PERFORMANCE OF UHP-SHCC MATERIAL IN REPAIRING RC BEAMS SUBJECTED TO TORSION

دراسة أداء مادة UHP-SHCC في ترميم الكمرات الخرسانيه المسلحه المعرضة لعزوم اللي

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ABSTRACT:

Ultra high performance-strain hardening cementitious composite (UHP-SHCC) is a composite material comprising a cement–based matrix and short polypropylene fibers with outstanding mechanical and protective performance against some natural attack such as sea water. Jacketing with composites on the outer periphery is an effective method to enhance the torsional capacity of distressed reinforced concrete structures and to change the mode of failure from brittle to ductile. This study presents a study on the torsional behaviour of reinforced concrete beams repaired with UHP-SHCC material. Four repaired specimens in addition to the control specimen were tested to examine the beams repaired using a UHP-SHCC layer in different cracking levels and internal steel configurations. The control and the repaired beams were subjected to a pure torsional moment. The failure load, the twist angle of the beams and the strains in the longitudinal and, transverse reinforcement were recorded to failure. In the current study, the ductility ratios and the percentage increase in ductility were investigated. The experimental results revealed that the repairing techniques and materials could significantly increase the torsional capacity of the pre-cracked beams in torsion and also enhanced the post cracking behaviour of the repaired beams.

Keywords: Torsion, UHP-SHCC, Rehabilitation of structures, Beams, Repairing.

ملخص البحث:

المركبات عالية الأداء ذات الأساس الأسمنتيUHP-SHCC هي مواد مركبة من الأسمنت والفيبر القصير بنسب معينة. استخدام القمصان من هذه المركبات علي المحيط الخارجي للكمرات الخرسانية المسلحة من أفضل الطرق لزيادة كفاءة تلك العناصر لمقاومة اللي وتغيير نمط الانهيار من قصف إلي مرن. هذا البحث يدرس سلوك اللي لكمرات خرسانية مسلحة تم ترميمها باستخدام UHP-SHCC. خمس عينات منها عينة حاكمة وأربع أخرى تم ترميمها باستخدام طبقات من UHP-SHCC وحديد تسليح داخلي وقد عرضوا لعزوم لي خالصة .تم تسجيل كل من حمل الانهيار وزاوية اللي والانفعال في حديد التسليح الطولي والعرضي. وأيضا في هذه الدراسة تم حساب معامل المرونة ونسبة الزيادة فيها للعينات المختبرة. النتائج العملية أوضحت تأثير UHP-SHCC في ترميم الكمرات الخرسانية المسلحة المشرخه نتيجه عزوم اللى وكذلك في زيادة مقاومتها لعزوم اللي و أيضا في تحسين سلوك شروخ اللي بعد الترميم.

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1. INTRODUCTION

In reinforced concrete structures usually bending moments and shearing forces control their design. However, torsion moments may be a governing factor in the design of very limited cases. These cases may include spandrel beams, edge beams carrying cantilever stairs or some special beams carrying projected slabs for architectural considerations. Torsion is also important in the design of eccentrically loaded box beams and curved girders. Increase in service loads, changes in the function of the structure, construction faults and degradation problems are common engineering problems that may lead to the need for repairing and rehabilitation of existing structures; Panchacharam and Belarbi (2002) [1] and Etman and Beeby (2000) [2]. Repairing reinforced concrete (RC) members was traditionally achieved by concrete jacketing of the defected member. The use of steel plates for external repairs, mainly, for flexural members was used and approved as a reliable method for the repair of this type of members. The use of Fiber Reinforced Polymers (FRP) in the civil engineering industry, such as Carbon Fiber Reinforced Polymers (CFRP) and Glass Fiber Reinforced Polymers (GFRP) has gained acceptance in the last three decades. These FRP materials were externally installed on the surface of the deficient members using suitable adhesives.

Repair techniques for reinforced concrete beams subjected to torsion have seldom been reported in the literature. Niema, (1993) [3], studied the effect of adding steel fibers to the concrete mix of reinforced concrete beams subjected to pure torsion. It was stated that the use of internal steel fibers could successfully arrest cracks and considerably enhance the ultimate torsional capacity of these beams.

