



BEHAVIOR OF HYBRID REINFORCED CONCRETE BEAMS ON FLEXURAL STRENGTH

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<https://doi.org/10.30572/2018/kje/150203>

ABSTRACT

The objective of this research is to experimentally study the flexural behavior of hybrid reinforced concrete beams. Three test beams, each with dimensions of (2200 X 150 X 240) mm, were fabricated for this purpose. The first beam was constructed using ordinary concrete, while the second beam consisted of two layers of high-strength concrete in the compression zone and normal concrete in the tension zone. The third beam was entirely cast using high-strength concrete. In terms of reinforcement, all beams were equipped with 2 ϕ 12 steel bars in the tension zone and 2 ϕ 12 steel bars in the compression zone. Additionally, ϕ 12 steel bars were employed to resist shear forces, distributed along the length of the beams with a spacing of 125 mm c/c. Two-point loading was applied to all beams until failure occurred. The results obtained from the experimental tests reveal that the use of hybrid concrete beams enhances the ultimate load capacity by approximately 20.93%. On the other hand, beams constructed entirely from high-strength concrete exhibited an increase in failure load capacity by approximately 28.68%.

KEYWORDS

Hybrid Concrete, High Strength Concrete, Flexural Strength, Reinforcement Normal Strength Concrete.



1. INTRODUCTION

While the concept of hybrid concrete is not novel, its significance has grown in recent times due to its ability to enhance load-bearing capacity and cost-effectiveness. In civil engineering construction, the objective is to select materials that can fully exploit their properties to achieve optimal performance for the structure (Al-Shadidi and Mahmoud, 2006). The assessment of material superiority is based on factors like availability, workability, structural strength, durability, and cost. Given the challenge of finding a single material that possesses all desired properties to a satisfactory level, engineers are tasked with optimizing the use of different materials and construction methods (Yam, 1981). Hybrid layered systems, incorporating various strength materials, have found application in civil engineering construction (Abtan and Jaber, 2016).

Hybrid concrete involves the incorporation of multiple types of concrete, enabling the utilization of each type's distinct properties. An advantageous approach is to combine high-strength concrete with conventional concrete in hybrid members to leverage the strengths of both materials effectively (Agha and Alwash, 2020). In a flexural context, a typical hybrid concrete structure consists of two layers. For instance, the upper layer is cast with high-strength concrete, while the lower layer, subjected to tensile stress, is made using ordinary concrete. This combination addresses the issues of brittle failure associated with high-strength concrete and the durability concerns associated with ordinary concrete (Al Shami and Al-Katib 2022).

Luma, et al. studied the hybrid RC beams behavior. Eight beams were casted, two of them are made from self-compact concrete (SCC) and normal strength concrete (NSC) and used as a control beams. the others contain two layers, the upper layer made of self-compacted concrete (SCC) while the tension layer made of normal strength concrete (NSC). The use of hybrid concrete improved the behavior of models and increased the failure load but had no effect on the crack load comparison with NSC beam (Luma, 2021). Ragheed, et al. investigate eight flat slab specimens, two flat slabs specimens were constructed using only one type of concrete (NSC and HSC), serving as control beam. The remaining six specimens were constructed as hybrid flat slabs, utilizing a combination of NSC and HSC. In three of these hybrid flat slabs, HSC was used in the tension zone, while in the other three, it was used in the compression zone. The results indicated that when HSC was used fully in the control flat slab instead of NSC, there was an observed increase in the ultimate load capacity of approximately 19.4%. Additionally, the hybrid flat slabs with HSC in the compression zone exhibited higher ultimate loads compared to the hybrid flat slabs with HSC in the tension zone. Moreover, the

compression zone hybrid flat slabs were found to be stiffer in terms of the load-deflection curve compared to the tension zone hybrid flat slabs (Makki et al., 2019).

Abtan and Jaber investigated the hybrid RC beams behavior. twelve simply support beams made and tested in flexure. For the tensile layer lightweight concrete was used. As for the compression layer, reactive powder concrete was used. The results demonstrated that there was an increase in cracking and ultimate load and reduction in deflection by increasing the thickness of the reactive powder concrete layer. The type of failure was flexural mode for all models examined (Abtan and Jaber, 2016). Hisham et al. studied the flexural behavior of hybrid tee beams The experimental results showed that using reactive powder concrete (RPC) in the web and normal strength concrete in the flange effectively enhanced performance of hybrid T-section beams when compared with normal strength concrete T-beam, however, the increases in the first crack load, ultimate flexural load and ultimate deflection were 86.67%, 60% and 29.19% respectively, while, the increases for the case of using RPC in the flange and normal strength concrete in the web were 20%, 34.28% and 14.97 respectively when compared with normal strength concrete T-beam (Al-Hassani et al., 2015).

