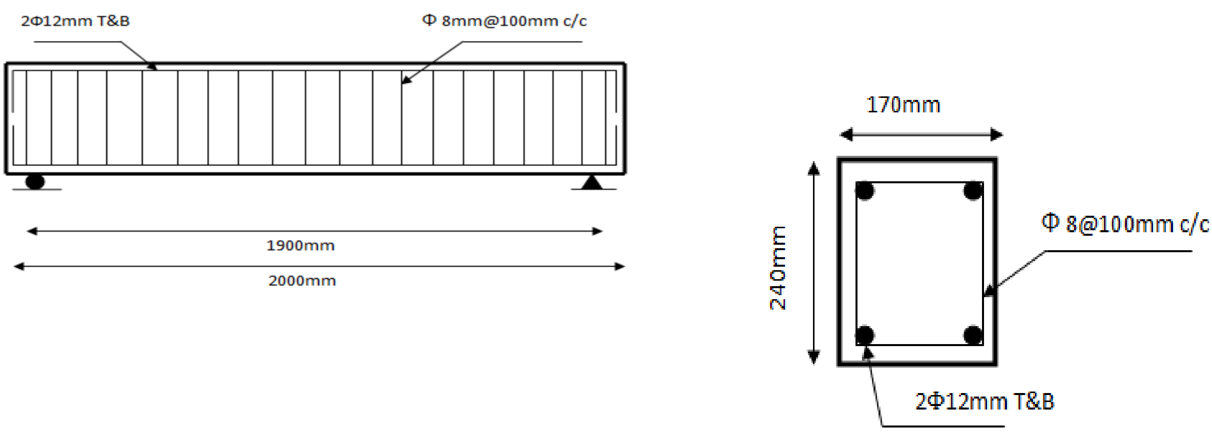
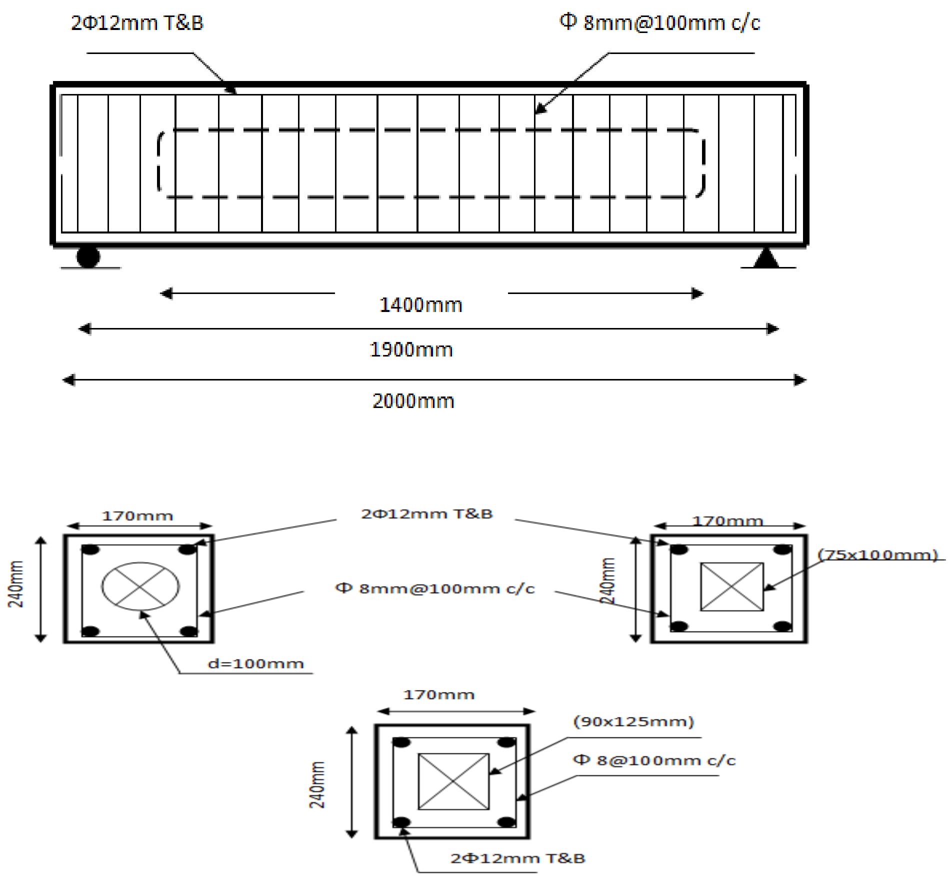


a: Solid Beam Specimen.



b: Hollow Beam Specimens.
Fig. (1): Cross Sections Dimensions, Reinforcement Details of the Tested Specimens.

Fig. (2): Arrangement of Steel Reinforcement, Polystyrene and Plastic pipe of Beam

Table (2): Properties of steel bars.

Bar size	Yield Strength, MPa	Ultimate Strength, MPa	Elongation%
Φ12-mm	532	715	10.9
Φ8-mm	467	677	11.4

Table (3): Mix proportions for Normal and High Strength Concrete:

Mix Notation	Nominal Compressive Strength (MPa)	W/C ratio	Mix Proportions (kg / m^3)				Super-plasticizer Liter /100 kg cement
			Water	Cement	Sand	Gravel	
NSC	21	0.5	200	400	800	1200	---
HSC	57	0.3	150	500	700	1100	0.8

4. Test Setup:

The hydraulic universal testing machine (MFL system) was used to test the beam specimens. The normal load can just be applied by this machine on the specimen at several points. In this research the applied loads outside the bed of the universal machine are needed in order to get torsional movement.

