

Flexural Behavior of Reinforced Concrete Beams with Varying Carbon Content in Steel

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Received: 27 November 2025 | Revised: 20 January 2026 and 9 February 2026 | Accepted: 11 February 2026

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ABSTRACT

This study examines the influence of carbon content in reinforcing steel on the flexural behavior of reinforced concrete beams subjected to two-point loading. Three categories of reinforcing steel were investigated: low-carbon (0.302%), medium-carbon (0.318%), and high-carbon (0.411%), with three beam specimens tested for each type. The average ultimate loads (P_u) were 48.78 kN for Low-Carbon Bars (LCB), 57.39 kN for Medium-Carbon Bars (MCB), and 62.28 kN for High-Carbon Bars (HCB). The corresponding average mid-span deflections at ultimate load were 85.14 mm, 51.09 mm, and 47.72 mm, respectively. An increase in carbon content resulted in an approximately 28% increase in ultimate strength from LCB to HCB, accompanied by a 54% reduction in ductility (μ). In terms of structural response, LCB beams exhibited significant plastic deformation and gradual flexural crack development, indicating high energy dissipation capacity. MCB beams demonstrated a balanced combination of strength and ductility. In contrast, HCB beams achieved the highest strength but exhibited limited post-yield deformation and more pronounced crack localization.

Keywords-carbon content; reinforcing steel; reinforced concrete beam; flexural behavior; ductility

I. INTRODUCTION

Reinforced concrete structures are among the most widely used construction systems in civil engineering due to their high compressive strength, durability, and capacity to resist both static and dynamic loads [1]. Since concrete is inherently brittle and weak in tension, reinforcing steel is required to provide tensile resistance, thereby improving flexural capacity and enabling plastic deformation of structural members [2]. However, reinforcing steel available in the market is often produced from recycled scrap metal, particularly by local manufacturers [3]. This production process makes it difficult to control the chemical composition of the steel, especially its carbon content. Although reinforcing bars may appear uniform in diameter and surface characteristics, variations in carbon content can result in significant differences in mechanical properties, directly affecting ductility and flexural strength [4]. Furthermore, commonly used reinforcement specifications typically refer only to grade classifications, such as BJTP or BJTD, without detailed consideration of chemical composition. Consequently, the actual mechanical performance of the

reinforcement may not fully align with the structural demands assumed in design [5]. The mechanical properties of reinforcing steel, such as yield strength, ultimate tensile strength, and ductility, are significantly influenced by its chemical composition, particularly the carbon content. Increasing carbon content generally enhances tensile strength but reduces ductility due to microstructural changes, including a higher proportion of harder and less ductile pearlite phases [6]. Therefore, achieving an appropriate balance between strength and deformability is crucial to ensure the optimal structural performance of reinforced concrete members.

The material properties of reinforcing steel and the use of carbon-based materials significantly influence the flexural behavior and ductility of reinforced concrete elements. Authors in [7] reported that variations in carbon content and microstructure can increase strength but reduce ultimate strain, hence decreasing ductility. Authors in [8] tested four types of reinforcing steel and observed that higher carbon content enhances yield strength (431.2 MPa–505.4 MPa) and ultimate tensile strength (614 MPa–673 MPa), while reducing ductility.

Authors in [9] found that increasing carbon content in Medium Carbon Steel (MCS) (0.3%–0.55%) improves yield and ultimate strengths without significantly affecting elongation. In [4], it was reported that reinforcing steel bars produced from scrap metals exhibit variations in strength and ductility depending on chemical composition, highlighting the need for careful material selection. Based on these findings, the present study systematically investigates low, medium, and high-carbon reinforcing steels in concrete beams under flexural loading, allowing direct comparison with previous experimental results.

