JOURNAL LA MULTIAPP

VOL. 07, ISSUE 04 (849-862), 2026
DOI: 10.37899/journallamultiapp.v7i4.5233

Analysis of Mechanical Characteristics of Plain and Deep Reinforced ...Ø10 mm Through Tensile Test and Bend Test

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Article Info

Article history:
Received 25 June 2026
Received in revised form 10 August 2026
Accepted 14 September 2026

Keywords:
Reinforcing Steel
Plain Rebar
Threaded Rebar
Tensile Test
Bending Test

Abstract

Reinforcing steel is the main component in reinforced concrete structures that functions to withstand tensile forces, control cracks, and ensure structural ductility. Plain rebar and 10 mm diameter deformed rebar are the most widely used in residential construction in Indonesia, but studies comparing them through two testing methods are still limited. This study aims to compare the mechanical characteristics of plain rebar Ø10 mm and D10 mm deformed rebar based on tensile and bending tests as a basis for selecting residential construction materials in Jakarta. The method used is quantitative with a laboratory experimental approach. Twelve specimens were tested at the Civil Engineering Laboratory of Esa Unggul University, each with three tensile test specimens and three bending tests per type of reinforcement, referring to ASTM E8/E8M, ASTM E290, and SNI 2052:2017. The tensile test results showed that plain rebar had an average breaking strength of 516.33 MPa and a yield strength of 375.33 MPa, while the deformed rebar had 511.67 MPa and 360.00 MPa. In the bending test, the bending strength of both was almost equal (848.33 MPa and 848.00 MPa), but the energy absorption of the deformed rebar was higher (43.15 Joules compared to 41.38 Joules) and all specimens did not crack or break. The shape of the reinforcement surface was proven to have no significant effect on strength, but rather on the ability of plastic deformation, so that deformed rebar is still recommended as the main reinforcement.

Introduction

The construction sector is a key driver of national economic growth due to its direct role in providing infrastructure, residential areas, and public facilities. According to the Construction Indicators for the Fourth Quarter of 2024 published by the Central Statistics Agency (BPS), the construction sector contributed 10.43% to Indonesia's Gross Domestic Product. This figure indicates a growing demand for construction materials that meet quality, safety, and sustainability standards, particularly in urban areas with high residential development rates, such as Jakarta.

One of the main materials in residential construction is reinforced concrete, a composite material that combines concrete to resist compressive forces and reinforcing steel to resist tensile forces (Lee et al., 2023; Vairagade & Dhale, 2023; Chahar & Pal, 2022; Sabouni, 2023; Altobgy et al., 2026). The compatibility of the thermal expansion coefficients between the two materials allows them to work as a composite, resulting in a structural system with better

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strength, stiffness, and ductility than unreinforced concrete (Nilson et al., 2018; Huang et al., 2023; Mostafaei et al., 2025; Ostrowski et al., 2026). In this system, reinforcing steel plays a role in resisting tensile forces, controlling cracks, increasing ductility, and maintaining the stability of structural elements when subjected to static and dynamic loads.

Reinforcing steel circulating in Indonesia is generally divided into two types: plain reinforcing bar and deformed reinforcing bar (Asiani & Djamaluddin, 2026; Sudjati, 2024). Plain reinforcing bar has a smooth surface, making it easier to cut and bend during the fabrication stage, while deformed reinforcing bar has fins on its surface that enhance the mechanical bond with the concrete, thereby increasing the force transfer capacity between the steel and concrete. These differences in surface geometry are thought to result in different mechanical behaviors when the material receives a load (Sokollu et al., 2022).

The 10 mm diameter is one of the most widely used reinforcing steel sizes in residential construction in Indonesia, both as the main reinforcement and as dividing reinforcement in sloofs, beams, practical columns, ring beams, and floor slabs of low-rise buildings. The high intensity of use of Ø10 mm reinforcement makes the evaluation of its mechanical characteristics have high practical value, because the test results can be directly used as a basis for material selection in the field. The quality requirements are regulated in SNI 2052:2017 concerning Concrete Reinforcement Steel, which stipulates the classification, dimensional requirements, mechanical properties, and testing methods that must be met (National Standardization Agency, 2017; Curbach et al., 2024; Noor et al., 2025; Wong et al., 2025).

