Comparative Experimental Investigation of Flexure and Shear Strength in Hybrid - Trapezoidal Reinforced Concrete Sections

Majid Jafar Sada1*, Sa'ad Fahad Resan1
1 Civil Engineering Department, Engineering College, University of Misan, Amarah, Iraq
*E-mail: majid.jafer.sada@uomisan.edu.iq

Abstract. The structural behavior of the hybrid reinforced concrete beams of the trapezoidal section is investigated in this paper. This study aims mainly to investigate the interaction effect of hybrid concrete compressive strength for section has geometry variation upon beam strength characteristics. Throughout the considered experimental program, 10 simply supported reinforced concrete beams were prepared and tested using a four-point load setting. All specimens had equal cross-sectional area. These specimens were divided into two groups, each group contain 5 beams. The first group deals with flexural behavior and the second group concerned with shear behavior. In addition to hybrid compressive strength considerations, two types of concrete with different compressive strengths of (25 and 50 MPa) were used and three trapezoidal geometries with different alignment side angles (75, 80, and 85) are adopted. The experimental testing showed that the effectiveness of the hybrid trapezoidal force formation maintained the strength of the samples decreased more than the hybrid effect force. As for the flexural behavior, the ultimate strength decreased by (2.82%) and the deflection increased by (56.81%) with respect to rectangular specimens. For shear behavior, the ultimate load was close or identical to the control specimens with deflection increment ranging from (9% to 60%) with respect rectangular specimen. The effect of area distribution within section (section shape sides orientation) was clearly on the first crack load where the angle (80) recorded a highest value of crack load.

Keywords: Flexural Strength, High Strength Concrete, Hybrid Concrete, Shear Strength, and Trapezoidal Section.

1. Introduction.
The smart distribution of section area and the optimum selection of proper strength are powerful factors used in the design philosophy for economic structural members. In addition to determining the factors of complexity, durability, economy, and construction time are the main elements considered in measuring successful construction. The adoption of these elements for each part of the project ultimately leads to a reduction in construction cost with the least possible time. Moreover, the most important part of the
construction project is the concrete members; thus, improving their properties, increase their strength, using certain additives, and employing simple construction methods effectively contribute to the success of the project [1]. Numerous ways of improving the properties of concrete include those related to increasing its strength by using additives and implementing concrete in certain forms that are generally appropriate to the facility and contribute to increasing its durability. Meanwhile, the use of hybrid concrete (with two strengths) effectively contributes to the reduction in construction cost [2]. The effective use of concrete in beam members in the compression region within the beam section and its quality and efficiency requirements are relatively reduced in the tension region. This phenomenon fulfills the requirements of global codes, of which the most important is ACI 318 cod [3]. Obtaining high-strength concrete beams with low costs is possible by using hybrid concrete with certain forms of beam cross-sections. Moreover, the trapezoidal shape is proportionate to the compressive and tensile strengths, which increases the compression area. Thus, the compression strength is increased, whereas the opposite is observed for the tensile area, wherein the rebar strength distributed tensile stresses. Many researchers have studied the structural behavior of hybrid concrete beams. The use of composite or hybrid concrete is one of the advanced technologies in modern constructions, especially in concrete beams. Researchers have benefited from the stress distribution within the beam cross-section. Thus, finding the optimal section of the concrete beam is necessary; that is, the concrete with high strength is in the upper part of the beam, while that with low strength is under the section, thus producing concrete with high efficiency and low cost [4-13]. Other researchers have benefited from the theory of varying stress distribution within the cross-section based on its shape. The redistribution of areas inside the cross-section increased the compression area and reduced the tensile area, resulting in a triangular or trapezoidal shape [14-17]. The effect of the non-prismatic shape on the structural behavior of concrete beams was also investigated [18-25]. Most of the above-mentioned studies considered one aspect of modern technologies for the production of concrete beams and the general effect of these techniques on structural behavior. More than one technique was incorporated in this study, that is, hybrid concrete was used with a trapezoidal cross-section within reinforced concrete beams. The effect of these techniques on flexural stresses generated inside the concrete was also investigated. Many scholars and researchers addressed the issue of bending performance in reinforced concrete beams and the extent of the effect of the cross-section shape and hybrid concrete on flexural stresses.