Authors in [10] emphasized that variations in the mechanical properties of reinforcing steel significantly influence beam stiffness, post-cracking deformation capacity, and overall flexural performance. These findings underscore the importance of rigorous quality control and appropriate material selection to ensure sufficient ductility, particularly for structures located in seismic-prone regions. Experimental investigations on reinforced concrete beams further demonstrate that different reinforcement characteristics lead to variations in crack patterns, stiffness degradation, and flexural capacity. Authors in [11, 12] reported that the incorporation of carbon-based materials can enhance flexural strength, while ductility depends on the specific material properties and the interaction between reinforcement and concrete. Authors in [13] observed that different reinforcement types produce distinct flexural responses and crack development patterns. In addition to material type, the reinforcement ratio plays an important role in flexural behavior. Authors in [14] indicated that increasing the reinforcement ratio proportionally increases flexural strength, while authors in [15] confirmed that higher tensile reinforcement ratios result in greater moment capacity. Furthermore, in [16], it was demonstrated that variations in the tensile strength of reinforcing steel affect the flexural capacity of hollow reinforced concrete beams. Despite these contributions, experimental studies that directly quantify the influence of carbon content variation in reinforcing steel on the flexural behavior of full-scale reinforced concrete beams, considering strength, ductility, steel strain response, and crack patterns, remain limited. The present study attempts to fill this research gap by systematically investigating these effects under controlled experimental conditions to provide quantitative guidance for material selection and structural design.

II. MATERIALS

In this study, ready-mix concrete with an average 28-day compressive strength of 23.74 MPa was used. The nominal slump value did not exceed 100 mm, complying with [17]. The compressive strength was determined from compression tests on cylindrical concrete specimens with a diameter of 150 mm and a height of 300 mm, conducted in accordance with [19]. In addition, the flexural strength of the concrete was determined according to [20]. The results of the compressive strength tests are presented in Table I.

The reinforcing steel used in this study consisted of three types: Low, Medium, High Carbon Steel Bars. The mechanical properties of the reinforcing steel were evaluated through tensile testing to determine the yield strength, ultimate tensile strength, yield strain, and ultimate strain. All tensile tests were

conducted in accordance with [21] and the reinforcing steel testing method specified in [22]. In addition, Optical Emission Spectroscopy (OES) analysis was performed to determine the carbon content of each type of reinforcing steel. The results of the tensile tests and OES analysis are presented in Table II.

TABLE I. COMPRESSIVE STRENGTH AT 28 DAYS

Specimens	Section area (mm ²)	Load (kN)	Compressive strength (Mpa)	Average (Mpa)
1	7850	187770	23.92	23.74
2	7850	185000	23.57	
3	7850	186385	23.73	

TABLE II. TENSILE TEST RESULTS AND CARBON CONTENT OF REINFORCING STEEL

Steel type	Carbon (%)	Yield strain, ϵ_y ($\mu\epsilon$)	Ultimate strain, ϵ_u ($\mu\epsilon$)	Young's modulus of steel, E_s (MPa)	Ductility index ϵ_u/ϵ_y (μ)
LCS	0.302	2226	117593	233918	52.83
MCS	0.318	1990	63101	273069	31.7
HCS	0.411	2415	113943	354421	26.06

Figure 1 illustrates the stress-strain behavior of the reinforcing steel obtained from the tensile tests. The curves describe the elastic region, yielding point, strain hardening, and ultimate tensile behavior of each steel type, providing a comparison of their mechanical performance, as influenced by carbon content.

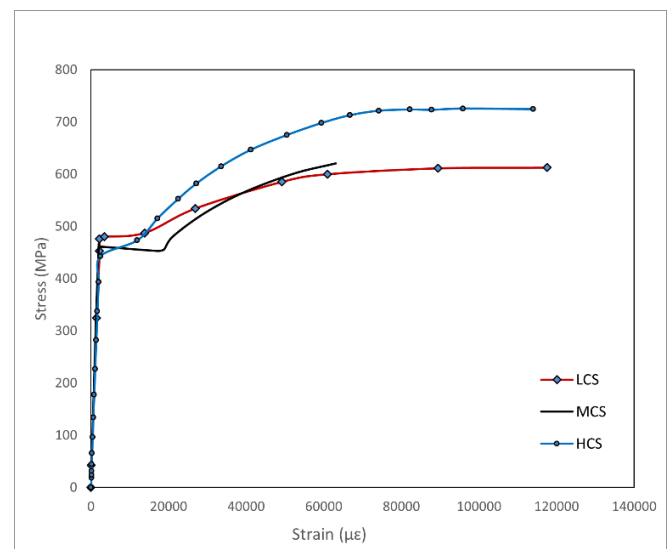


Fig. 1. Stress-strain reinforcing steel.