The special clamping loading frame on each end of the beam was used as shown in **Fig. (3)**. This frame consists of two large steel clamps which work as arms for applied torque with separated faces to connect them over the sample by large bolts; four bolts are used for each arm. This frame is made of thick steel plate (10 mm) with two steel shafts attached by welding. The final shape is similar to a bracket. These arms were capable of providing a maximum eccentricity of (500mm) with respect to the longitudinal axis of the beam. In order to get pure torsion the center of support should coincide with the center of the moment arm. Steel girder of (300 mm) depth and (3 m) length is used to transmit the loads from the center of the universal machine to the two arms (pure torsion). This girder was clamped to the universal machine as shown in **Fig. (3)**

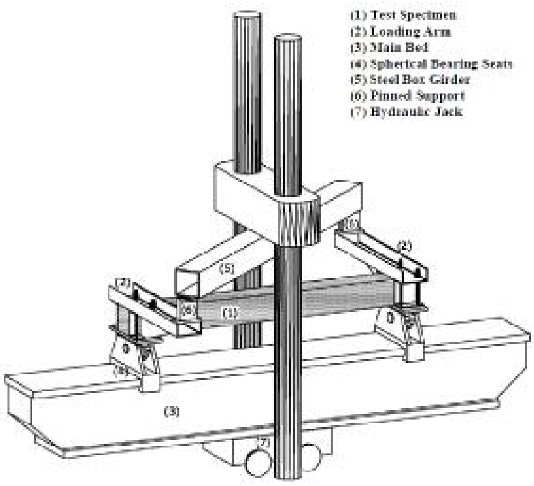


Fig.(3) Test setup & Arrangement Specimens and Instrumentation.

5. Measuring Instruments

5.1 Angle of Twist Measurements

A simple method was used to estimate the angle of twist by using two dial gages having an accuracy of (0.01 mm) attached the side fiber of the end and quarter of beam as shown in **Fig. (3).**

5.2 Elongation Measurements

Two dial gages having an accuracy of (0.01 mm) were fixed at the center of the beam side ends to measure the elongation of the beam as shown in **Fig. (3).**

6. Test Results and Discussions:

The test results of all specimens were provided; crack and failure torques, torque-twist relationship ,beams elongations and crack pattern. The test results are listed in **Table (4):**

Table (4): Crack torque, ultimate torque and ultimate angle of Twist:

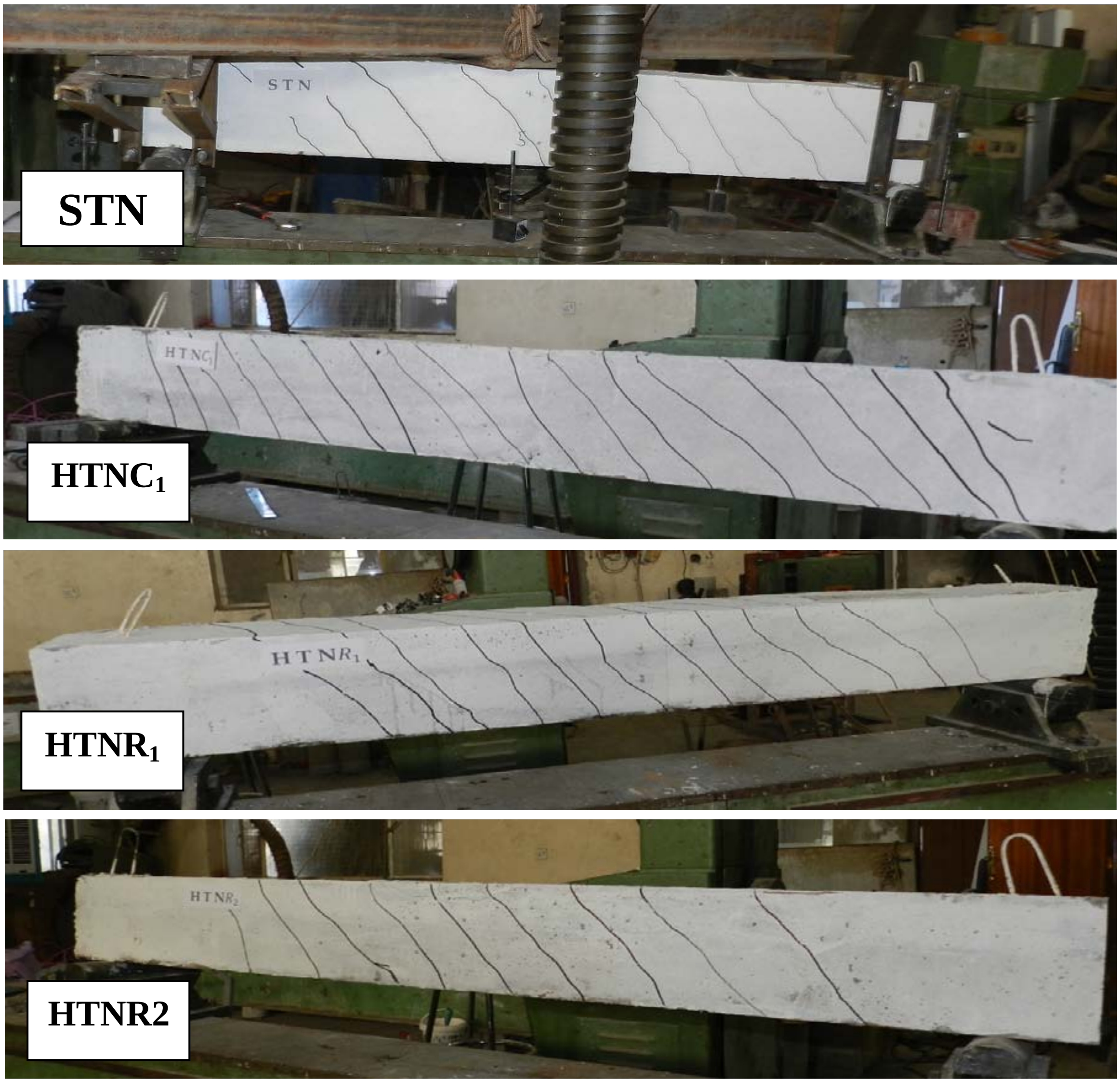
Group No.	Beam Symbol	Hollow area%	T_{cr} (kN.m)	T_{cr} /T_{cr}* %	T_u (kN.m)	T_u /T_u* %	Ultimate Angle of Twist (rad)	T_{cr}/T_u %
1	STN*	-	6.25	100	11.25	100	0.042	55
	$HTNC_1$	18	5	80	10	89	0.051	50
	$HTNR_1$	18	3.75	60	9.375	83	0.056	40
	$HTNR_2$	27	3.75	60	8.75	78	0.049	42
2	STh	-	12.5	200	18.75	166	0.032	67
	$HThC_1$	18	8.75	140	16.25	145	0.034	54
	$HThR_1$	18	7.5	120	15	133	0.032	50
	$HThR_2$	27	6.25	100	14.25	127	0.028	44

*Control to All Specimens.