2. Experimental methodology

2.1 Experimental Program
The experimental work of this study includes the testing of 10 reinforced concrete beams divided to two groups. Group one (GR1) contains 5 specimens with length 2100 mm for flexural behavior study. While group two (GR2) contain 5 specimens with 1000 mm length for shear behavior study. In every group there were two specimens beams with homogenous concrete as a references beams. One of them have a rectangular cross-section, while the other beam has a trapezoidal cross-section with 75 side angles. The remain specimens had trapezoidal cross-section of hybrid concrete $f_c(bottom)/f_c(top)= 0.5$ with side angle (75, 80, and 85), respectively, as shown in Figure (1). The concrete used compressive strengths of 50, and 25 MPa as shown in Table (1). Figure (2) shows the details of the reinforcement used for each beam.
Figure 1. Geometrical details of developed specimens.

Figure 2. Reinforcement details.
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2.2. Materials
The following materials are utilized throughout the current study:

1- Cement type I: Iraqi cement (Karasta cement), which is produced by Lafarge company, was used (5R.42-L-A / II C) for all concrete mixtures in the experiment. The test results complied with American Society for Testing and Materials (ASTM) and Iraqi standard specifications (IQS No.5/1984) [26].

2- Fine aggregate: Natural sand was used in all concrete mixtures as a fine aggregate. The maximum grain size is 4.75 mm, and the coefficient of smoothness is 2.82. Laboratory tests for sand were performed following the Iraqi specifications (No. 45/1984) [27].

3- Coarse aggregate: Crushed gravel with a maximum particle size of 19 mm was used as a coarse aggregate for normal strength concrete mixes. Sampling was conducted by ASTM C702-98 (reapproved 2003) [28]. The obtained grading curve lies within the ranges defined by IQR NO.45/1984.

4- Water: Reverse Osmosis (RO) water was used in the manufacture and treatment of concrete and proven through laboratory testing to conform to the limits of Iraqi Standard No. 1703/1992 [29].

5- Additive: Superplasticizer (Sika ViscoCrete-225 S) was added to concrete admixtures to improve workability and compressive strength which is compatible with ASTM C 1240-03 [30].

6- Reinforcing Steel Bars: Ukrainian steel bars were used in manufacturing considering reinforced concrete beams. Steel bars with diameters of Ø12 and Ø8 mm were respectively used as longitudinal and stirrups reinforcements and tested following ASTM 370-0 [31].