Holman and Cook, (1984) [4], investigated experimentally the use of steel plates in repairing pre-cracked reinforced concrete spandrel beams. The results showed a significant increase in the strength and the beams failed in flexure rather than in torsion. An investigation of the application of GFRP sheets to reinforced concrete beams subjected to torsion was carried by El-Behairy et al. (2002) [5]. They studied experimentally using four specimens of RC beams the efficiency of using GFRP in the repair of beams for torsion. Their evaluation successfully showed a good agreement between the behavior of the repaired beams and that of a beam designed to resist torsion.

Ultra high performance-strain hardening cementitious composites (UHP-SHCC) developed by Kamal et al. (2007) [6] can be simply defined as cement based matrix containing short polypropylene fibers with higher mechanical and protective performance. Fig. 1 shows the stress-strain response of (UHP- SHCC) in uniaxial tensile tests compared to that of ordinary SHCC and ordinary Ultra high performance fiber reinforced concrete (UHPFRC). The condition for strain-hardening behavior can be simply expressed in terms of the post-cracking strength in tension being higher than the cracking strength. This study presents an experimental work devoted for exploring the behavior of reinforced concrete beams after cracking in pure torsion and repaired externally using UHP-SHCC materials as a new repairing material.

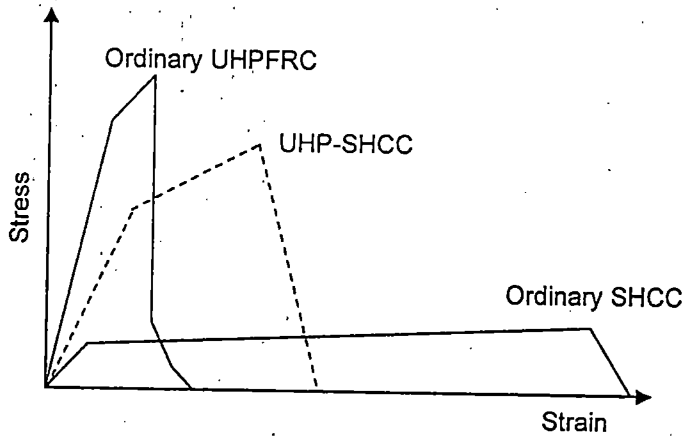

Figure 1 Schematic image of UHP-SHCC material tensile behaviour compared to that of other materials (Kunieda *et al.* 2007).

2.EXPERIMENTAL PROGRAM

2.1 Specimens description

The experimental program included the testing of five reinforced concrete beams having the same cross section of 150×350 mm with a 1400 mm overall length and span of 1200 mm. To apply a torsional moment on the beam, two heavily reinforced concrete arms of 200×350 mm in cross section and 350 mm in length were added at both ends of each beam in an anti-symmetric position as shown in Fig. 2. The specimens were reinforced with six 10mm diameter high grade longitudinal bars located at four corners of the cross-section and at the mid height. Closed stirrups composed of 8 mm diameter deformed bars were spaced at 150 mm on center throughout the test region. The layout and dimensions of tested beams are illustrated in Fig. 2. The specimens were divided, according to their cracking level, into two groups; the first group of specimens, GRI, were preloaded to 65% of their failure load and the second group of specimens, GRII, were preloaded loaded to 85% of their failure load. For all repaired specimens a 20 mm thick UHP-SHCC material shell was placed on the outer perimeter without wrapping on top and bottom face. Additionally, five bars with C- shaped bars were added to specimens GRI-2 and GRII-2 on both faces. Specimen details and cross sections for all beams are shown in Fig. 2 and 3 and presented in Table1.

Table1 Details of test specimens.

Group	Specimen	Pcr/Pu	UHP-SHCC thickness (mm)	No. of external R.F.T bars /side	fc' (ordinary concrete) (MPa)	fc' (UHP-SHCC) (MPa)	f_t (UHP-SHCC) (MPa)
Control	GC	-	-	-	25	-	-
GRI	GRI-1	0.65	20	-	26	77	8.5
	GRI-2	0.65	20	5 bars	26	77	8.5
GRII	GRII-1	0.85	20	-	25	78	9
	GRII-2	0.85	20	5 bars	25	78	9