The three considered types of reinforcing steel were used as the main tensile reinforcement in the fabrication of the reinforced concrete beam specimens. Each beam had dimensions of 150 mm × 250 mm × 3300 mm and was designed as a single reinforced beam. The tensile reinforcement consisted of two D16 bars, while two D10 bars were provided as compression reinforcement. Shear reinforcement was provided in the form of Ø8 mm stirrups, spaced at 100 mm

over the outer one-third spans at both beam ends and at 200 mm spacing in the midspan region. The beam details are shown in Figure 2, while the specimens after casting are depicted in Figure 3. The complete specifications of the reinforced concrete beam specimens are summarized in Table III.

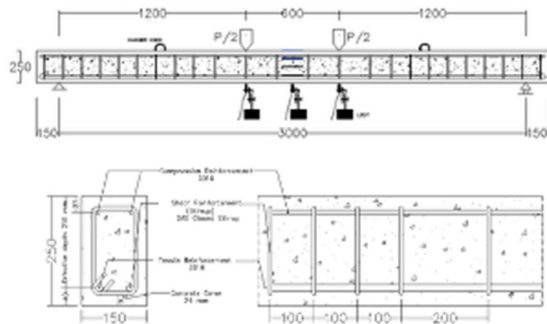


Fig. 2. Beam geometry and cross-sectional detailing with exact dimensions and reinforcement layout.



Fig. 3. The beam specimens.

TABLE III. SPECIFICATIONS OF THE REINFORCED CONCRETE BEAM SPECIMENS

Beam specimens	Type of reinforcement	Loading type	Number of specimens
LCB	LCS	Static	3
MCB	MCS	Static	3
HCB	HCS	Static	3

The reinforced concrete beam specimens were designed in accordance with the provisions of [18] to ensure flexural failure governed by steel yielding (under-reinforced behavior). A strength reduction factor (ϕ) of 0.90 was adopted for flexural design, complying with [17, 18]. This factor implicitly accounts for material safety by considering uncertainties in concrete compressive strength and reinforcing steel yield strength, consistent with the strength design philosophy. The nominal flexural capacity of the beams was calculated using the rectangular stress block approach. The nominal moment capacity (M_n) was determined as:

$$M_n = A_s f_y \left(d - \frac{a}{2} \right)$$

where a is:

$$a = \frac{A_s f_y}{0.85 f'_{cb}}$$

The design approach is consistent with [17], which adopts the same flexural design principles as [18]. The calculated reinforcement ratio ($\rho = \frac{A_s}{bd}$) confirmed that all beam specimens satisfied the under-reinforced design requirements.

All experiments were conducted at the Structural and Materials Laboratory, Department of Civil Engineering, Hasanuddin University. The beam specimens were tested under two-point static loading after the concrete reached 28 days of curing. Loading was applied using a hydraulic testing machine with a maximum capacity of 1500 kN. The tests were performed under displacement control at a loading rate of 0.2 mm/s, measured at midspan. The applied load was monitored using a calibrated 200 kN load cell to ensure accurate force measurement throughout the test. To monitor beam deflection, three Linear Variable Displacement Transducers (LVDTs) were installed at the midspan and directly beneath the two loading points. During testing, strain, stress, and deformation data were automatically recorded using a computer-based strain-gauge data-acquisition system, as portrayed in Figure 4.



Fig. 4. Beam test specimens.

III. RESULTS AND DISCUSSION

A. Load and Deflection of Reinforced Concrete Beam

Figure 5 presents the load-deflection curves of nine beam specimens tested under static two-point loading. All beams exhibited typical reinforced concrete behavior, uncracked elastic phase, cracked elastic phase up to steel yielding, and post-yield phase leading to ultimate failure. Generally, all specimens exhibited the typical behavior of reinforced concrete beams, consisting of the uncracked elastic phase, the cracked elastic phase up to the yielding of the reinforcement steel, and the post-yield phase leading to ultimate failure. A significant difference in the ultimate load (P_u) among the beam groups, which directly correlates with the carbon content and tensile strength of the reinforcement steel, is illustrated in Figure 5 and quantitatively detailed in Table IV.