The primary objective of this research is to study and analyze the flexural behavior of hybrid concrete beams that consist of a combination of high-strength concrete and normal concrete.

2. METHODOLOGY

2.1. Models' details

This study includes three reinforced concrete beams, the first beam) NSB) made with normal strength concrete (compressive strength 25 Mpa) and consider as reference beam, the second beam (HBC) casted in two-layer, concrete with compressive strength (50 Mpa) in the compression layer and normal strength with compressive strength (25 Mpa) in the tension zone and the third beam (HSB) casted with high strength concrete (compressive strength 50 Mpa). Each specimen consists of total length of 2200 mm and the dimensions of a cross section with a width of 150 mm and a height of 240 mm. The effective span was 2000 mm. The flexural reinforcement of all beams consists of 4 ϕ 12 steel bars. Furthermore, to prevent shear failure ϕ 12 steel bars were used, distributed along the length of the specimens spaced at 125 mm c/c as shown in Fig.1. Depending on ACI 318-19 (American Concrete Institute [ACI], 2019) beams were designed to be failed in flexure failure.

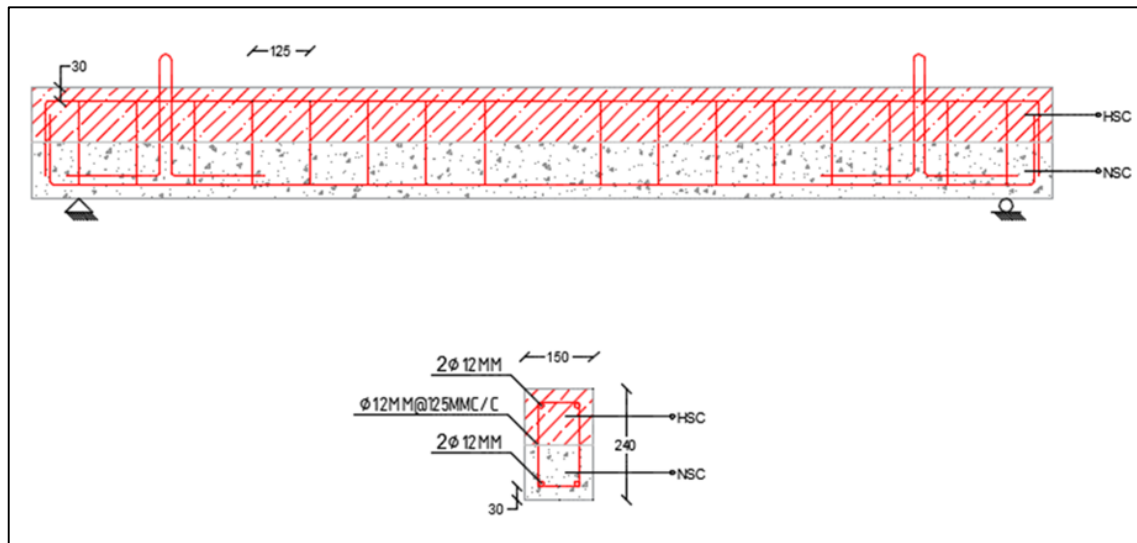


Fig. 1. Details of Tested Beams.

2.2. Material properties

In preparing the concrete mix for all the beams, ready-mixed concrete was used. The concrete mix consisted of Al-Nibaae coarse aggregate with a maximum size of 19mm, natural sand from the Al-Najaf region, AL-JESR cement, tap water, silica fume, and concrete additive. Two different concrete mixtures were created to achieve different compressive strengths, show [Table 1](#). The reinforcement used in the beams was Rouhina steel. Both the top and bottom longitudinal reinforcement in the beams were comprised of $\phi 12$ steel bars., while $\phi 12$ steel bars were used as shear reinforcement (stirrups). The material properties of the steel reinforcement were measured using a hydraulic loading frame in the Civil Engineering Structural Laboratory and are listed in [Table 2](#).

Table 1. Components of concrete mix.