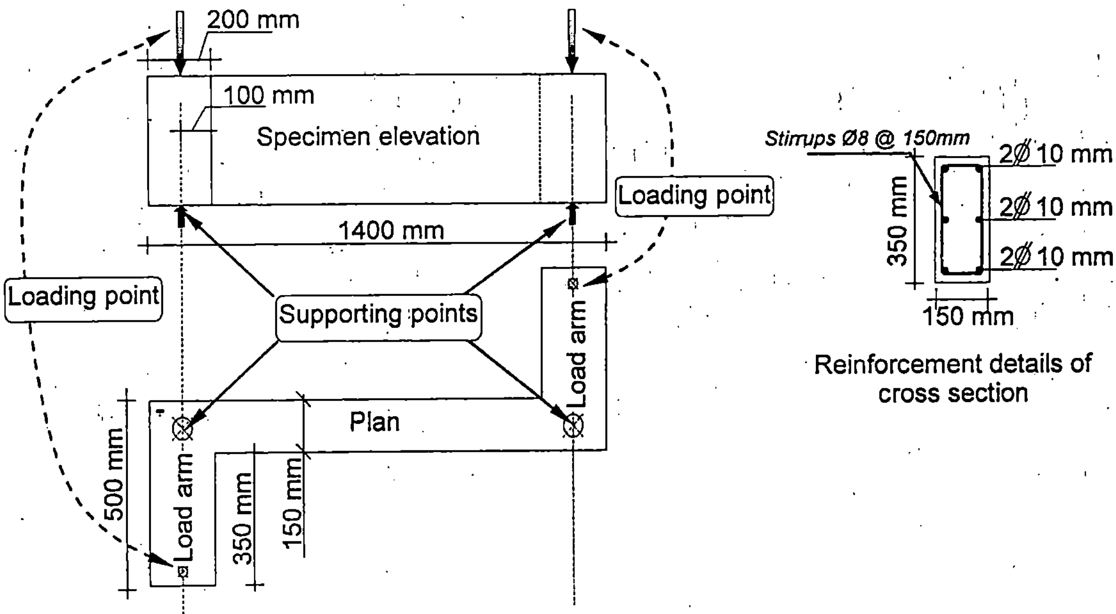

Figure 2 schematic drawing showing specimen geometry and concrete dimensions.

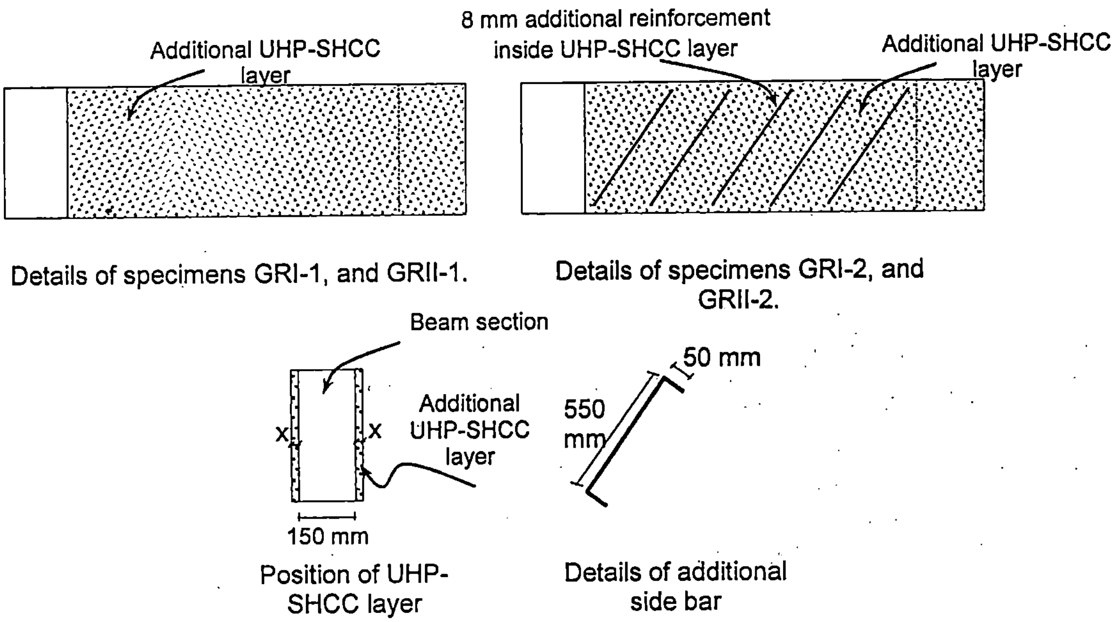

Figure 3 Details of repair techniques for tested specimens.