The mechanical characteristics of reinforcing steel are generally evaluated through tensile and bending tests. Tensile tests produce parameters such as yield stress, maximum tensile stress, strain, and modulus of elasticity, which describe the material's ability to withstand axial loading to fracture (Ispir et al., 2022; Kazakeviciute et al., 2022; Wang et al., 2023). Bending tests evaluate the material's ability to withstand deformation due to flexural loading without cracking or premature failure. These two tests are complementary because they simultaneously describe the material's strength and ductility (Callister & Rethwisch, 2020; Hibbeler, 2021; Li et al., 2022; Wu et al., 2023).

A review of previous research shows that most studies still focus on a single type of testing, for example, evaluating the quality of reinforcing steel based on tensile tests (Safina et al., 2025; Sinaga & Saidah, 2023), the effect of production processes on mechanical properties (Purwanto, 2021), or the effect of chemical composition on ductility (Malim et al., 2025). Research that specifically integrates tensile and bending test results to compare the mechanical characteristics of Ø10 mm plain rebar and D10 mm deformed rebar as a basis for material selection recommendations in residential construction is still relatively limited. This condition becomes the research gap that underlies this study.

The novelty of this research lies in the integrated analysis of the mechanical characteristics of both types of reinforcement with the same nominal diameter by combining two testing methods in one series of experiments. Based on the description, this study aims to analyze the mechanical characteristics of plain rebar Ø10 mm and D10 mm deformed rebar based on the results of tensile and bending tests, compare the mechanical parameters of both, and provide recommendations for the most suitable type of reinforcement to be applied to residential construction in Jakarta.

Methods

Research Design, Location, and Time

This research used a quantitative method with a laboratory experimental approach. The analyzeddata were primary test results, which were then processed descriptively and comparatively to determine the differences in the mechanical characteristics of the two types

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of reinforcing steel. All testing was conducted at the Civil Engineering Laboratory of Esa Unggul University, Jakarta. The research stages included preparation and literature review, specimen preparation, tensile and bending testing, data processing, mechanical characteristic analysis, and report preparation.

Test Materials and Specimens

The materials used consisted of plain rebar with a nominal diameter of Ø10 mm and threaded rebar with a nominal diameter of D10 mm obtained from the same material source. Both types of reinforcement are shown in Figure 1. Specimens were cut and prepared in accordance with the provisions of SNI 2052:2017 and ASTM E8/E8M-24. The number and details of the specimens used are presented in Table 1.

Table 1. Number and Details of Research Specimens

Types of Reinforcing Steel	Tensile Test	Bending Test	Total
Plain concrete iron Ø10 mm	3	3	6
D10 mm threaded rebar	3	3	6
Total	**6**	**6**	**12**

Source: Research Data, 2026

Figure 1. Reinforced Concrete SamplePlain Ø10 mm (Left) and Threaded Rebar D10 mm (Right)

Source: Author's Documentation, 2026

The number of three specimens for each combination of material type and test type was chosen so that the test results could be compared representatively and to reduce the influence of individual material variations on the average value obtained.

Testing Tools and Procedures

The equipment used includes a Universal Testing Machine (UTM), a bending test machine, a vernier caliper, a tape measure, a steel cutting machine, a digital scale, and documentation equipment. Tensile testing was carried out following ASTM E8/E8M-24 to obtain breaking strength, yield strength, and proof strength values, while bending testing was carried out following ASTM E290-23 to obtain flexural strength, reference flexural strength, modulus, and absorbed energy values, accompanied by visual observation of the specimen surface condition after bending. The implementation of both tests is shown in Figure 2.