The LCB beams had P_y of 41.7 kN–42 kN, P_u of 48 kN–50 kN, and ultimate deflections of 71 mm–93 mm ($\mu = 4.64$ –5.75), indicating very high ductility. MCB beams showed P_y of 51 kN–57 kN, P_u of 55 kN–61 kN, and ultimate deflections of 38 mm–57 mm ($\mu = 2.09$ –2.86), reflecting moderate ductility. The HCB beams were the strongest, with P_y of 55 kN–62 kN, P_u of 58 kN–67 kN, and ultimate deflections of 40 mm–62 mm ($\mu = 1.94$ –3.24), demonstrating moderate post-yield deformation.

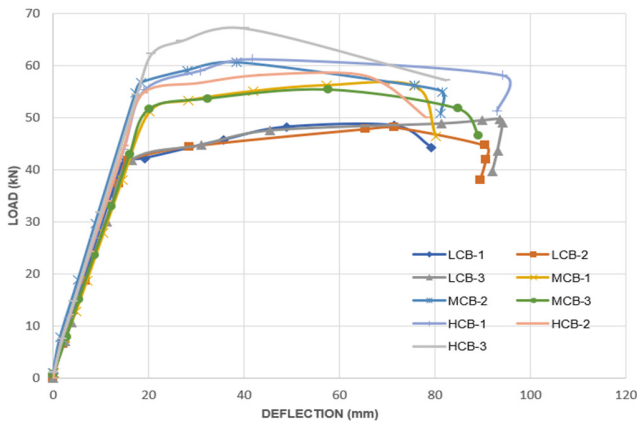


Fig. 5. Load and deflection response.

TABLE IV. LOAD AND DEFLECTION OF REINFORCED CONCRETE BEAM

Beam ID	Pcr (kN)	Py (kN)	Pu (kN)	Δy (mm)	Δu (mm)	$\mu = \Delta u / \Delta y$
LCB-1	7.9	41.98	48.44	15.39	71.41	4.64
LCB-2	7.4	41.71	48.18	15.73	90.48	5.75
LCB-3	7.1	41.78	49.71	16.44	93.52	5.68
Average	7.4	41.82	48.31	15.83	85.13	5.36
MCB-1	7.6	51.11	56.24	20.18	57.28	2.83
MCB-2	7.7	56.64	60.57	18.33	38.41	2.09
MCB-3	7.9	51.64	55.37	20.13	57.58	2.86
Average	7.73	53.13	57.39	19.54	51.09	2.59
HCB-1	6.9	55.31	61.24	19.06	41.37	2.17
HCB-2	7.5	54.77	58.5	19	61.66	3.24
HCB-3	7.4	62.17	67.1	20.59	40.13	1.94
Average	7.26	57.41	62.28	20.59	47.72	2.45

Pcr is crack load, Py is yield load, and Pu is ultimate load

These results confirm that increasing carbon content enhances ultimate strength but reduces post-yield deformability. The ductility index μ provides a quantitative measure to explain flexural performance in line with the measured deflections. Figure 6 illustrates this trend by comparing the ultimate load capacity (Pu) of beams reinforced with different steel types. The bar chart shows the progressive increase in Pu from LCB to HCB specimens, confirming that higher carbon content in reinforcing steel significantly enhances the flexural strength of the beams.

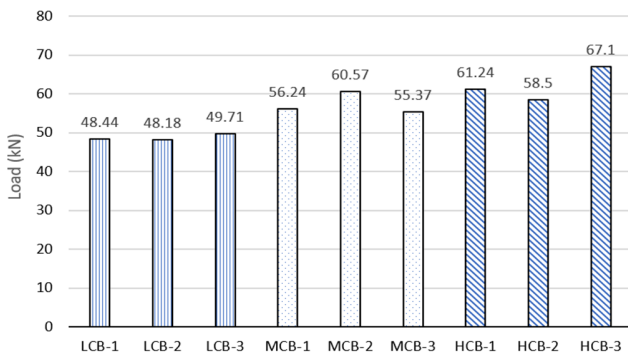


Fig. 6. Ultimate load (Pu) of reinforced concrete beams.