2.2 Material properties

The concrete mix was made with ordinary Portland cement, sand and coarse aggregate of maximum size 20mm. The mix proportions for the ordinary concrete and the UHP-SHCC layer material are shown in Table 2. At the age of 28 days, the averaged strengths of the UHP-SHCC and ordinary concrete from the cylindrical specimens (ϕ100x200 mm) were 77 MPa and 25 MPa, respectively. Indirect tensile test was performed on the UHP-SHCC concrete to calculate the tensile strength of this material. Both beams and cylinders were kept under the same curing condition until testing. The compressive and tensile strength results of concrete are shown in Table1. The longitudinal reinforcement of the specimens investigated in this study was high tensile steel reinforcement with average yield strength and ultimate strength of 450MPa and 610MPa respectively. For web reinforcement and additional external reinforcement an ordinary reinforcement having an average yield strength of 250MPa was used.

Table 2 Mix proportions of ordinary concrete and UHP-SHCC.

	Cement	Water	Sand	Coarse aggregate	Super-plasticizer	Silica fume	Fiber content (6mm)
Ordinary Concrete	1	0.40	1.60	2.20	---	---	---
UHP-SHCC	1	0.225	0.10	---	0.02	0.15	1.5

2.3 Test setup and Instrumentation

All beams were tested under pure torsion using the test setup shown in Fig. 4. A hydraulic jack of 250kN capacity was used to apply the load on the beams through loading arms. For all repaired specimens, the two sides were roughened and moistened with water before adding the UHP-SHCC layer. For specimens with additional external reinforcement a hole of 50mm depth was made and filled with UHP-SHCC material before adding the reinforcement and an external layer. Several instruments were used to monitor the behaviour of the RC beams. These instruments recorded the strain in the horizontal and vertical reinforcement and the specimen displacement at four different locations of the cross section. Three located at the middle vertical stirrups and one at middle horizontal bar. The rotation of the specimen was calculated based on the readings from displacement transducers. In addition, to provide backup data, a load cell recorded the force during the test.

Figure 4 Test setup.

3. Discussion of Test Results

3.1 Crack patterns and mode of failure

For the control specimen the cracks started at mid-height of the beam section at approximately 45° with the longitudinal axis of the beam. The cracks extended along the beam in spiral pattern with the increase in load until failure. The first crack for concrete beams repaired with UHP-SHCC material appeared on the upper and lower concrete face. However first cracking appeared on the repaired longer faces for beams and on further loading a few more small segmental cracks was noticed. The ultimate failure was found to be due to the formation of a single crack on the un-repaired face with an inclination of approximately 45° to the longitudinal axis. De-bonding was noticed at the interface of the concrete and UHP-SHCC material at failure. The comparison between specimens with internal reinforcement inside UHP-SHCC layers GRI-2 and GRII-2 and specimens without internal reinforcement inside UHP-SHCC layers GRI-1 and GRII-1 shows an increase in the number cracks at both longitudinal sides for specimens GRI-2 and GRII-2. This is due to the improved tension behaviour created by the UHP-SHCC material in this case. The distributions of cracks near failure for all tested specimens are shown in Fig. 5.