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Figure 2. Implementation of Tensile Test (Left) and Bend Test (Right) Using UTM

Source: Author's Documentation, 2026

The independent variables in this study were the types of reinforcing steel, namely plain rebar Ø10 mm and threaded rebar D10 mm. The dependent variables included breaking strength, yield strength, proof strength, modulus of elasticity, flexural strength, absorbed energy, and specimen condition after testing. The controlled variables included nominal diameter, specimen length, number of specimens, testing machine, laboratory operator, loading speed, laboratory room temperature, and the testing standards used.

Data Analysis Techniques

The test results data were analyzed using descriptive statistics and presented in the form of tables and graphs. Stress was calculated as the ratio between the load and the cross-sectional area of the specimen, as in Equation (1)..

$$\sigma = P / A \qquad (1)$$

where σ is stress (MPa), P is tensile load (N), and A is the cross-sectional area of the specimen (mm^2).

Strain is calculated as the ratio between the increase in length and the initial length of the specimen, as in Equation (2).

$$\varepsilon = \Delta L / L_0 \qquad (2)$$

where ε is the strain, ΔL is the increase in length (mm), and L_0 is the initial length of the specimen (mm).

The modulus of elasticity is obtained from the ratio of stress to strain in the elastic region, as in Equation (3).

$$E = \sigma / \varepsilon \qquad (3)$$

where E is the modulus of elasticity (MPa or GPa).

The mean value and standard deviation of each parameter are calculated using Equation (4) and Equation (5).

$$\bar{x} = \Sigma x / n \qquad (4)$$

$$SD = \sqrt{[\, \Sigma(x - \bar{x})^2 / (n - 1) \,]} \qquad (5)$$

where $\bar{x}$ is the mean value, x is the observed value, n is the number of specimens, and SD is the standard deviation.

The magnitude of the difference between types of reinforcement is expressed as a percentage difference as in Equation (6).

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$$Difference\ (\%) = [(X_2 - X_1) / X_1] \times 100\% \quad (6)$$

where X_1 is the value of plain rebar and X_2 is the value of threaded rebar.

Results and Discussion

Tensile Test Results

Tensile testing was conducted to determine the material's ability to withstand axial loading to fracture. A summary of the test results for the six specimens is presented in Table 2, while a comparison of the average values is presented in Table 3.

Table 2. Summary of Tensile Test Results

Specimen Code	Breaking Strength (MPa)	Yield Strength (MPa)	Proof Strength (MPa)
Plain 1	516	376	366
Plain 2	516	373	343
Plain 3	517	377	373
Plain average	**516.33**	**375.33**	**360.67**
Thread 1	513	360	364
Thread 2	513	360	360
Thread 3	509	360	364
Average thread pitch	**511.67**	**360.00**	**362.67**

Source: Laboratory Test Results, 2026

Table 3. Comparison of Average Values of Tensile Test Results

Parameter	Plain Ø10 mm	D10 mm thread	Differenc e	Difference (%)
Breaking Strength (MPa)	516.33	511.67	−4.66	−0.90
Yield Strength (MPa)	375.33	360.00	−15.33	−4.08
Proof Strength (MPa)	360.67	362.67	+2.00	+0.55

Source:Data Processing Results, 2026. The difference is calculated against the value of plain concrete iron

Based on Table 3, plain rebar has an average breaking strength of 516.33 MPa, while deformed rebar has 511.67 MPa. The difference of 4.66 MPa or 0.90% indicates that the maximum tensile capacity of the two materials is practically equivalent. A more visible difference occurs in the yield strength, which is 375.33 MPa for plain rebar compared to 360.00 MPa for deformed rebar, or a difference of 15.33 MPa (4.08%). These values indicate that in the tested samples, plain rebar is able to maintain elastic behavior up to higher stresses before entering the plastic region. In contrast, the proof strength values of the two materials are almost identical, namely 360.67 MPa and 362.67 MPa with a difference of only 2.00 MPa (0.55%), so the initial elastic response of both materials can be said to be equivalent. A comparison of these three parameters is visualized in Figure 5.

The material behavior during loading can be observed through the load–extension curve recorded automatically by the UTM. The curve for the plain rebar test results is shown in Figure 3, while the curve for the deformed rebar is shown in Figure 4.