Figure 7 complements the strength comparison by presenting the average ductility index (μ) of the reinforced

concrete beam groups. The ductility index was calculated as the ratio of ultimate deflection to yield deflection ($\mu = \Delta u / \Delta y$), representing the deformation capacity of the beams before failure. The use of average values for each group enables a comparison of the influence of reinforcing steel carbon content on the ductile behavior of the beams.

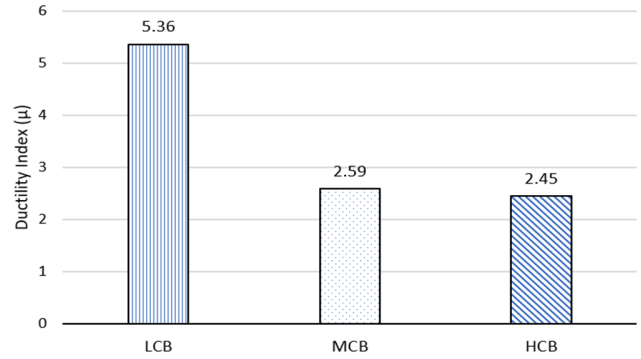


Fig. 7. Average ductility index (μ) of reinforced concrete beam groups.

According to the seismic design in [18], reinforced concrete beams should exhibit ductile behavior characterized by steel yielding and sufficient post-yield deformation to dissipate seismic energy. The test results show that all beams failed after yielding of the tensile reinforcement, indicating under-reinforced behavior. Beams reinforced with LCS and MCS exhibited higher ductility indices, making them more suitable for seismic-resistant structures, while HCS beams, although stronger, showed reduced ductility.

B. Load and Strain Response of the Reinforcing Steel

Figure 8 presents the strain response recorded on the main tensile reinforcement during loading.

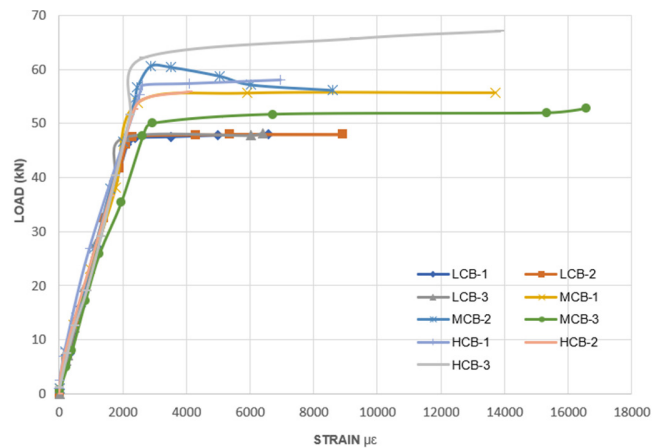


Fig. 8. Load and strain response.

In the initial elastic phase at low loads, all curves exhibit an almost linear relationship. However, at loads of approximately 40 kN–50 kN (and strains around 2000 $\mu\epsilon$), a drastic reduction in slope occurs. This reduction in slope indicates that the reinforcing steel has reached its yield point. Yield strain (ϵ_y) in the steel. Theoretically, steel yields at around 2000 $\mu\epsilon$. The

graph shows that the different beams reached the yield point at slightly different load levels, which is consistent with the P_y (yield load) analysis in Table IV. After yielding, the steel strain increases significantly with little to no increase in load (strain hardening occurs).

C. Crack Patterns

The observed crack patterns of the three beam groups exhibited differences depending on the type of reinforcing steel used. In all specimens, the first crack appeared at midspan when the applied load reached the cracking level. This initial crack originated at the bottom fiber as a vertical flexural crack due to maximum tensile stress in the tension zone. With increasing load, additional flexural cracks formed and propagated upward toward the compression zone, accompanied by gradual crack widening. Beams reinforced with LCS developed a larger number of uniformly distributed cracks with relatively smaller crack widths. This crack pattern indicates stable crack propagation and higher deformation capacity before failure. Beams reinforced with MCS exhibited fewer cracks, and the crack widths increased more rapidly after yielding. This behavior reflects a balanced response between strength and ductility. In contrast, beams reinforced with HCS typically developed one or two dominant flexural cracks with significantly larger openings. The localization of cracking suggests reduced plastic deformation capacity and a more rapid progression toward failure. At ultimate load, all specimens experienced crushing and spalling of the concrete in the compression zone, indicating failure initiated by the collapse of the top fibers following progressive flexural cracking. Figures 9-11 depict the crack development and final failure patterns, supporting the analysis of the flexural response of each beam group.