2.3. Concrete Mixes

Table 1. Description of the tested specimens

| Group No. | Stricture behavior | Specimen symbol | Concrete compressive strength \( (f_{cu}) \) (MPa) | Main longitudinal steel bars reinforced | Stirrups | Cross-section width (mm) | Side* angle (degree) |
|-----------|-------------------|----------------|-----------------------------------------------|----------------------------------|----------|-----------------------|---------------------|
| GR1       | Flexural          | BL6            | 50  50  2Ø12  Ø8@50mm  175  90               | top 50  bottom 50  top 2012  bottom 4Ø12 | Ø8@50mm  | 175  175              | 75.96               |
|           |                   | BL7            | 50  50  2Ø12  Ø8@50mm  250  75.96             | top 50  bottom 50  top 2012  bottom 4Ø12 | Ø8@50mm  | 250  100              | 75.96               |
|           |                   | BL8            | 50  25  2Ø12  Ø8@50mm  250  75.96             | top 50  bottom 25  top 2012  bottom 4Ø12 | Ø8@50mm  | 250  100              | 75.96               |
| GR2       | Shear             | BL9            | 50  25  2Ø12  Ø8@50mm  225  80.54             | top 50  bottom 25  top 2012  bottom 4Ø12 | Ø8@50mm  | 225  125              | 80.54               |
|           |                   | BL10           | 50  25  2Ø12  Ø8@50mm  200  85.24             | top 50  bottom 25  top 2012  bottom 4Ø12 | Ø8@50mm  | 200  150              | 85.24               |
|           |                   | BS6            | 50  50  2Ø12  Ø8@50mm  175  90               | top 50  bottom 50  top 2012  bottom 4Ø12 | Ø8@50mm  | 175  175              | 75.96               |
|           |                   | BS7            | 50  50  2Ø12  Ø8@50mm  250  75.96             | top 50  bottom 50  top 2012  bottom 4Ø12 | Ø8@50mm  | 250  100              | 75.96               |
|           |                   | BS8            | 50  25  2Ø12  Ø8@50mm  225  80.54             | top 50  bottom 25  top 2012  bottom 4Ø12 | Ø8@50mm  | 225  125              | 80.54               |
|           |                   | BS9            | 50  25  2Ø12  Ø8@50mm  250  75.96             | top 50  bottom 25  top 2012  bottom 4Ø12 | Ø8@50mm  | 250  100              | 75.96               |
|           |                   | BS10           | 50  25  2Ø12  Ø8@50mm  225  80.54             | top 50  bottom 25  top 2012  bottom 4Ø12 | Ø8@50mm  | 225  125              | 80.54               |

* The side angle measure is calculated considering the horizontal axis as shown in Fig. (1).
Several mix designs were originally considered using the British design method (BS 5328 – 2:1997) [32]. Moreover, several trial mixes were performed. The final mixes used are shown in Table (2), while Table (3) presents the concrete properties.

| No | Compression strength | Max aggregate size (mm) | Cement kg/m³ | Sand kg/m³ | Gravel kg/m³ | Superplasticizer % | Water/cement % |
|----|----------------------|------------------------|---------------|------------|--------------|-------------------|----------------|
| 1  | 25                   | 19                     | 300           | 650        | 1150         | 0                 | 0              | 54             |
| 2  | 50                   | 19                     | 433           | 628        | 1190         | 0.5               | 2.17           | 38             |

### Table 3. Concrete properties

| Batch | Compressive strength, (f₅₀) Mpa | Modulus of elasticity (fₑ) Mpa | Splitting strength, (fₗ) Mpa | Rupture modulus (fᵣ) Mpa |
|-------|---------------------------------|--------------------------------|-------------------------------|--------------------------|
| 1     | 25                              | 29962                          | 3.8                           | 3.381                    |
| 2     | 50                              | 35273                          | 3                             | 4.845                    |

2.4. Preparation of Test Specimens

All molds comprised timber with a plywood face. These molds were made following the required sizes that fit the standard dimensions of the beams considering length, depth, and upper and lower widths. All molds were prepared, cleaned, and lubricated before casting, and the reinforcing steel cages were installed inside considering the provision of the appropriate cover for the rebar using plastic spacers. The concrete pouring process was performed after preparing all the work requirements. The concrete mixture was gradually placed in half of the mold. The mixture was then compressed by the vibrator, and the second layer was cast and compacted with a vibrator. Afterward, the outer surface was leveled with a hand trowel. The formwork was removed when the concrete hardened, and the water curing process started when the concrete was covered with a cloth to preserve moisture.

2.5 Test Setup

The testing process was conducted by supporting the beams simply from both ends. Then, a two-point center load was applied by a 600 KN capacity test machine. The load was gradually increased, with increment rates ranging from 5 kN until ultimate failure was realized. Observations, such as deflections, strains, and crack patterns, were recorded with each load increment. The change in strains was measured at mid-span in the tensile and compression regions, and these strain gauges were connected electrically to the data logger and personal computer.