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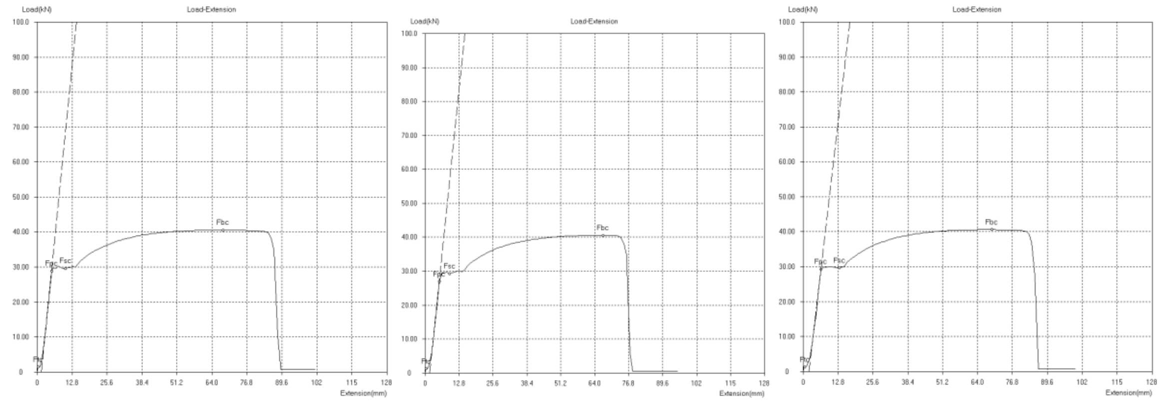

Figure 3. Load-Extension Curve of Plain Ø10 Mm Reinforced Concrete Specimens 1, 2, and 3

Source: Laboratory Test Results, 2026

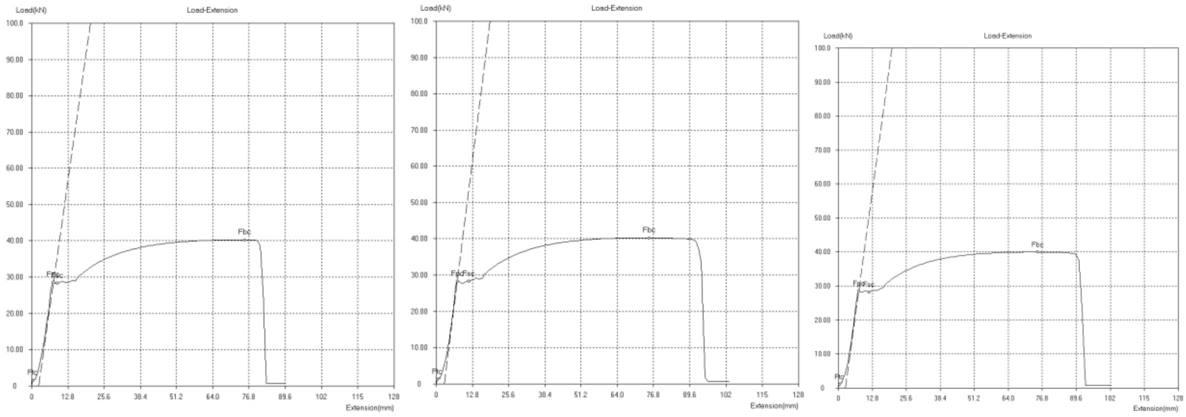

Figure 4. Load-Extension Curve of D10 Mm Deformed Reinforced Concrete Specimens 1, 2, and 3

Source: Laboratory Test Results, 2026

Figures 3 and 4 show that both types of reinforcement exhibit similar and complete curve patterns, including a linear elastic region according to Hooke's Law, a yield point, a plastic region with a large increase in strain at a small increase in stress, a maximum stress, and a fracture stage. No indication of brittle fracture was found in all specimens; all of them experienced plastic deformation and necking before breaking. This condition confirms that both materials have ductile properties as required for structural reinforcing steel.