7. Crack Pattern:

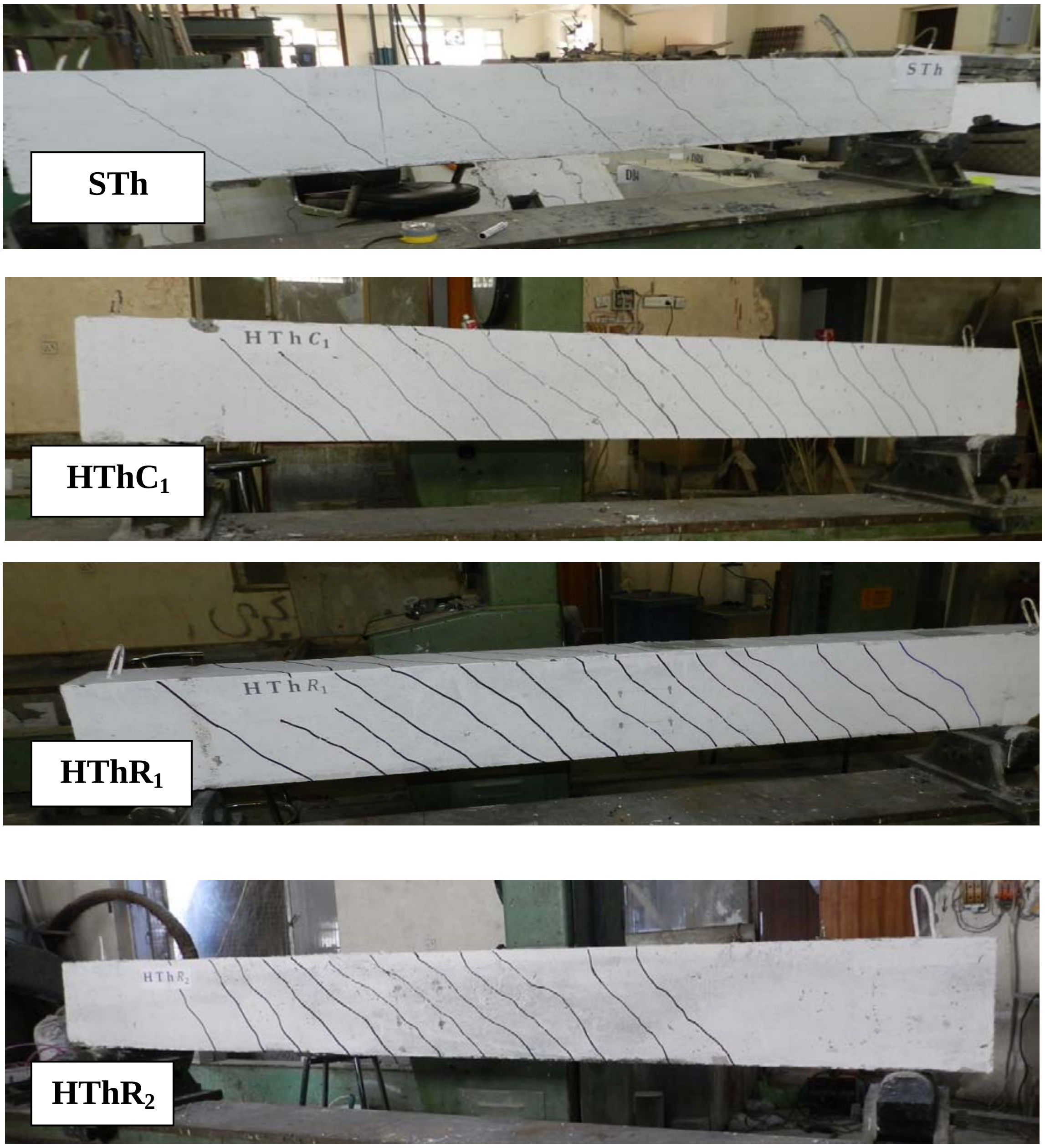
In groups (1 and 2), as the torque increased after appearance of the first crack, an increasing number of cracks were seen to form at angle 45 degree with respect to the longitudinal axis of the beam (spiral cracks) along the tested beams the crack extended to the other side of the specimen, eventually the crack connected to the four sides of specimen as shown in **Fig.(4).** The cracking torque is about (40-55) % of the ultimate torque for beams with normal concrete strength and about (44-67) % for beams with high strength concrete. From all above, it can be concluded that:

- ❖ In general, the number of cracks was larger in beams of hollow section than in the beam of solid section.
- ❖ The experimental results of groups indicate that the type of beam (solid or hollow) and type of concrete has no major effect on the angle of inclination of the cracks.
- ❖ Beams with high strength concrete failed after a short time from the appearance of the first crack, and this may be the reason of the brittle failure that occurs for high strength concrete beams.



A): Group No.(1).

Fig. (4): Crack Pattern.



(B): Group No.(2).

Fig. (4): Continue.

8. Torque - Twist Behavior:

Figs.(5 to 10) show the effect of different variables ; hollow core shape and area and concrete strength on relationship between torque and angle of twist, For each specimen, the general relationship between torque and angle of twist is such that, initially linear elastic behavior at a low loading stage was observed. The load gradually increased up to failure.

9. Torque – Elongation Behavior:

Figs.**(11 to 16)** show the effect of different variables ; hollow core shape and area and concrete strength on relationship between torque and elongation at the center of supported edge of the tested specimens.