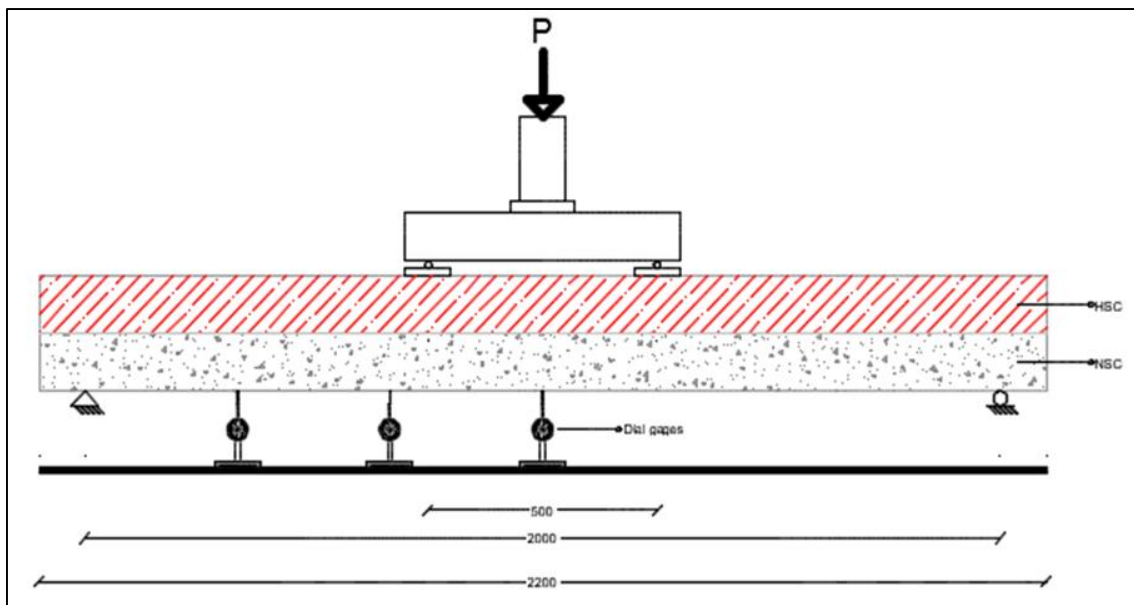
Materials	Mix type A	Mix type B
Cement (Kg)	500	350
Corse aggregate (Kg)	800	1200
Fine aggregate (Kg)	880	800
W/S	26%	42%
Superplasticizer (L/M ³)	7.5	-----
Silica fume (% of cement)	15	-----

Table 2. Steel bars properties.

Normal diameter (mm)	Yield strength (Map)	Ultimate strength (Map)	Elongation %
12	525	697	16
ASTM A615M	>420 ok	>620 ok	>9 ok

2.3. Experimental setup

The flexural tests were conducted in the Structural Testing Laboratory of the Faculty of Engineering at Kufa University. The tested beams were simply supported, and plates and rollers were placed beneath the load points and supports to prevent local concrete crushing. The supports were positioned 100 mm from the ends of the test specimens, creating an effective span of 2000 mm. Fig. 2 illustrates the experimental test setup for the beam. To measure the deflection of beams, three dial gauges were used, placed at the mid-span and at distances of 660 mm and 330 mm from the support. The actuator rate during the test was maintained at 5 kN/min. Additionally, the crack width of the beams was measured using a crack meter.