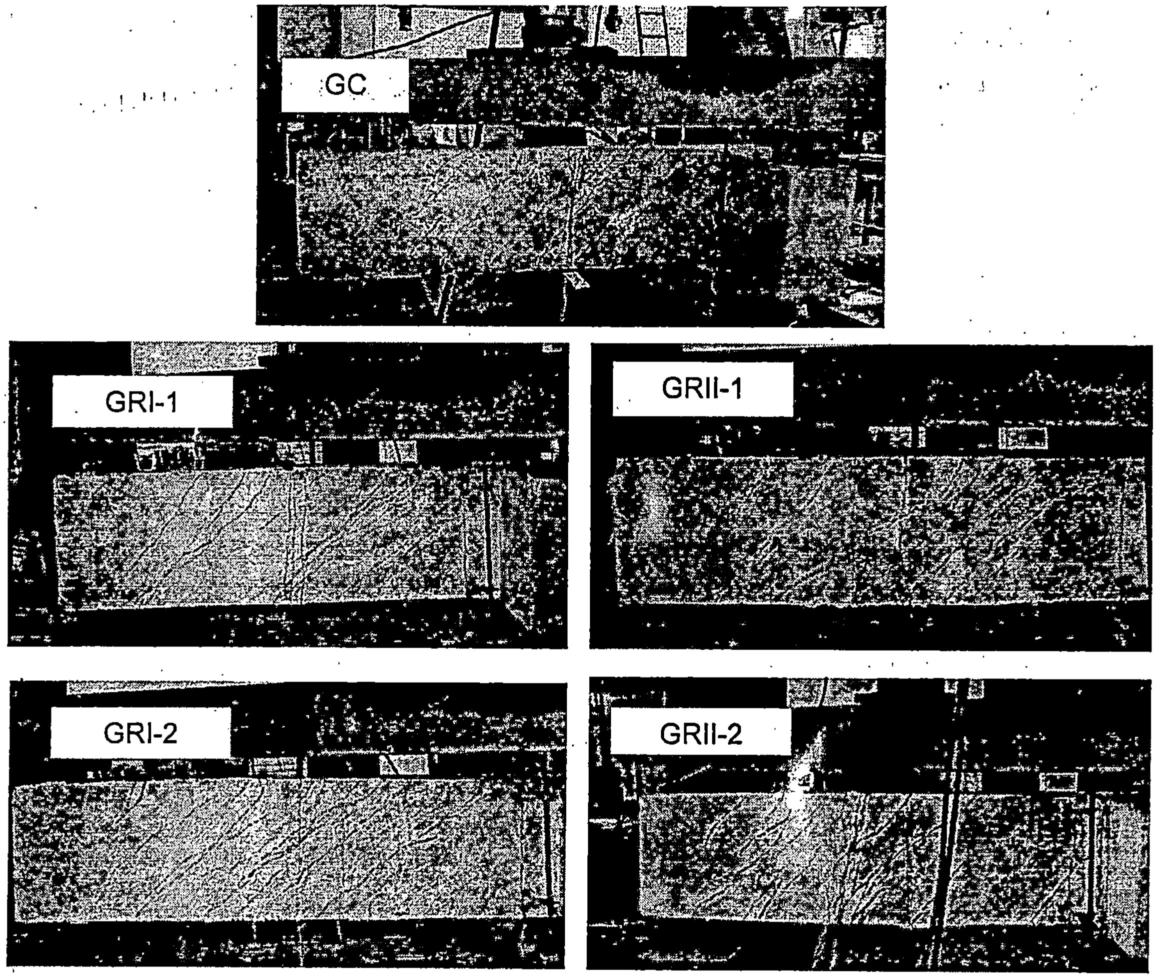

Fig. 5 Crack patterns near failure.

3.2 Rotations

For the control specimen, sudden excessive torsional rotation at ultimate load was noted. Specimens repaired using the UHP-SHCC material indicated had reduced torsional rotation values at early load stages compared to the control specimen. Specimens GRI-2 and GRII-2 with internal embedded reinforcement inside UHP-SHCC layer had greater torsional stiffness after the failure load compared to specimens GRI-1 and GRII-1 with UHP-SHCC layer only as shown in Fig. 6 and 7.