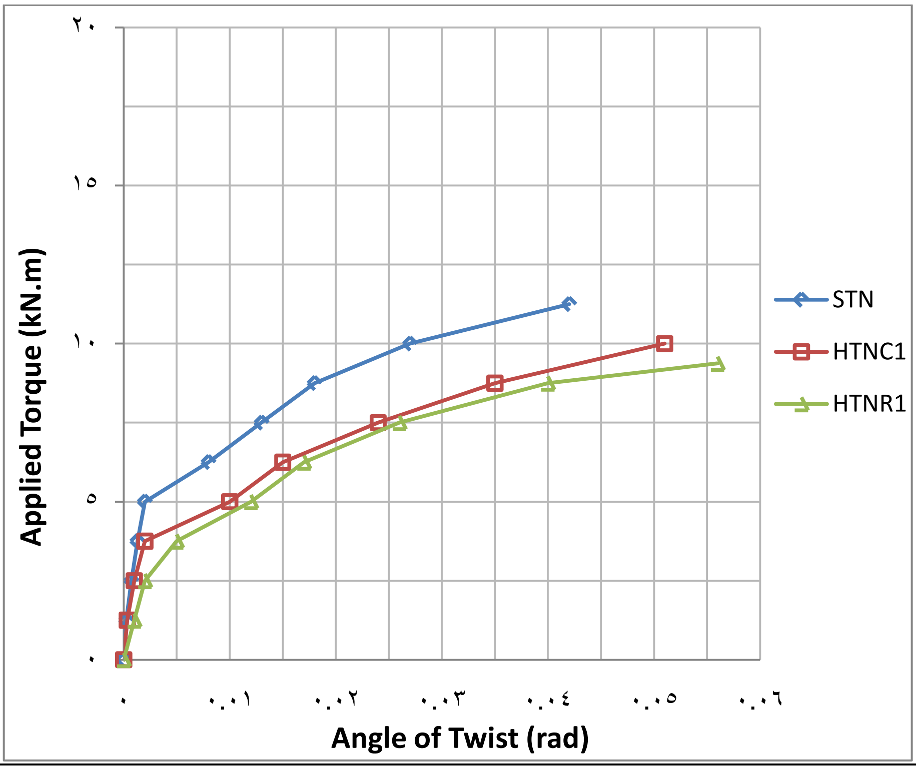


Fig. (5): Effect of Hollow Shape on Torque-Angle of Twist curve of Group (1).

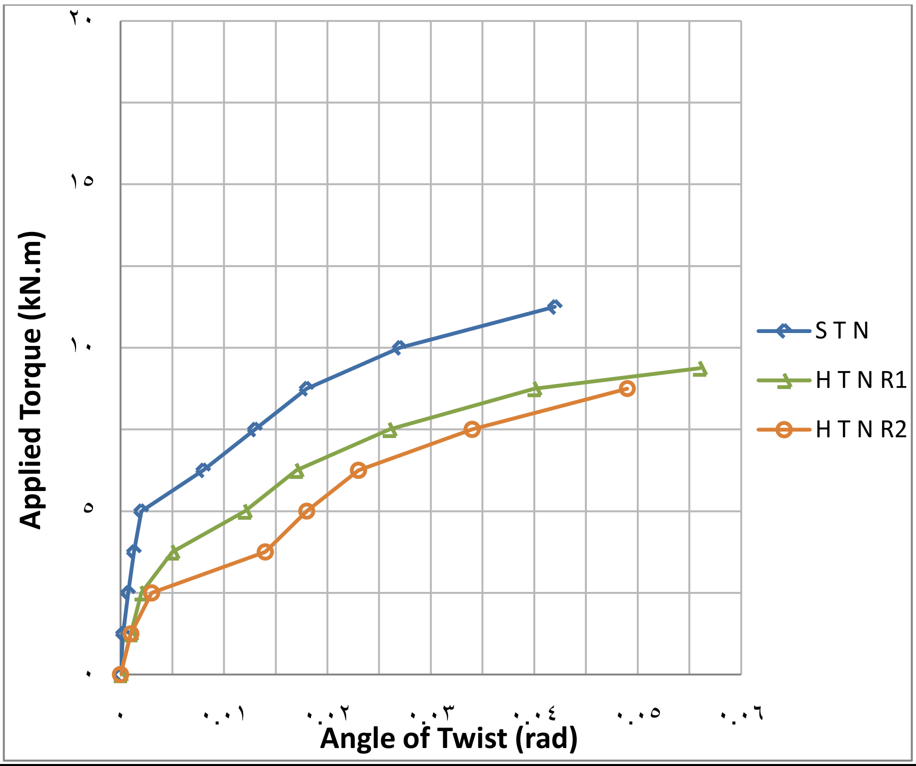


Fig. (6): Effect of Hollow area on Torque- Angle of Twist curve of Group (1).

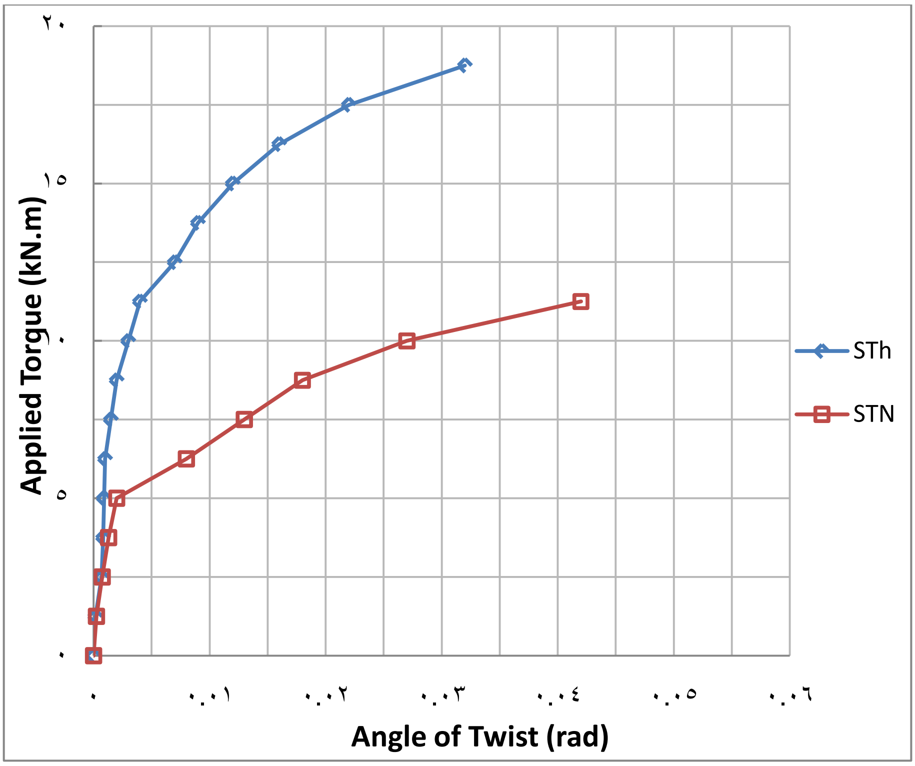


Fig. (7): Torque-Twist Behavior: Effect of Concrete Type on Solid Beams.