**Fig. 2. Loads and supports location.**

3. RESULTS

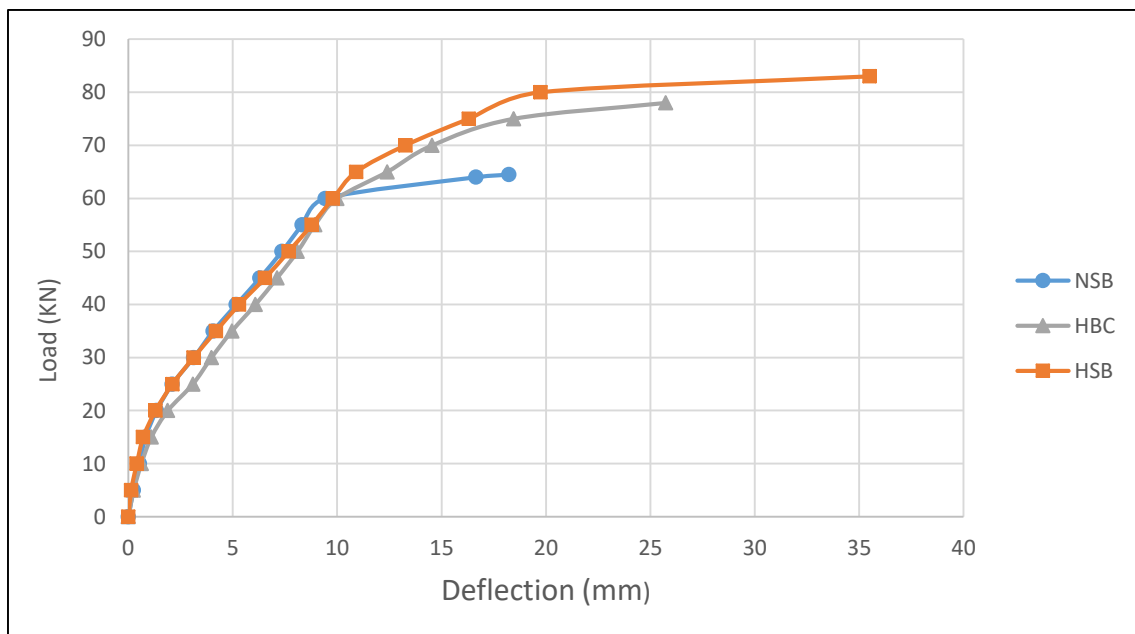
The test results obtained from the examination of the three samples are presented in Table 3. it was observed from the results that there is an increase in the final load by 20.93%, while there was no effect on the first crack load for the HBC compared with control beam. For HSB, the ultimate load was increased about 28.68% and the first crack load enhanced about 33.33% relative to NSB.

Table 3. Experimental test results.

	First crack load (kN)	Percentage of Increase in first crack load (%)	failure load (kN)	Percentage of Increase in failure load (%)	Deflection at failure (mm)	Failure modes	Max. Crack width
NSB	15	-----	64.5	-----	18.22	Flexural failure	1.75
HBC	15	-----	78	20.93	25.73	Flexural failure	2.17
HSB	20	33.33	83	28.68	35.5	Flexural failure	1.42

3.1. Load- Deflection Curves

The load-deflection curves for beams showed in Fig. 3. In the first stage, all samples showed linear behavior up to the first crack. It was found that the first crack load increased by 33.33% for HSB. While the HBC there was no enhanced in the first crack load compared to the NSB. Also, there was slight effect on the deflection and stiffness of the HSB compared to the NSB at this stage. In the second stage, the behavior of curves was nonlinear until to failure point. the deflection was increased about 94.84% and 41.21% for HSB and HBC respectively compared with NSB. the stiffness increased slightly in HSB compared to NSB. While the HBC, this effect did not appear. The Fig. 4 shows the deflected shape along the beam for models at different loading stages.