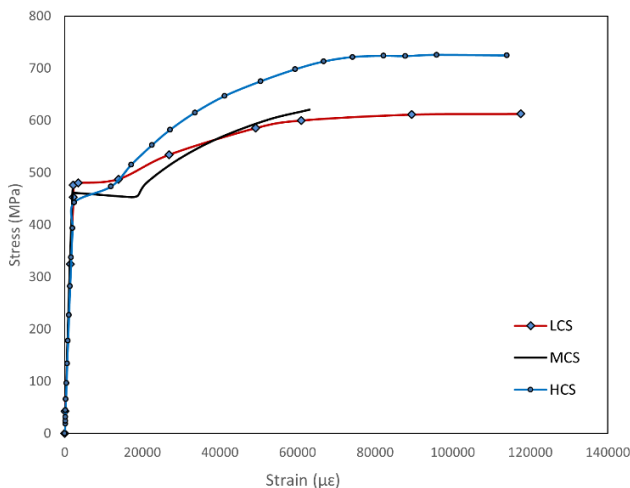


Fig. 9. Flexural crack pattern at ultimate load for reinforced concrete beams with LCS reinforcement.

Figure 10 shows cracks that are gradual and widely distributed, showing significant plastic deformation before failure, while, in Figure 11 we see cracks that are moderate in width and distribution, indicating a balanced combination of strength and ductility. Figure 12 illustrates the residual condition of the beam reinforced with HCS after static testing.

The specimen exhibits a single dominant flexural crack accompanied by limited permanent curvature of the tensile reinforcement. This localized cracking pattern and reduced bar deformation indicate a relatively brittle response, characterized by rapid degradation of the compression zone at ultimate load.

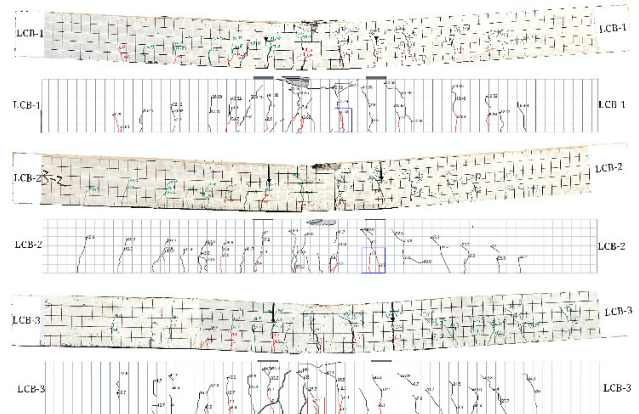


Fig. 10. Flexural crack pattern at ultimate load for reinforced concrete beams with MCS reinforcement.

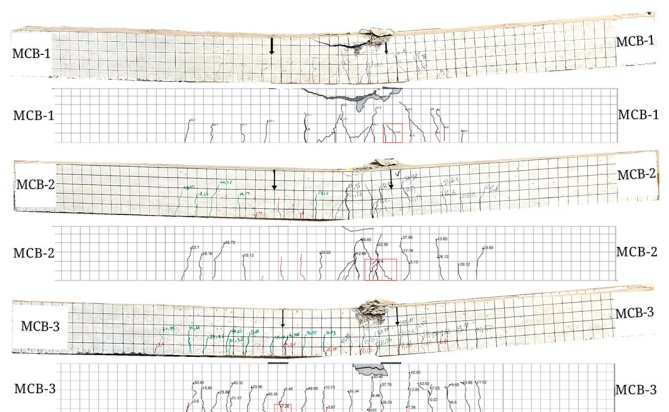


Fig. 11. Flexural crack pattern at ultimate load for reinforced concrete beams with HCS reinforcement.



Fig. 12. Residual condition of beam specimen HCB-1.