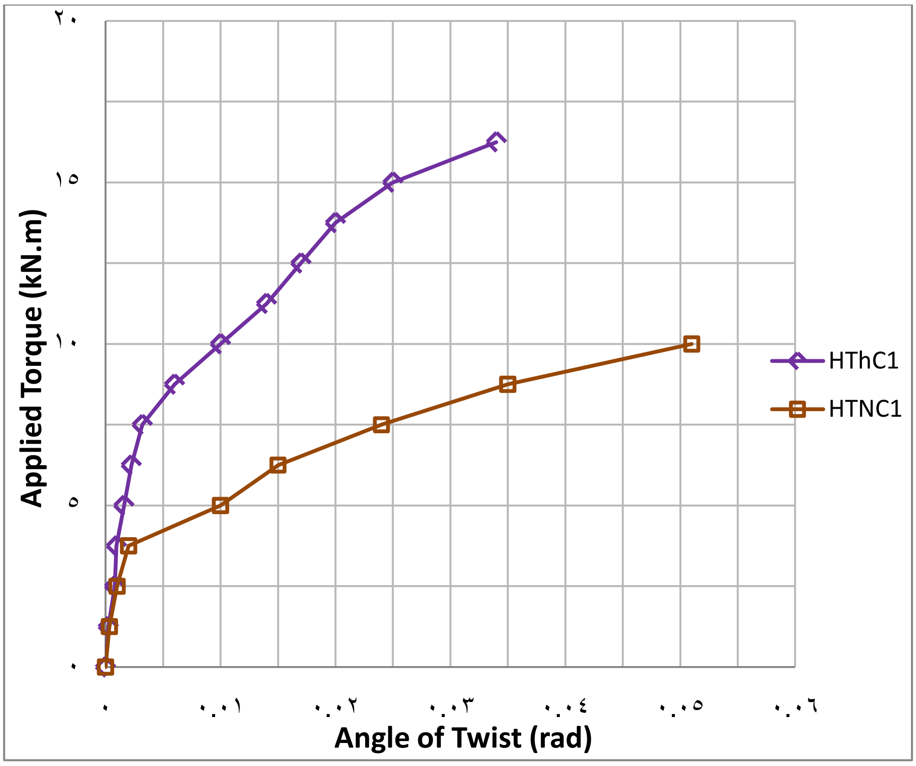


Fig. (8): Torque-Twist Behavior: Effect of Concrete Type on Circular Hollow Beams.

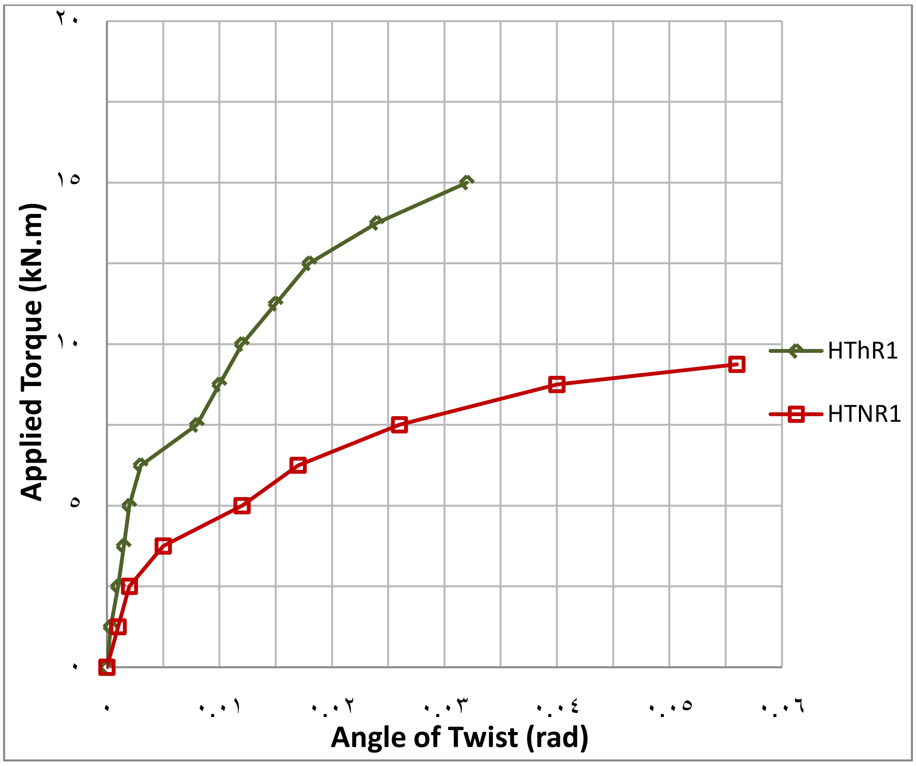


Fig. (9): Torque-Twist Behavior: Effect of Concrete Type on Rectangular Hollow area 18% Beams