**Fig. 3. load-deflection curves for beams.**

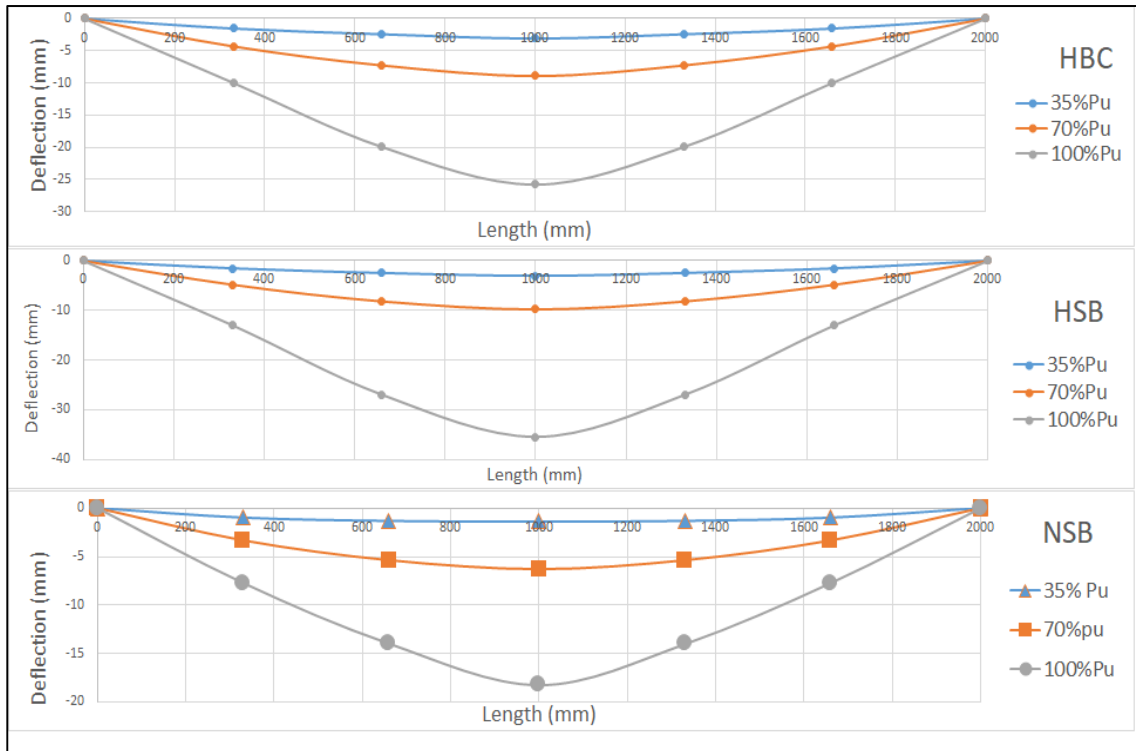


Fig. 4. deflected shape.

3.2. Failure Modes

Fig. 5 illustrate the failure modes of beams tested in this research. All beams failed by flexural, as cracks appeared in the middle of the samples in the tensile zone, after which the cracks extended vertically until the concrete crashed in the compression zone. The failure mode of the models did not change as the type of the concrete changed due to the presence of sufficient reinforcement in the shear zone.

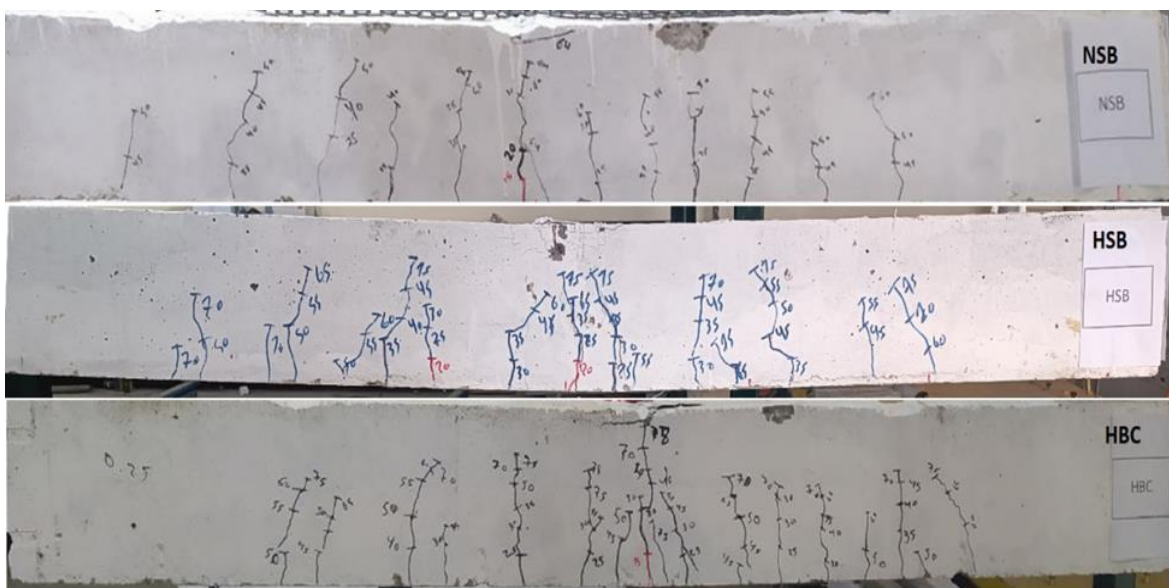


Fig. 5. Failure Mode for beams.

3.3. Crack width

A crack meter was used to measure cracks width less than 0.1mm, and the vernier caliper was used for cracks width greater than 0.1mm, show Fig. 6. Fig. 7 show the effect of concrete type on the crack width. The crack width increased about 14.28% and 24% for beam HSB and HBC respectively compared with NSB.



Fig. 6. Testing Instruments.