Figure 13 presents the residual condition of the beam reinforced with MCS. Moderate permanent curvature of the tensile bars and intermediate crack widening are observed. The crack distribution and deformation pattern reflect a balanced structural response, combining increased strength with adequate deformation capacity. Figure 14 displays the residual

condition of the beam reinforced with LCS. The tensile reinforcement displays pronounced and continuous curvature, along with more uniformly distributed flexural cracks. This behavior indicates greater plastic deformation capacity and enhanced energy dissipation before failure.



Fig. 13. Residual condition of beam specimen MCB-1.



Fig. 14. Residual condition of beam specimen LCB-1.

IV. CONCLUSIONS

This study investigated the effect of carbon content in reinforcing steel on the flexural performance of reinforced concrete beams through experimental testing. The results demonstrate that carbon content plays a significant role in governing both strength and ductility characteristics of the beams. An increase in carbon content leads to higher flexural strength, with HCB achieving the highest ultimate load capacity, approximately 28% greater than LCB, while MCB shows an 18% increase compared to LCB. However, this strength enhancement is accompanied by a significant reduction in ductility. The ductility index decreases from $\mu = 4.6\text{--}5.7$ for LCB to $\mu = 2.1\text{--}2.9$ for MCB and $\mu = 1.9\text{--}3.2$ for HCB, which is consistent with the observed reduction in steel ultimate strain. From a behavioral perspective, beams reinforced with LCB demonstrate greater plastic deformation and more gradual, distributed crack development, reflecting higher energy dissipation capacity. In contrast, beams reinforced with HCB exhibit a comparatively brittle response, characterized by crack localization and more sudden failure. Beams with MCB showed intermediate performance, providing a balanced combination of strength and ductility. From a structural design perspective, LCB is preferable for applications requiring high ductility and energy absorption, such as seismic-resistant structures. MCB may be selected when a balance between load capacity and deformation capability is desired, while HCB is suitable for structural elements where maximum strength is the main requirement and post-yield deformation demand is limited. Overall, the findings

provide quantitative experimental evidence to support informed selection of reinforcing steel based on combined strength and ductility considerations.