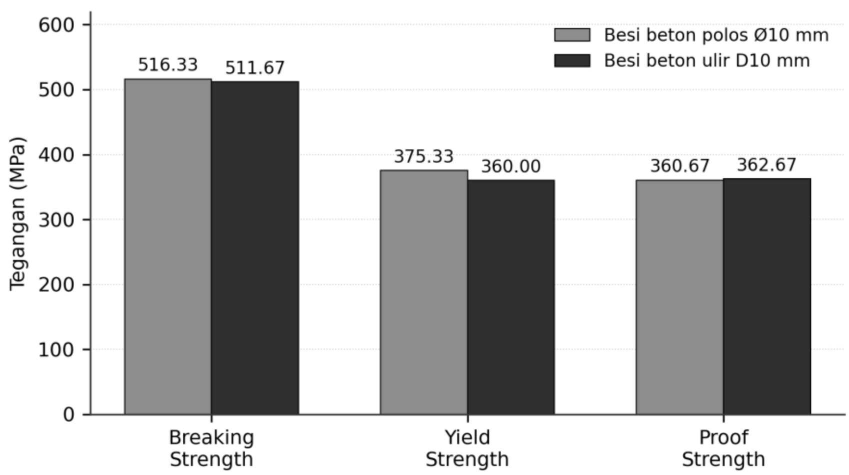

Figure 5. Comparison of Average Values of Tensile Test Parameters for Both Types of Reinforcement

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Source: Data Processing Results, 2026

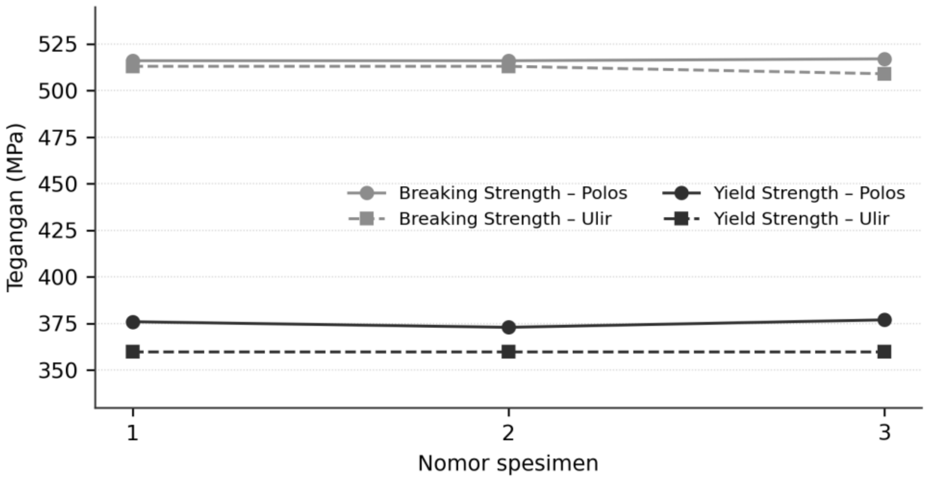

Figure 6. Distribution of Breaking Strength and Yield Strength Values for Each Specimen

Source: Data Processing Results, 2026

Figure 6 shows that the distribution of values between specimens is within a narrow range. In plain rebar, the breaking strength only varies between 516 MPa and 517 MPa, while in deformed rebar, it varies between 509 MPa and 513 MPa. The yield strength value of deformed rebar is even identical in all three specimens, namely 360 MPa. This consistency indicates a uniform manufacturing process as well as a controlled testing procedure, so that the average value can be used as a representation of the characteristics of each type of reinforcement. The physical condition of the specimens after tensile testing is shown in Figure 7.

Figure 7. Specimen Condition After Tensile Test: Plain Reinforced Concrete (Left) and Deformed Reinforced Concrete (Right)

Source: Author's Documentation, 2026

Bending Test Results

Bending tests are conducted to evaluate the ability of reinforcement to withstand bending loads without cracking or fracturing. This capability is important because reinforcement is often formed into stirrups, hooks, or joints that require bending before installation. A summary of the test results is presented in Table 4, and a comparison of the average values is presented in Table 5.