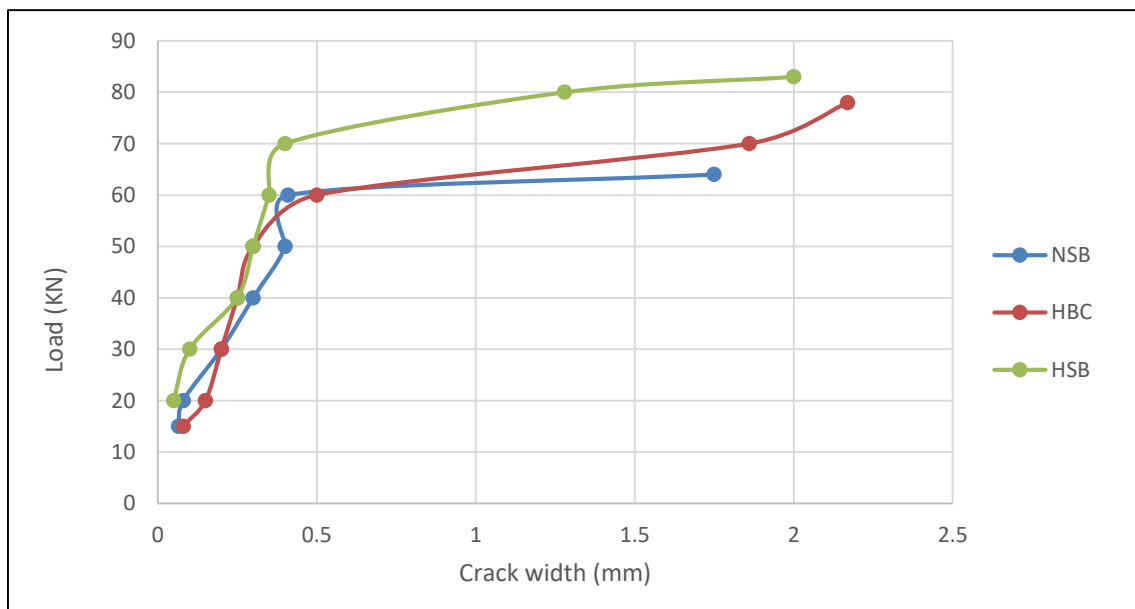


Fig. 7. Load-Crack Width for beams.

3.4. Toughness

Toughness of a material refers to its ability to absorb energy in the plastic domain until it reaches the point of rupture. Evaluating this parameter can be challenging, but one approach involves calculating the total area (A) bounded by the stress-strain or load-deflection curve, divided by the volume of the tested sample. This area provides an indication of the amount of energy per unit volume that the material can withstand until it ruptures (Park, 1988) (refer to Fig.8).

In this study, the area under the load-deflection curve was computed for all models, and the results are summarized in Table 4. It was noted that the toughness index improved by 7.47% and 14.58% for the hybrid concrete (HBC) and high-strength concrete (HSB) beams, respectively, relative to normal strength beam (NSB) as Increasing the compressive strength of concrete led to increased toughness.