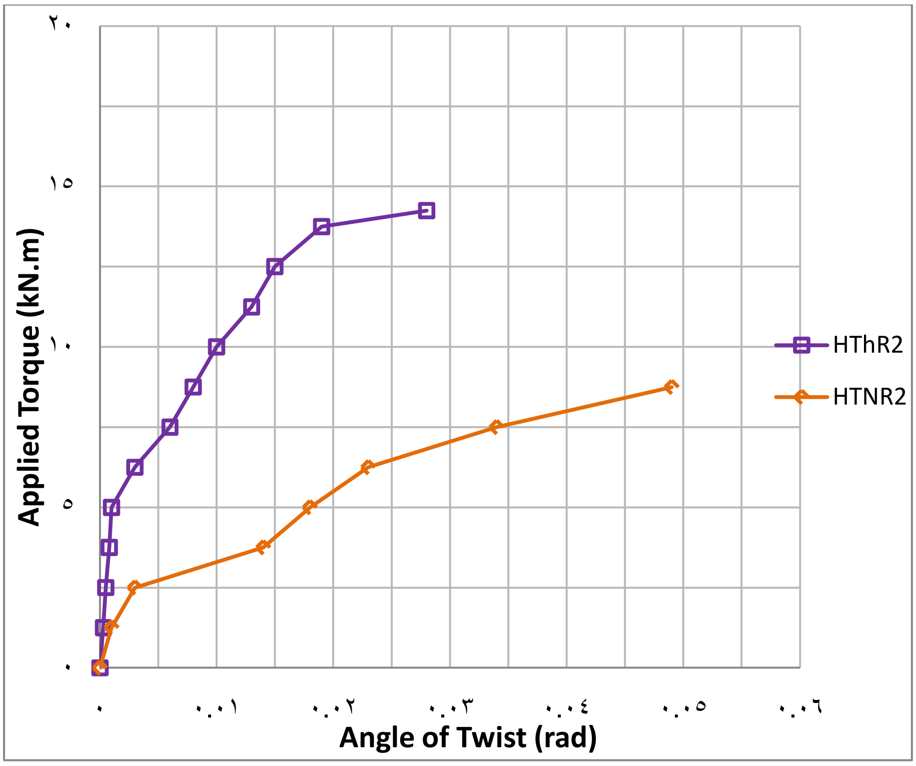


Fig. (10): Torque-Twist Behavior: Effect of concrete type on Rectangular Hollow area 27% Beams.

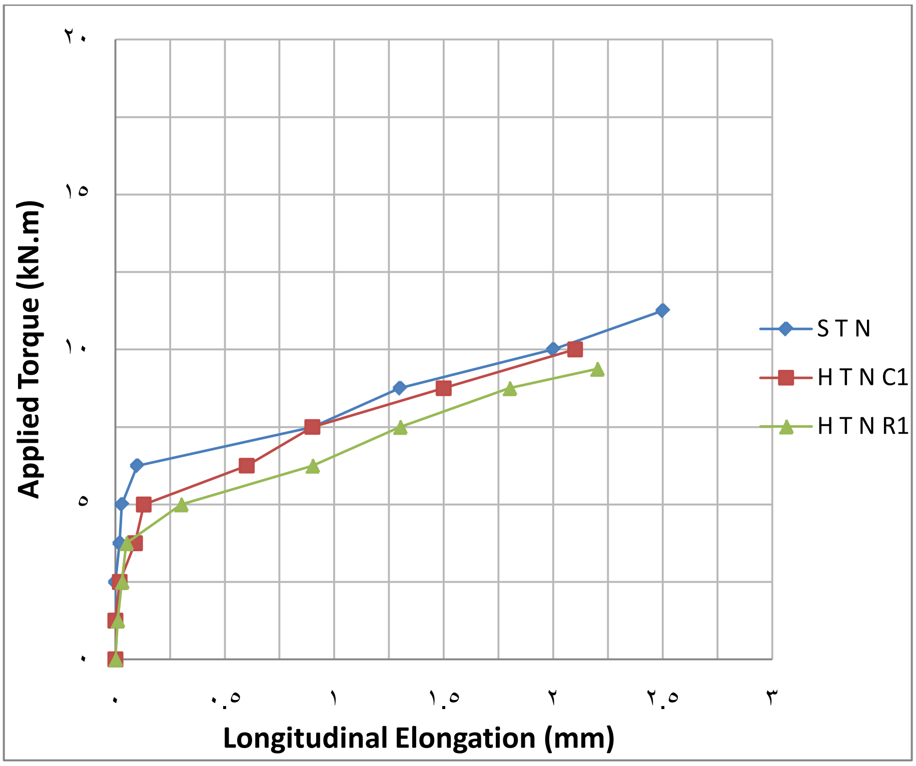


Fig. (11) Effect of Hollow Shape on Longitudinal Elongation for beams Group (1).

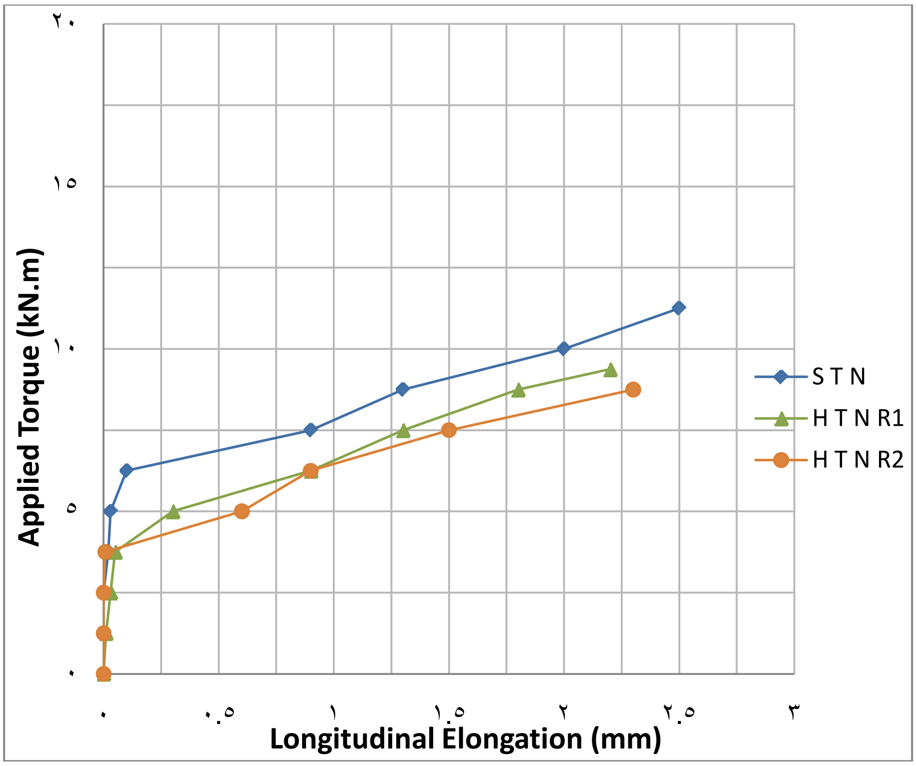


Fig. (12): Effect of Hollow area on Longitudinal Elongation for beams Group (1).