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Table 4. Recapitulation of Bending Test Results

Specimen Code	Rbb (MPa)	Rpb (MPa)	Modulus (GPa)	Absorbed Energy (J)
Plain 1	848	636	299.5	41,418
Plain 2	824	387	349.5	40,262
Plain 3	873	686	299.5	42,468
Plain average	**848.33**	**569.67**	**316.17**	**41,383**
Thread 1	848	399	249.5	42,296
Thread 2	848	624	299.5	41,908
Thread 3	848	462	299.5	45,256
Average thread pitch	**848.00**	**495.00**	**282.83**	**43,153**

Source:Laboratory Test Results, 2026. Rbb = bending strength; Rpb = proof bending strength.

Table 5. Comparison of Average Values of Bending Test Results

Parameter	Plain Ø10 mm	D10 mm thread	Differen ce	Differen ce (%)
Bending Strength, Rbb (MPa)	848.33	848.00	−0.33	−0.04
Proof Bending Strength, Rpb (MPa)	569.67	495.00	−74.67	−13.11
Modulus (GPa)	316.17	282.83	−33.34	−10.54
Absorbed Energy (J)	41.38	43.15	+1.77	+4.28

Source:Data Processing Results, 2026. The difference is calculated against the value of plain concrete iron.

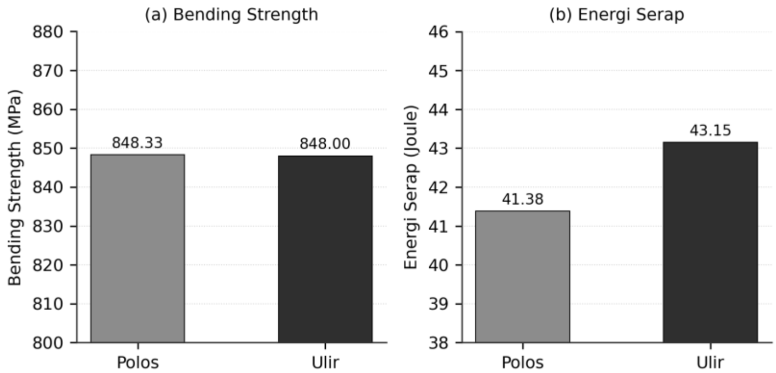

Figure 8. Comparison of Bending Strength and Absorbed Energy of Two Types of Reinforcement

Source: Data Processing Results, 2026

Figure 8 shows that the bending strength of both materials is practically identical, namely 848.33 MPa for plain rebar and 848.00 MPa for threaded rebar, with a difference of only 0.33 MPa or 0.04%. This indicates that changing the surface shape from plain to threaded does not significantly affect the material's basic flexural strength. More determining factors are steel grade, chemical composition, and manufacturing process, as also stated by Purwanto (2021) and Malim et al. (2025).

A more significant difference appears in the energy absorption. Deformed rebar can absorb an average of 43.15 Joules of energy, compared to 41.38 Joules for plain rebar, resulting in an excess of 1.77 Joules, or 4.28%. Energy absorption is an indicator of ductility because it describes the amount of energy a material can absorb during deformation before failure. A higher value for deformed rebar indicates slightly better plastic deformation capability, a

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property that is important in structures subjected to dynamic loads such as vibration, shock loads, and earthquake loads.

Visual observations after testing, as shown in Figure 9, indicate that all specimens successfully underwent the bending process without experiencing surface cracks or fractures. In plain rebar, the surface remained relatively smooth with permanent deformation following the bending shape. In deformed rebar, the fin profile remained intact and no cracks were found at the base of the threads, so the presence of fins did not cause excessive stress concentration during bending. This finding is in line with the requirements of SNI 2052:2017, which requires reinforcing steel to be able to undergo bending without showing defects that reduce its structural function.