3. Results and Discussion

3.1 Ultimate loads

Table (4) and Table (5) summarized test results. In general, the result shows that the ultimate load increases with the compression area, and the reduction in concrete strength in the tensile area negatively affects the ultimate load. However, this decrease is relatively smaller compared with that in the strength of the concrete in half. The results revealed that the effectiveness of hybrid strength trapezoidal configuration
maintained specimen strength, demonstrating reductions more than that of the hybrid strength influence compared with the last ratios. The test results indicated the absence of slipping failure. The best result for all hybrid strength trapezoidal sections are indicated in the specimens of $\theta = 76^\circ$. Figure (3) shows mode failure and crack pattern of all tested specimens.

3.1.1 Flexural strength
Table (6) briefly shows the moment strength capacity of tested specimens and the comparative analysis of reference specimens. The comparison of results with the hybrid strength reduction index shows that the average rating varies between 0.83–0.93 and 0.78–0.87 considering rectangular specimens and the trapezoidal section of uniform strength, respectively.

### Table 4. Test results of specimens dominated by flexural failure mode

| Group | Specimen | Description | Ultimate Load (kN) | Deflection (mm) | Crack Load (kN) | Strain (mm/mm) |
|-------|----------|-------------|-------------------|----------------|----------------|----------------|
|       |          |             | Ultimate         | Elastic        |                | Tension        | Compression    |
| GR1   | BL6      | Rectangular ($f_c = 50$ MPa reference (3)) Trapezoidal, $76^\circ$ | 310 | 14.1 | 9.5 | 65.5 | 0.000175 | 0.003168 |
|       | BL7      | angle, ($f_c = 50$ MPa, reference (4)) Trapezoidal, $76^\circ$ | 331 | 19.35 | 11.6 | 55.7 | 0.000196 | 0.004401 |
|       | BL8      | angle, ($f_{ct} = 50$ MPa, $f_{cb} = 25$ MPa) Trapezoidal, $80^\circ$ | 289 | 22.11 | 14.6 | 54.2 | 0.00019 | 0.004577 |
|       | BL9      | angle, ($f_{ct} = 50$ MPa, $f_{cb} = 25$ MPa) Trapezoidal, $85^\circ$ | 268 | 21 | 14 | 55 | 0.000105 | 0.005393 |
|       | BL10     | angle, ($f_{ct} = 50$ MPa, $f_{cb} = 25$ MPa) | 257 | 17 | 14.1 | 52.4 | 0.000272 | 0.004839 |

3.1.2 Shear strength
Table (6) shows the shear capacity of tested specimens, along with a comparison of results with the hybrid strength reduction index. The average rating varied between 0.97 and 0.99 for rectangular specimens and from 0.93 to 0.96 for trapezoidal sections of uniform strength.

3.2 Load–deflection response
Figure (3) shows the load–deflection curves for all tested specimens, which depict that specimen behavior is distinguished by three portions. The first straight portion exhibits specimen response in the elastic range, which is of identical slope and stiffness for all beams. The second portion begins after the initiation of the first cracks and depicts the steel yielding level. This portion is characterized by a slight variation in the progression of load–deformation increment. The last portion represents the plastic response, which corresponds to strain hardening of the provided steel reinforcement and the extension to the ultimate strength. This condition is similar for all trends and different in corresponding load levels. The assigned regions of the load–deflection curve have been varied following section type and considered parametric.
3.2.1 Specimens dominated by flexural failure mode
The geometry analysis results revealed that when the cross-section of the beam was changed from rectangle (BL1) to trapezoid with a homogeneous concrete (BL2), the deflection results respectively increased by 37.23%. The result analysis considering the interaction effect of hybrid strength and section shape indicated that when the cross-section of the beam was changed from rectangle BL1 to trapezoid...
with a hybrid concrete BL3, the deflection results increased by 56.81%. Table (6) briefly exhibits the mid-span deflection and comparison analyses of tested and reference specimens. The comparison of results with the hybrid strength reduction index shows that the average ratings varied between 1.2-1.57 and 0.88-1.14 respectively considering rectangular specimens and the trapezoidal section of uniform strength. The best result for all hybrid strength trapezoidal sections are indicated in the specimens of $\Theta = 76^\circ$.