REFERENCES

- [1] Md. I. K. Rahat *et al.*, "Synergistic effect of pre-cyclic loading on tensile properties and microstructural changes in low-carbon steel," *Journal of Alloys and Metallurgical Systems*, vol. 11, Sept. 2025, Art. no. 100197, <https://doi.org/10.1016/j.jalmes.2025.100197>.
- [2] S. R. L. Utami, N. Nuroji, and A. Antonius, "Pengaruh Pembalutan Carbon Fiber Wrap (CFW) terhadap Daktilitas Balok Beton Bertulang," *INERSIA Informasi dan Ekspose Hasil Riset Teknik Sipil dan Arsitektur*, vol. 12, no. 2, pp. 140–155, 2016, <https://doi.org/10.21831/inersia.v12i2.12589>.
- [3] J. Duan, D. Farrugia, C. Davis, and Z. Li, "Effect of impurities on the microstructure and mechanical properties of a low carbon steel," *Ironmaking & Steelmaking*, vol. 49, no. 2, pp. 140–146, Feb. 2022, <https://doi.org/10.1080/03019233.2021.1972270>.
- [4] C. K. Kankam and M. Adom-Asamoah, "Strength and ductility characteristics of reinforcing steel bars milled from scrap metals," *Materials & Design*, vol. 23, no. 6, pp. 537–545, Sept. 2002, [https://doi.org/10.1016/S0261-3069\(02\)00028-6](https://doi.org/10.1016/S0261-3069(02)00028-6).
- [5] A. V. Lopes, T. Lou, and S. M. R. Lopes, "On the ductility of RC beam section: A revision and up to date of conclusions," *Engineering Structures*, vol. 322, Jan. 2025, Art. no. 119105, <https://doi.org/10.1016/j.engstruct.2024.119105>.
- [6] V. L. de la Concepción, H. N. Lorusso, and H. G. Svoboda, "Effect of Carbon Content on Microstructure and Mechanical Properties of Dual Phase Steels," *Procedia Materials Science*, vol. 8, pp. 1047–1056, Jan. 2015, <https://doi.org/10.1016/j.mspro.2015.04.167>.
- [7] A. Leal Matilla, D. Ferrández, M. I. Prieto Barrio, and H. Varum, "Systematic Review on the Behaviour of Carbon and Stainless Steel Reinforcing Bars in Buildings Under High Temperatures," *Buildings*, vol. 15, no. 9, Jan. 2025, Art. no. 1539, <https://doi.org/10.3390/buildings15091539>.
- [8] W. O. A. R. Malim, R. Djamaluddin, R. Irmawaty, and Fakhruddin, "The Effect of the Carbon Content on the Ductile Behavior of Reinforcing Steel," *Engineering, Technology & Applied Science Research*, vol. 15, no. 5, pp. 26808–26813, Oct. 2025, <https://doi.org/10.48084/etasr.12148>.
- [9] A. Calik, A. Duzgun, O. Sahin, and N. Ucar, "Effect of Carbon Content on the Mechanical Properties of Medium Carbon Steels," *Zeitschrift für Naturforschung A*, vol. 65, no. 5, pp. 468–472, May 2010, <https://doi.org/10.1515/zna-2010-0512>.
- [10] A. Y. Turki and M. H. Al-Fartoosi, "Investigation of the Stiffness and Ductility of Pre-Cracked RC Beams after repairing with CFRP using Different Strengthening Methods," *Engineering, Technology & Applied Science Research*, vol. 13, no. 6, pp. 12423–12426, Dec. 2023, <https://doi.org/10.48084/etasr.6555>.
- [11] S. Suharyatma and Y. Kristiandono, "Analisis Pengaruh Pencampuran Serat Karbon Terhadap Kekuatan Beton dalam Menahan Beban Desak, Beban Tarik dan Beban Lentur: Indonesia," *AJIE (Asian Journal of Innovation and Entrepreneurship)*, pp. 140–146, Sept. 2022, <https://doi.org/10.20885/ajie.vol6.iss3.art5>.
- [12] S. Layang and Eliatun, "Kekuatan Lentur Balok Beton dengan Penambahan Serat Karbon (Carbon Fiber Reinforced Polymer)," *Buletin Profesi Insinyur*, vol. 7, no. 2, pp. 64–70, Aug. 2024, <https://doi.org/10.20527/bpi.v7i2.243>.
- [13] S. Kim and S. Kim, "Flexural behavior of concrete beams with steel bar and FRP reinforcement," *Journal of Asian Architecture and Building Engineering*, vol. 18, no. 2, pp. 89–97, Mar. 2019, <https://doi.org/10.1080/13467581.2019.1596814>.
- [14] H. A. Suhartono and E. Febriyanti, "Uji Profisiensi Antar Laboratorium Uji Tarik Baja Tulangan Sirip," *Majalah Ilmiah Pengkajian Industri; Journal of Industrial Research and Innovation*, vol. 13, no. 1, pp. 23–30, 2019, <https://doi.org/10.29122/mipi.v13i1.1798>.

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- [15] S. Andean, M. D. J. Sumajouw, and R. S. Windah, "Pengujian Kuat Lentur Balok Beton Bertulang Dengan Variasi Ratio Tulangan Tarik," pp. 175–182, 2015.
- [16] S. Sariman and R. Irmawaty, "Analisis Kapasitas Lentur Balok Beton Tulang Berongga Akibat Perbedaan Kuat Tarik Tulangan," *Jurnal Ilmiah Ecosystem*, vol. 21, no. 3, pp. 681–689, Dec. 2021, <https://doi.org/10.35965/eco.v21i3.1302>.
- [17] SNI 2847:2019 Persyaratan beton struktural untuk bangunan gedung. Indonesia: Standar Nasional Indonesia, 2013.
- [18] ACI 318-19 Building Code Requirements for Structural Concrete. USA: American Concrete Institute, 2019.
- [19] SNI 1974:2011 Cara uji tekan beton dengan benda uji silinder. Indonesia: Standar Nasional Indonesia, 2011.
- [20] SNI 4431:2011 Cara uji lentur beton normal dengan dua titik pembebanan. Indonesia: Standar Nasional Indonesia, 2011.
- [21] SNI 2052:2017 Baja tulangan beton. Indonesia: Standar Nasional Indonesia, 2017.
- [22] SNI 07-0371-1998 Batang uji tarik untuk bahan logam. Indonesia: Standar Nasional Indonesia, 1998.