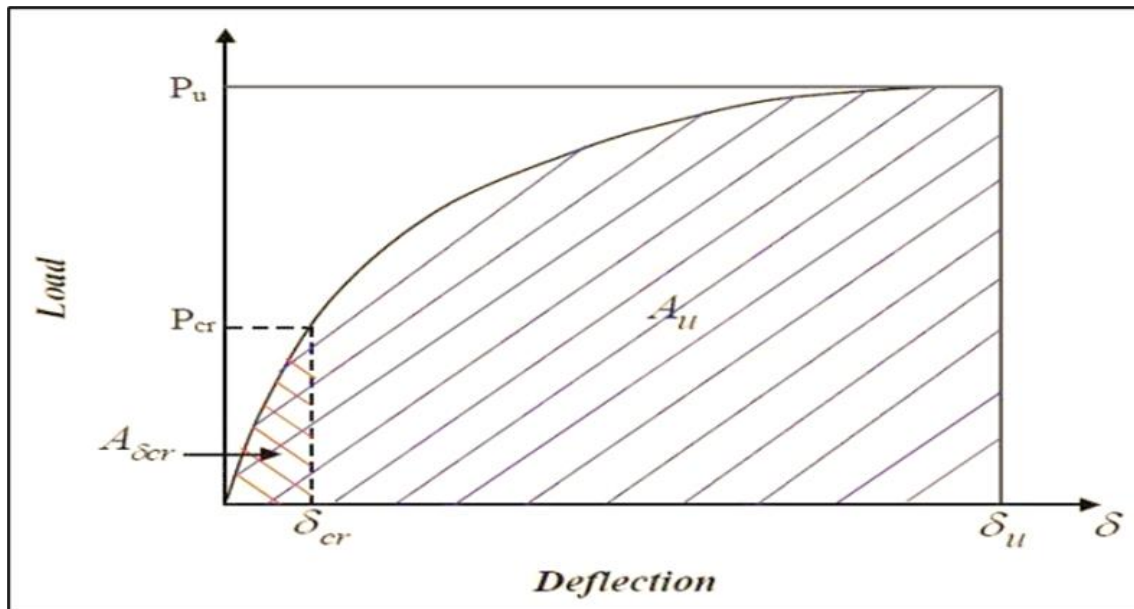


Fig. 8. Load-Deflection Curve and Toughness Parameter.

Table 4. Result of Toughness of Beams.

no	name	$A_{\delta cr}$	Toughness (kN.mm)	Toughness Index
1	NSB	15.075	893.355	59.26
2	HBC	23.225	1479.145	63.69
3	HSB	34.775	2361.39	67.90

3.5. Stiffness

The stiffness (k) is defined as an elastic body resistance to deformation. It was expected that the effective secant stiffness which is dependent on the strength in the service load stage, would be present ($0.75 \times P_u$) (Dawood and Abdulkhaleq, 2017), show Fig. 9. The measured values of the specimen's stiffness are presented in Table 5 below. The stiffness did not increase for the hybrid concrete beam (HBC), but it was increased by 12.5% for the high-strength concrete beam (HSB) compared to the normal concrete beam (NSB).

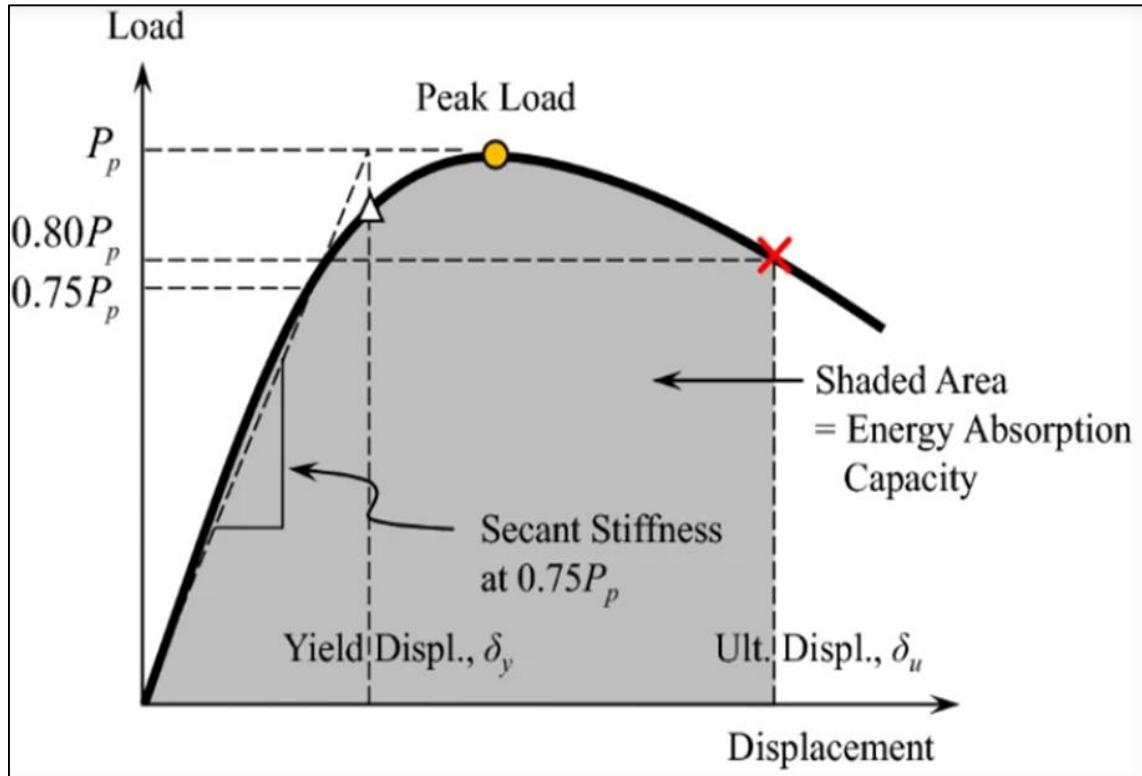


Fig. 9. stiffness typical curve.