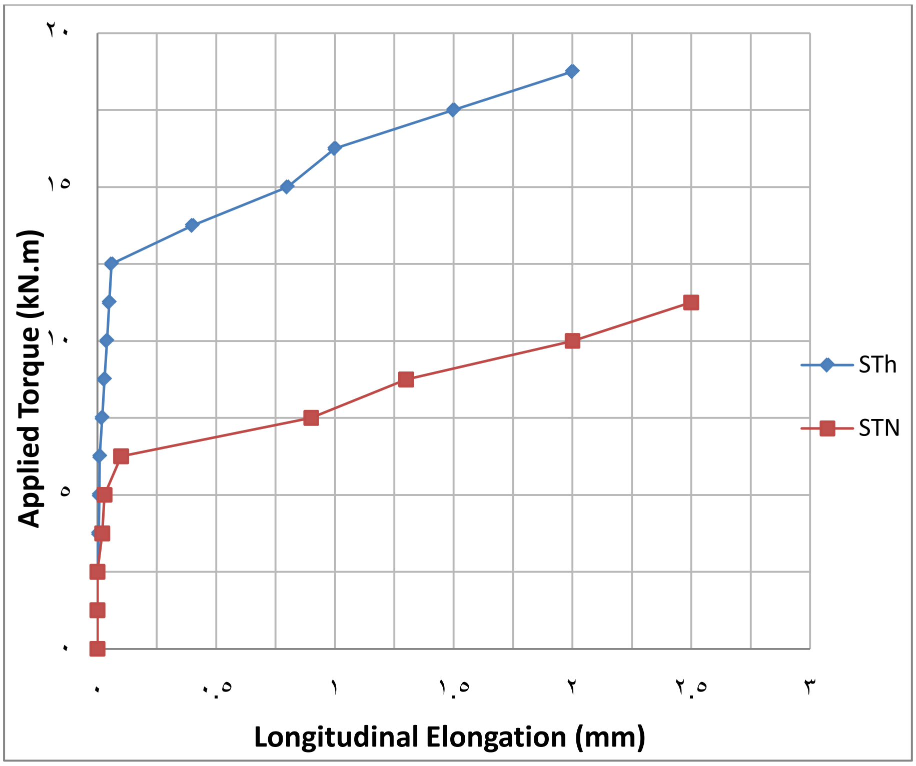


Fig. (13) Beam Longitudinal Elongation Behavior: Effect of concrete type on Solid Beams.

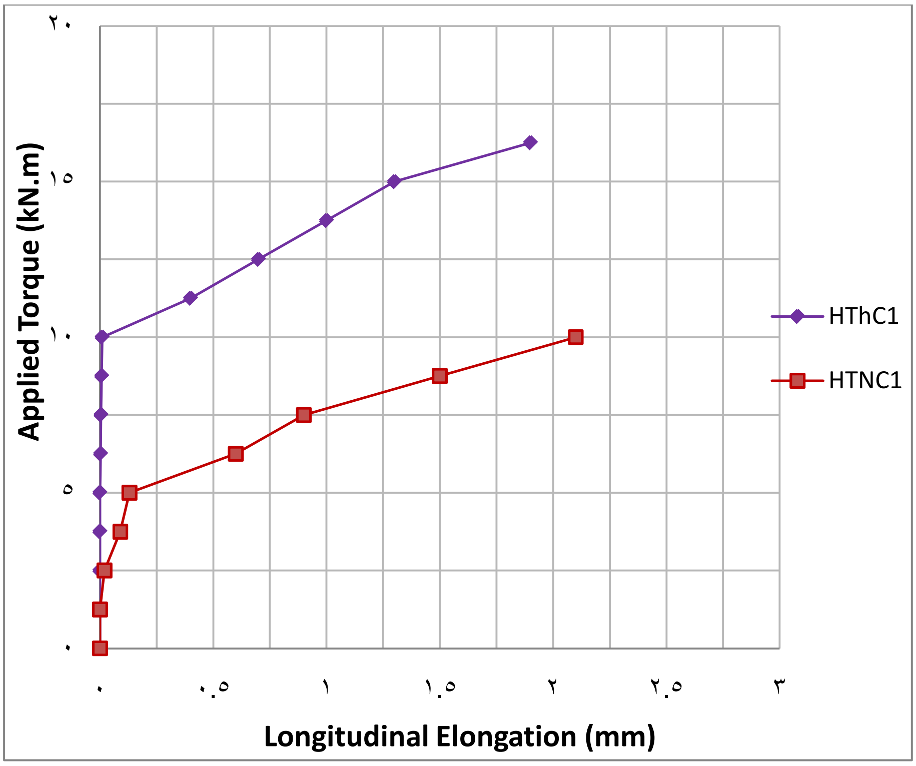


Fig. (14) Beam Longitudinal Elongation Behavior: Effect of concrete type on Circular Hollow Beams.