3.2.2 Specimens dominated by shear failure mode
The results showed that specimens with a trapezoidal section and with uniform concrete, BS2 gave better results than specimens with a rectangular section and uniform concrete, BS1. Table (6) offers the mid-span deflection analysis of tested specimens, and a comparison analysis with reference specimens. The comparison of results showed the average rating varies between 1.22-1.60 with respect to rectangular specimens, and from 0.87-1.14 with respect to the trapezoidal sections of uniform strength. The best result for all hybrid strength-trapezoidal sections was found in specimens of $\Theta=80^\circ$.

3.3 Ductility
Ductility is one of the most important features to be taken into account in the designs of structures exposed to a large number of inelastic deformations resulting from different loading conditions [33]. The shear degradation and the concrete contribution to the shear strength of RC members have been predicted as a function of ductility demand [34–42], deflection capacity [43] and drift ratio [44]. Ductility of a beam is its ability to sustain inelastic deformation without any loss in its load carrying, prior to failure. The flexural ductility is measured in terms of a ductility index, given by:

$$\mu = \frac{\Delta u}{\Delta y}$$ \hspace{1cm} (1)

Where:
- $\mu$: ductility index, unitless
- $\Delta u$: Maximum deflection corresponding to maximum strength, mm
- $\Delta y$: Deflection corresponding to elastic or yield behavior limit, mm
3.3.1 Specimens dominated by flexural failure mode
Table (6) briefly exhibited moment strength capacity of tested specimens, besides; comparison analysis in scope of references specimens. The ductility index varies between (0.8-1.018) in respect to rectangular specimens and from (0.7-0.903) in respect to trapezoidal section of uniform strength. The best result for all hybrid strength-trapezoidal section are indicated in specimens of \(\Theta=76^\circ\) and \(\Theta=85^\circ\). The assigned flexural ductility of tested specimens has been varied according to section type.

3.3.2 Specimens dominated by shear failure mode
The comparison of results with hybrid strength reduction index shows that as the average rating varies between (0.94-1.19) in respect to rectangular specimens and from (0.74-0.94) in respect to trapezoidal section of uniform strength. Best result for all hybrid strength-trapezoidal section are indicated in specimens of \(\Theta=76^\circ\).

Table (6) briefly exhibited ductility index analysis of tested specimens, besides; comparison analysis in scope of references specimens.

3.4 Trapezoidal Section Area Distribution Effectiveness and Hybrid Strength Reduction Index Effect
Figure 4. clearly denotes that the effectiveness of trapezoidal section area of distribution on ultimate shear strength and ultimate flexural strength. For all tested beams of hybrid strength, ultimate shear strength and ultimate flexural strength are upgrade with section compression zone extension (\(\Theta\) exchange from 76 to 85). This observation confirmed the compatibility of trapezoidal section to developed efficient compression stress block with proper tension zone, without any significant effect of hybrid strength upon tension zone performance where the predicate failure modes likewise traditional failure mode. Figure 5. shows the effectiveness of trapezoidal section of hybrid section up on plastic deformation ability predicted by ductility improvement for deep beams. Although they are dominated by shear failure mode due to distributed stress which is associated with brittleness response, they are exhibited ductility indexes close up to specimens that failed by flexural mode and this observation could be contributed hybrid strength-trapezoidal interaction effect.