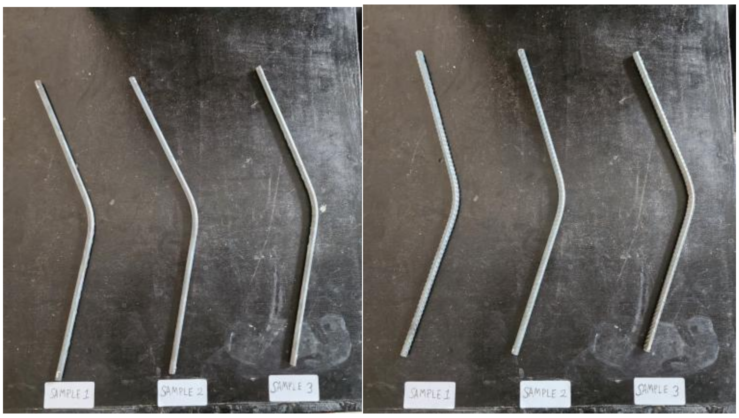

Figure 9. Specimen Condition After Bending Test: Plain Reinforced Concrete (Left) and Deformed Reinforced Concrete (Right)

Source: Author's Documentation, 2026

Descriptive Statistics and Data Consistency

To assess the reliability of the data, the mean value, standard deviation (SD), and coefficient of variation (CV) of each parameter were calculated as presented in Table 6.

Table 6. Mean Value of Descriptive Statistics

Parameter	Plain: Average	Plain: SD	Plain: KV (%)	Thread: Average	Thread: SD	Thread: KV (%)
Breaking Strength (MPa)	516.33	0.58	0.11	511.67	2.31	0.45
Yield Strength (MPa)	375.33	2.08	0.55	360.00	0.00	0.00
Proof Strength (MPa)	360.67	15.69	4.35	362.67	2.31	0.64
Bending Strength (MPa)	848.33	24.50	2.89	848.00	0.00	0.00
Absorbed Energy (J)	41.38	1.10	2.66	43.15	1.83	4.24

Source: Data Processing Results, 2026. SD = standard deviation; KV = coefficient of variation

Table 5 shows that the coefficient of variation for all parameters is below 5%, with the highest values for the proof strength of plain rebar at 4.35% and the absorption energy of deformed rebar at 4.24%. The low coefficient of variation reinforces the indication that the material quality is uniform and the testing procedure is consistent. It should be noted that this study used three specimens for each combination, so the analysis is descriptive and comparative. Inferential statistical testing such as the independent sample t-test requires a larger number of specimens and is recommended for further research.

Discussion Based on Theory and Standards

According to the theory of mechanics of materials, the strength of steel is determined by its chemical composition, grain size, hot rolling process, heat treatment, and cooling rate (Callister & Rethwisch, 2020; Gere & Goodno, 2020). The surface shape of the reinforcement

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is not a determining factor in tensile or flexural strength, but is designed to increase bond strength to concrete. The results of this study are consistent with this theoretical framework: the difference in breaking and bending strength between the two types of reinforcement is below 1%, while more visible differences appear in parameters related to deformation behavior, namely yield strength and absorbed energy.

Based on SNI 2052:2017, both types of reinforcement demonstrated adequate performance. All specimens successfully passed the bending test without cracking or breaking, and all underwent clear plastic deformation before breaking in the tensile test. The tensile testing procedure, which refers to ASTM E8/E8M-24 and the bending testing procedure, which refers to ASTM E290-23, ensure that the resulting parameters are comparable with other studies using the same standards.

Comparison with Previous Research

Safina et al. (2025) concluded that increasing steel grade increases the tensile and yield strength of reinforcement. A similar trend is seen in this study, where differences in values between reinforcement types reflect variations in material quality rather than surface shape. Sinaga and Saidah (2023) found that variations in grade contribute to differences in yield strength and maximum tensile strength; the results of this study support this finding with a difference in yield strength of 15.33 MPa despite the same nominal diameter of both specimens. The difference is that this study complements the analysis with a bending test so that material behavior can be evaluated from two sides simultaneously (Kallel & Elleuch, 2025; Shariati et al., 2024; Zhange et al., 2022; Cruz et al., 2024; Wu et al., 2023).