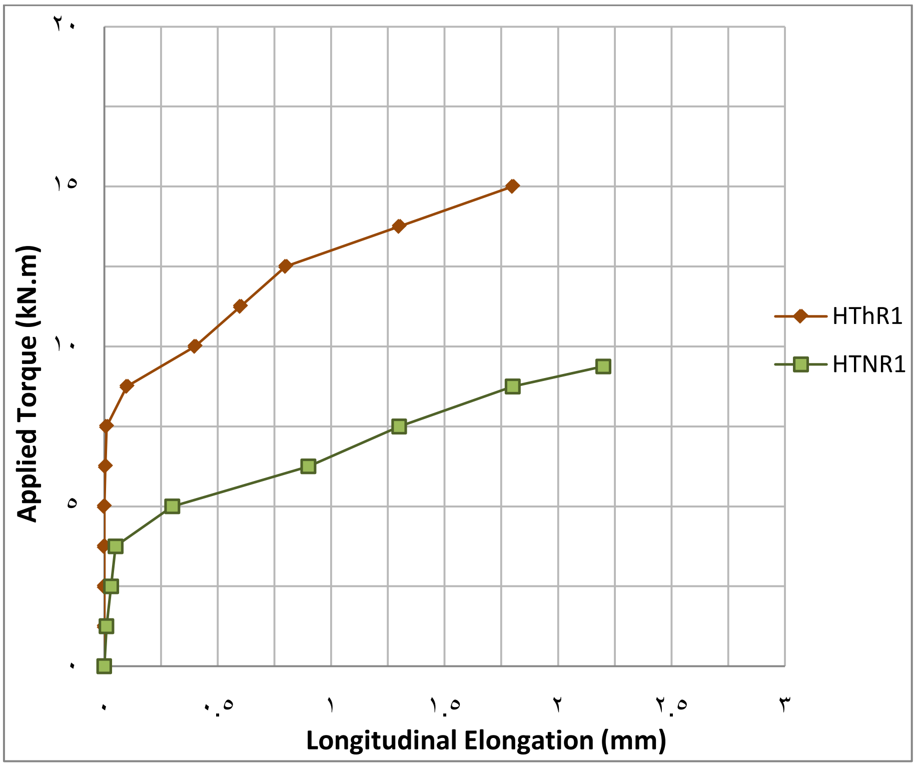


Fig. (15): Beam Longitudinal Elongation Behavior: Effect of concrete type on Rectangular Hollow area 18% Beams.

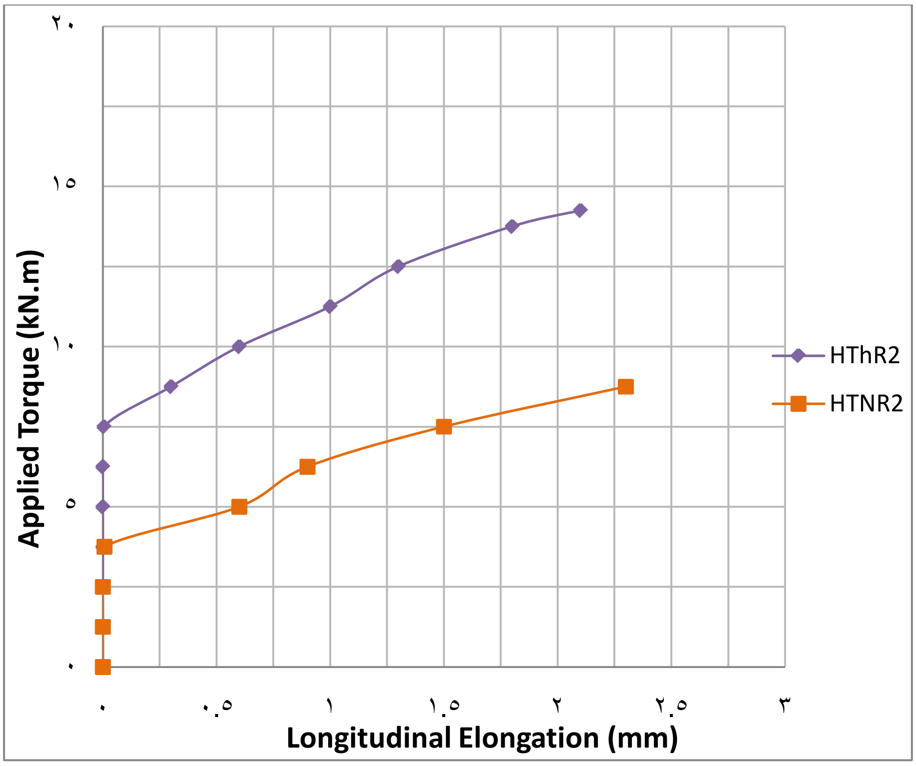


Fig. (16): Beam Longitudinal Elongation Behavior: Effect of Concrete Type on Rectangular Hollow area 27% Beams.

10. Conclusions

An experimental program was conducted to study the behavior of reinforced concrete hollow sections under torsion loading. Variables investigated in this test program included: hollow shape, hollow area and concrete type. Conclusions drawn from the experimental work are summarized below.

1. For all beams, the solid beam had a higher torsion stiffness than other hollow beams.
2. The ultimate torque (Tu) for hollow beams made with (circular hollow area 18%, rectangular hollow area 18% and rectangular hollow area 27%) exhibits a decrease of about (11%, 17% and 22%) respectively, compared with the ultimate strength for rectangular solid beam. The first cracking loads decreased by about (20%, 40%, and 40%) respectively. In addition there is increase in angle of twist when compared with solid beam by about (21%, 33%, 16%) respectively. The hollow beams behaved softer than the solid ones. Hollow core has a significant effect to decrease the crack and ultimate load capacity and ability to change the failure mode.
3. In high strength concrete beams, the solid beam and hollow beams made with (circular hollow area 18%, rectangular hollow area 18% and rectangular hollow area 27%) gave an increase in the ultimate torque was observed by (66%, 63%, 60%, 62%) respectively, and the cracking torque that increased by about (100%, 75%, 100%, 66%) respectively, in comparison with respect to the specimens of normal strength concrete. Increasing the concrete compressive strength give increasing the

stiffness of beam and decreasing the angle of twist (23%, 33%, 42%, 42%) and decrease the longitudinal elongation.

4. In general, the number of cracks was larger in the hollow sections than in the solid ones.
5. It has been observed from the tests carried out that the slope of cracks under pure torsion is about 45^o.
6. For all cases, circular hollow core is better than rectangular hollow core to resist more cracking and ultimate loads.

11. References:

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