### Table 6. Result Analysis

| Group | Speci. | \(\Psi\) | Ultimate load (kN) | \(\alpha_1\) | \(\alpha_2\) | Deflection (mm) | \(\gamma_1\) | \(\gamma_2\) | Ductility | \(\beta_1\) | \(\beta_2\) |
|-------|--------|--------|------------------|----------------|----------------|-----------------|--------------|--------------|------------|----------------|------------|
| G1    | BL6    | 1      | 310              | 1              | 1              | 14.1            | 1            | 1            | 1.484     | 1              | 1          |
|       | BL7    | 1      | 331              | 1              | 1              | 19.35           | 1            | 1            | 1.668     | 1              | 1          |
|       | BL8    | 0.5    | 289              | 0.9323         | 0.8731         | 22.11           | 1.568        | 1.1426       | 1.51       | 1.018         | 0.905      |
|       | BL9    | 0.5    | 268              | 0.8645         | 0.8097         | 21              | 1.4894       | 1.0853       | 1.5        | 1.011         | 0.899      |
|       | BL10   | 0.5    | 257              | 0.829          | 0.7764         | 17              | 1.2057       | 0.8786       | 1.206      | 0.813         | 0.723      |
| G2    | BS6    | 1      | 410              | 1              | 4.7            | 1               | 1.25         |              |            |                |            |
|       | BS7    | 1      | 425              | 1              | 6.6            | 1               | 1.586        |              |            |                |            |
|       | BS8    | 0.5    | 406.1            | 0.991          | 0.9555         | 7.55            | 1.6063       | 1.1439       | 1.49       | 1.192         | 0.939      |
|       | BS9    | 0.5    | 400              | 0.9756         | 0.9412         | 7.16            | 1.5234       | 1.0848       | 1.42       | 1.136         | 0.895      |
|       | BS10   | 0.5    | 397              | 0.9683         | 0.9341         | 5.76            | 1.2255       | 0.8727       | 1.18       | 0.944         | 0.744      |
4. Conclusion

1- For all tested beams of hybrid strength, ultimate shear strength and ultimate flexural strength are upgrade with section compression zone extension (θ exchange from 76 to 85). This observation confirmed the compatibility of trapezoidal section to developed efficient compression stress block with proper tension zone, without any significant effect of hybrid strength upon tension zone performance where the predicate failure modes likewise traditional failure mode.

2- Specimens of flexural mode are more response to section alignment side angle than those of shear mode.

3- In flexural behavior, the ultimate strength decreased by (2.82%) and the deflection increased by (56.81%) with respect to rectangular specimens. In shear, behavior gave an ultimate load close or
identical to the control specimens and increasing in deflection by average from (9% to 60%) with respect rectangular specimen. The effect of area distribution within section (section shape sides orientation) clearly affects the first crack load where the angle (90°) recorded a highest value of crack load.

4- The ultimate failure load of hybrid trapezoidal sections of reinforced concrete beams recorded a reduction ranging from 6.77% to 17% for the flexural failure mode, while the reduction ranging in shear failure mode was from 0.95% to 3.17%, compared with that of control specimens. This result indicates a slight reduction in strength, which depicts the positive effect of hybrid strength trapezoidal sections with the reduction in compression strength to half in the tension region. However, the homogeneous specimen with a trapezoidal cross-section achieved an increase in failure load by 6.77% for the flexural failure mode, and by 3.66% for the shear failure mode compared with the specimen with a rectangular cross-section.

5- The results reveal that the effectiveness of hybrid strength trapezoidal configuration maintained considerable specimen strength reduction compared with that of hybrid strength.

6- The results showed that the hybrid strength trapezoidal section yielded high deflection results. The increase rates were 20% to 57% for the flexural failure mode, and from 22% to 60% for the shear failure mode compared with that of control specimens. This result confirms the powerful effect of hybrid strength trapezoidal section in improving section ductility compared with those in the rectangular section or uniform strength.

Notation

Codes used throughout this research:

- $f'_c$: Concrete compressive strength, MPa
- $E_c$: Modulus of elasticity, MPa
- $f_s$: Splitting strength, MPa
- $f_r$: Rupture modulus, MPa
- $\alpha_i$: Ultimate load rating considering reference specimen i
- $\beta_i$: Ductility rating considering reference specimen i
- $\gamma_i$: Deflection rating considering reference specimen i

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