Purwanto (2021) emphasized that rolling and heat treatment processes significantly influence the mechanical properties of reinforcing steel. The small difference in values between the two types of reinforcement in this study supports this opinion, as both were derived from the same material source (Zaghloul et al., 2022; Prasad et al., 2024). Mislan et al. (2025) reported that higher-quality reinforcement has better plastic deformation capabilities; the absorbed energy results in this study showed a similar trend. Meanwhile, Malim et al. (2025) showed that carbon and alloying element content significantly influence the ductility of reinforcing steel. This study did not conduct a chemical composition analysis, so this relationship could not be directly verified, and this is both a limitation and a direction for further research.

Implications for Residential Construction in Jakarta

Jakarta is a region with a high level of seismic activity that must be taken into account in building planning, so residential structures need to be designed to withstand a combination of dead loads, live loads, wind loads, and earthquake loads according to SNI 2847:2019. In this context, ductility is a very important property because materials that can undergo plastic deformation before collapsing will provide early warning and evacuation time for occupants (Li et al., 2025; Rana & Shuvo, 2024; Chen et al., 2026).

The results of the study indicate that plain rebar has a slight advantage in tensile strength and yield strength, while deformed rebar is superior in energy absorption capacity. Because the difference in strength parameters is very small while the advantages of deformed rebar lie in ductility and bond to concrete, deformed rebar remains more suitable for use as the main reinforcement in beams, columns, and slabs. Plain rebar remains relevant for stirrups, tie bars, and other elements that do not require mechanical bonds as high as the main reinforcement, as long as its use complies with applicable planning provisions. For practitioners, these findings emphasize that the selection of reinforcement is not sufficient based on tensile strength alone, but must also consider the deformation capacity and interaction between the steel and concrete as a whole.

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Research Limitations

This study has several limitations that should be considered when interpreting the results. The number of specimens was limited to three for each combination, thus precluding inferential statistical testing. The diameter tested was limited to Ø10 mm, so the results are not directly representative of other diameters of reinforcement. The specimens were derived from a single material source, thus precluding inter-manufacturer variation. Testing was also limited to tensile and bending tests, with no hardness, impact, fatigue, corrosion, or microstructural analysis. All testing was conducted under controlled laboratory conditions, so real-world environmental influences such as high humidity, corrosion, and long-term repetitive loading were not evaluated.

Conclusion

Based on the results of laboratory tests on twelve specimens, it can be concluded that plain rebar Ø10 mm and D10 mm threaded rebar have the same mechanical characteristics that are adequate for use as reinforced concrete reinforcement, but with different advantages. In tensile testing, plain rebar obtained an average breaking strength of 516.33 MPa and a yield strength of 375.33 MPa, slightly higher than the threaded rebar which obtained 511.67 MPa and 360.00 MPa, while the proof strength values of both were practically equivalent at 360.67 MPa and 362.67 MPa. In the bending test, the bending strength of both materials was almost identical, namely 848.33 MPa and 848.00 MPa with a difference of only 0.04%, but the deformed rebar has a higher absorption energy, namely 43.15 Joules compared to 41.38 Joules, and all specimens were able to undergo bending without cracking or breaking with the coefficient of variation of all parameters below 5%. These findings indicate that the shape of the reinforcement surface does not have a major effect on tensile strength or flexural strength, but rather on the ability of plastic deformation, so for residential construction in Jakarta that must take into account earthquake loads, deformed rebar is still recommended as the main reinforcement because of its superior ductility and adhesion to concrete, while plain rebar can still be used in stirrups and ties according to applicable planning provisions..

Acknowledgment

The author would like to thank the Civil Engineering Study Program, Faculty of Engineering, Esa Unggul University for the academic support provided, as well as to the management and staff of the Civil Engineering Laboratory of Esa Unggul University for the facilities and technical assistance during the implementation of tensile testing and bending testing.

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