Table 5. Stiffness Results for Specimens.

Beam Name	Ultimate Load P_u (KN)	$0.75P_u$ (KN)	Deflection at $0.75P_u$ (mm)	Stiffness (K) (KN/mm)	Δk (kN/mm)	$\Delta k\%i^*$
HBC	78	58.5	9.679	6.044	0	0
HSB	83	62.25	10.299	6.044	0	0
NSB	64.5	48.375	7	6.910	0.866	12.5

4. CONCLUSIONS

In this research, the conclusions can be summarized in several points

1. using high-strength concrete beam (HSB) led to an enhance the ultimate load by 28.68%, while it increased by 20.93% for the hybrid concrete beam (HBC) compared to control beam (NSB). The first crack load had no effect on HBC, while it increased by 33.33% for the HSB compared with NSB.
2. The deflection increased by 41.21% when using HBC, while it increased by 94.84% when using HSB.
3. The crack width of the hybrid concrete beam (HBC) increased compared to the high-strength beam (HSB) because it was less stiffness.
4. All models failed with flexural and there was no change in failure mode.
5. The Toughness improved by 7.47% for the HBC, while there was no increase in the stiffness. For HSB, the toughness and stiffness were increased about 14.58% and 12.5% respectively compared with NSB.

5. RECOMMENDATIONS

1. Studying the hybrid concrete beam behavior with opening
2. Studying the hybrid beam concrete behavior strengthening with FRP bars
3. Study of hybrid beams using normal concrete and reactive powder concrete
4. Repairing high strength concrete using FRP sheets

6. REFERENCES

Abtan, Y. G., & Jaber, H. T. (2016). BEHAVIOR OF HYBRID REINFORCED CONCRETE BEAMS COMBINING REACTIVE POWDER CONCRETE AND VARYING YTPES OF LIGHTWEIGHT CONCRETE. *Journal of Engineering and Sustainable Development*, 20(2), 204-223.

ACI Committee 318. (2019), "Building Code Requirements for Structural Concrete (ACI 318M-19) and Commentary (318RM-19)", American Concrete Institute, Detroit. MI. U.S.A.

Agha, D. A., & Alwash, N. A, 2020. "Experimental Behavior of Composite Reactive Powder Concrete Girder and Normal Concrete Deck Slab". [HTTPS://www.researchgate.net/publication/341509405](https://www.researchgate.net/publication/341509405).

Al Shami.A. and Al-Katib. H. .2022. “Shear Behavior of Isolated Hybrid concrete beam with Circular openings strengthening with CFRP” *Journal of Hunan University Natural Sciences*), Vol. 49, No.06, June 2022.

Al-Hassani, H. M., Al-Kafaji, J. M., & Ismael, M. A. (2015). Flexural Behavior of Hybrid Tee Beams (Containing Reactive Powder Concrete and Normal Strength Concrete). *Journal of Engineering and Sustainable Development*, 19(2), 123-140.

Al-Shadidi M., Mahmoud K., (2006)," Mechanical behavior of hybrid of strength reinforced concrete beam", University of Baghdad College of Engineering Civil Engineering Department.

Dawood M. & Abdulkhaleq M. (2017). “Structural behavior of nonpragmatic reactive powder concrete (RPC) continuous members under the effect of static and repeated loads”. *Int. J. Sci. Eng. Res*, 8(1), 800-806

Hussein, L. F., Khattab, M. M., & Farman, M. S. (2021). Experimental and finite element studies on the behavior of hybrid reinforced concrete beams. *Case Studies in Construction Materials*, 15, e00607.

Makki, R. F., Alalikhan, A. A., & Al-Katib, H. A. (2019). Load-deflection behaviour of hybrid concrete flat slab. *Scientific Review Engineering and Environmental Sciences*, 28 (4), 516–525.

Park, R. 1988. “Ductility Evaluation from Laboratory and Analytical Testing.” *Proceedings of the 9th World Conference on Earthquake Engineering*, 2-9August 605–16.

Yam, L. (1981), “Design of Composite Steel-Concrete Structures”, Surry University Press, London, pp. 1981,168.