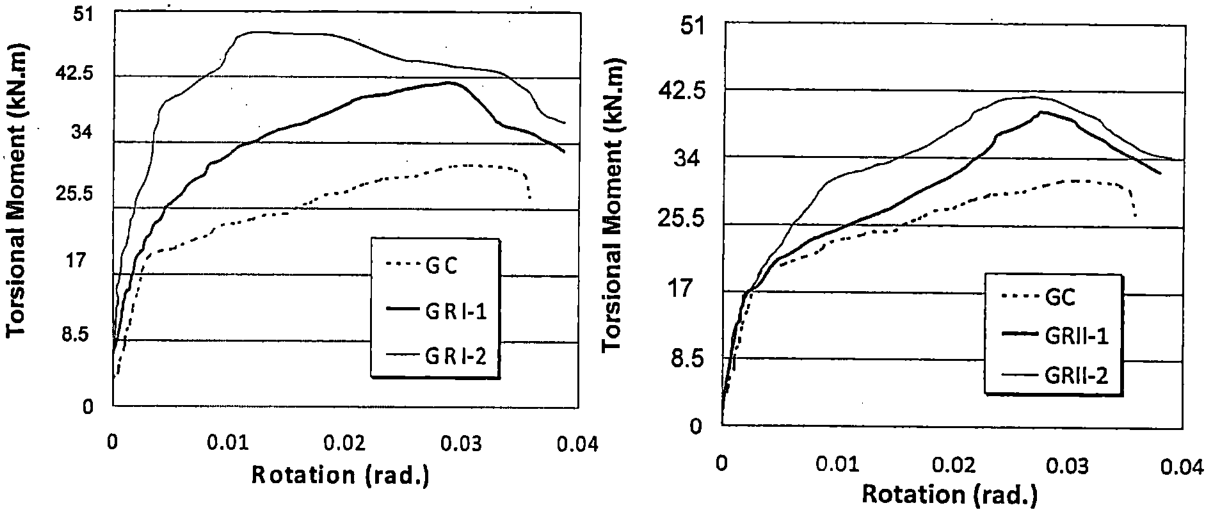

Fig. 6 Rotation results for tested specimens.

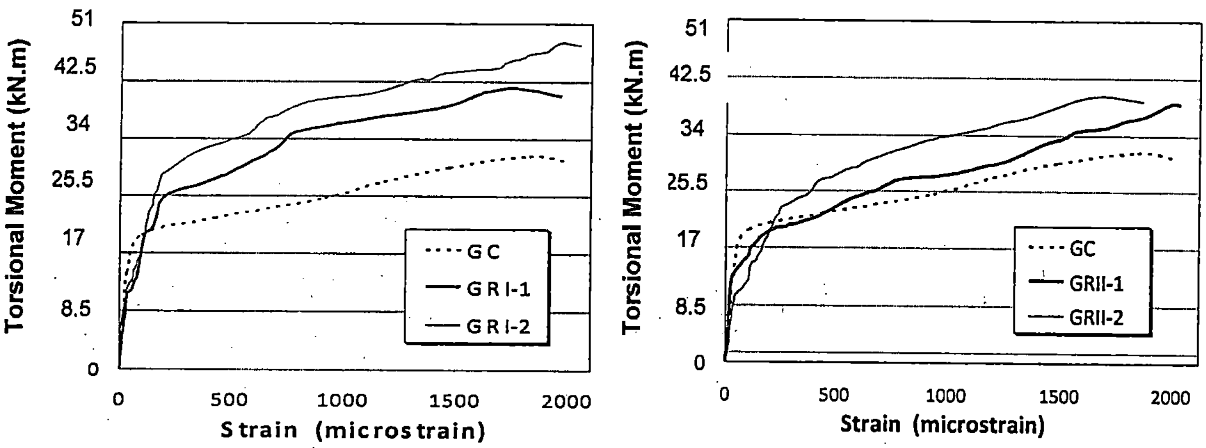

Fig. 7 Strain results at vertical middle stirrup.

3.3 Steel Strains

Fig. 7 and 8 show the strain results at the middle vertical stirrups and middle horizontal bar. These figures shows that repairing of cracked beams using UHP-SHCC material at 65% of ultimate moment delayed the appearance of first yielding of the reinforcement compared to beams that were loaded to 85% of ultimate torsional moment. This indicates that repairing using UHP-SHCC is more effective with flower primary cracking loads. On the other hand, all specimens including the control failed upon yielding of both longitudinal and transverse reinforcement followed by crushing of concrete.

3.4 Ductility

A consideration that may have to be added to the primary considerations of strength, serviceability and stability is ductility. It is important to ensure that in the extreme events the structure will behave in ductile manner. There are many measures to access ductility, in this study the ductility was described by the energy absorbed by the beam and indicated as the area under the load rotation curve. The ductility of the beams seems to be greatly affected by the use of the UHP-SHCC material as an external repair layer. Beams GRI-1 with 65% pre-cracking level showed a 46% increase in ductility when compared with control beam as shown in Fig. 9. When additional reinforcement is used insi le the UHP-SHCC layer, specimen GRI-2 the contribution of additional steel increases the ductility by about 24% compared to GRI-1. From Fig.9, it can be seen that the repaired beam GRII-1 and GRII-2 with 85% pre-cracked level showed about 24% and 43% increase in ductility compared to control beam respectively and about 10% decrease in ductility compared to GRI-1.

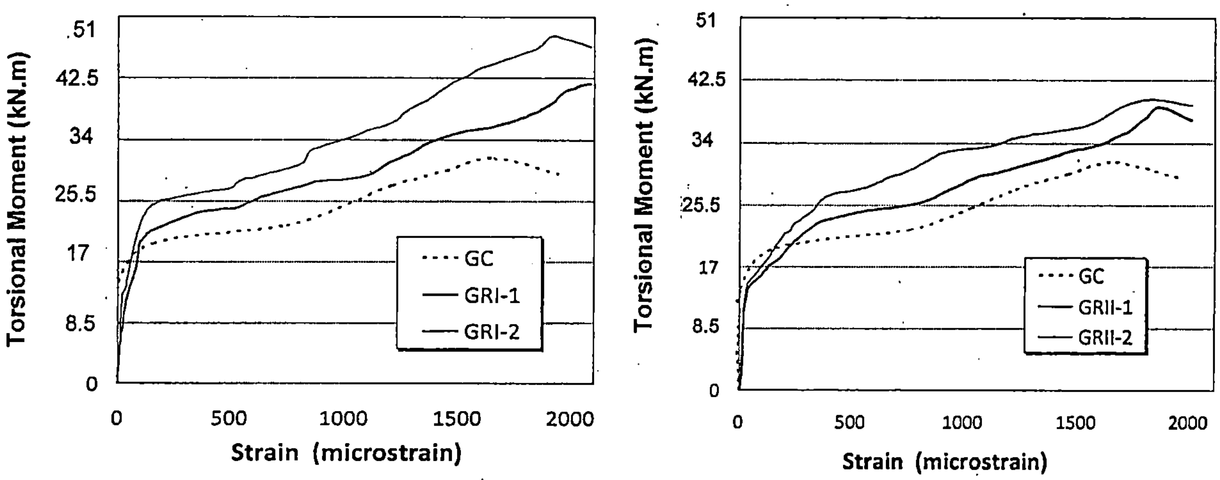

Fig. 8 Strain results at horizontal middle bar.

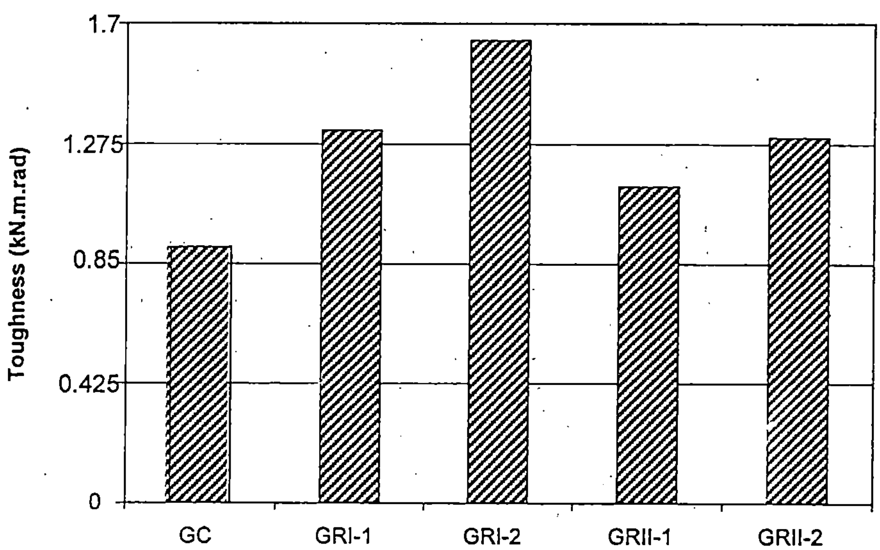

Fig. 9 Ductility result for tested specimens.

4. CONCLUSIONS

- The use of UHP-SHCC layers to repair reinforced concrete beams subjected to pure torsion increases the cracking and failure loads after reloading.
- Good bond between the UHP-SHCC layer and external surface of beams has been noticed until the failure load.
- All specimens repaired using the UHP-SHCC layer had a higher number of smaller cracks compared to the control specimen.
- The use of internal reinforcement inside the UHP-SHCC layer led to ductile failure with gradual increase in torsional rotation up to failure load.

5. ACKNOWLEDGEMENT

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