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EVALUATION OF CONCRETE PERFORMANCE OF CONCRETE MADE WITH STEEL TURNING WASTE FOR RIGID ROAD PAVEMENT

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Abstract

Concrete for rigid pavements requires sufficient mechanical strength to withstand repeated traffic loads. This study examines the effect of steel turning waste as an additive on the mechanical properties of concrete, particularly in terms of compressive and flexural strength. Experimental research was conducted in a laboratory using concrete mixtures containing 0%, 10%, and 15% steel turning waste by weight of cement. Cylindrical test specimens with dimensions of 15 × 30 cm were used for compressive strength testing, while beam-shaped test specimens measuring 15 × 15 × 60 cm were used for flexural strength testing. Testing was conducted at 7 and 28 days of age. At 7 days of age, the mixture with a 10% content recorded the highest compressive strength of 20.44 MPa, while the 15% mixture reached 19.48 MPa. At 28 days, the compressive strength increased to 29.07 MPa for the 10% mixture and 31.56 MPa for the 15% mixture, compared to normal concrete, which reached only 22.51 MPa. The 15% mixture also recorded the highest flexural strength at 28 days, at 4.03 MPa, higher than that of normal concrete at 3.17 MPa, representing an increase of approximately 27.1%. Although flexural strength decreased at 7 days with increasing waste content, the 15% mixture showed the highest mechanical performance at 28 days. The results indicate that steel turning waste can improve the compressive and flexural strength of concrete under the tested laboratory conditions.

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Keywords: Rigid Pavement, Steel Turning Waste, Flexural Strength, Compressive Strength, Sustainable Concrete

Introduction

The increasing demand for road infrastructure associated with the growth of land transportation requires pavement materials with adequate structural performance and long service life (Alfaries et al., 2026). Rigid pavement is widely applied to roads subjected to heavy traffic because its concrete slabs transfer vehicle loads to the subgrade and provide the primary structural capacity of the pavement system (Trianah, 2022). In this system, flexural strength is an important parameter because tensile stresses can develop within the concrete slab under repeated traffic loading, particularly at the bottom of the slab (Hasbullah & Jasman, 2022). When the tensile capacity of concrete is exceeded, cracking may occur and subsequently develop into structural deterioration (Sarmadika et al., 2022; Sandita Pranatya & Zain, 2025). The relatively brittle behavior and low tensile resistance of conventional concrete therefore remain important limitations in achieving durable rigid pavement performance (Alberda van Ekenstein et al., 2026).

The use of fiber reinforcement is one approach that has been developed to overcome these limitations. Fibers can bridge cracks within the concrete matrix, limit crack propagation, as well as improving the post-cracking behavior of concrete and enhancing its ductility (Deng et al., 2026; Delu, 2024). Steel fibers are highly effective because they have high tensile strength and a high modulus of elasticity, enabling them to transfer tensile stress along the crack plane and improve the flexural performance of concrete (Kamil et al., 2023). However, the use of commercially produced steel fibers has the potential to significantly increase material costs and cause environmental impacts due to the steel production process. Conversely, metal machining and fabrication activities generate large volumes of waste in the form of irregularly shaped steel shavings and scraps (Dhahir & Marx, 2026; Haavisto et al., 2026). This material is generally classified as metal waste with low economic value, while inadequate management has the potential to lead to the accumulation of metal waste and pose risks to the environment (Fan et al., 2020).

The mechanical properties of steel machining waste suggest its potential for use as an alternative reinforcing material in concrete. The steel content provides sufficiently high tensile strength and stiffness, while its irregular morphology can enhance mechanical interaction with the concrete matrix and help slow crack propagation (Ansori et al., 2019; A Guntur et al., 2018). A number of previous studies have shown that metal-based waste and other fibrous materials can improve the mechanical properties of concrete, particularly in terms of flexural performance and crack control (Susilawati, 2019; Höffgen & Dehn, 2025). The reuse of machining waste as a component in concrete aligns with the principles of material efficiency and the circular economy, namely by converting industrial waste into construction materials with added value (Sugiarto et al., 2024; De Side et al., 2025). Nevertheless, the behavior of steel cutting waste in concrete cannot be directly equated with the performance of commercially produced steel fibers (Lu & Chen, 2026). Differences in geometry, length, surface texture, and the distribution of waste materials within the concrete matrix can affect the quality of the interaction between these materials and the cement paste. These conditions, in turn, contribute to changes in the flexural behavior of concrete (Saputro et al., 2022; Surianti & Arham, 2017). Although the use of fibrous waste in concrete mixtures has been extensively studied, information regarding the use of waste from steel turning or cutting in rigid pavements remains relatively limited. This limitation is particularly evident in studies examining its contribution to improving the flexural strength of concrete and its suitability as an alternative material to conventional steel fibers (Yudi et al., 2025; Puri et al., 2025). These limitations indicate that there is room for further research. Therefore, the performance of steel machining waste needs to be verified through experimental testing on concrete mixtures designed for rigid pavement applications, so that its evaluation is not based solely on theoretical material characteristics (Mercedes Kind et al., 2026; Perez et al., 2026).

Based on this gap, the novelty of this study lies in the experimental utilization of steel turning waste as an alternative fiber reinforcement in rigid pavement concrete and in evaluating its influence on concrete flexural strength (Alnabawi et al., 2020; Strybny et al., 2026). The study also considers the potential of converting machining waste into a value-added construction material,

thereby connecting the improvement of pavement mechanical performance with a more sustainable approach to industrial waste utilization (Hamduwibawa et al., 2025). herefore, this study aims to experimentally evaluate the effect of steel turning waste addition on the flexural strength of rigid pavement concrete and to determine its potential as an alternative reinforcing material for improving the mechanical performance of concrete pavement (Shahnazi et al., 2026; Zhang et al., 2026). Although the potential is considerable, scientific studies on the use of steel turning waste in concrete, particularly for rigid pavement applications, are still relatively limited as shown in the photo of steel waste in Figure 1 (Setiawan & Supratman, 2025).



Figure 1. Steel Turning Waste

The growth of the machinery industry and metalworking shops has resulted in solid waste in the form of iron shavings and dust from the turning process. In practice, waste material generated from iron turning operations is still not being properly managed. This waste is often found discarded in the areas surrounding the workplace, posing a risk of negative impacts on the environment and human health. (Saepudin et al., 2022). The accumulation of metal waste that is not properly managed has the potential to impact the environment. When exposed to rainwater, metal materials can corrode, releasing metal elements into the soil and water, which can degrade environmental quality and disrupt the sustainability of ecosystems (Uno et al., 2022). In addition to its impact on the environment, metal waste in the form of fine particles can also be inhaled by humans. This is a particular concern for workers in workshops or industrial settings, as prolonged exposure can cause respiratory problems. Therefore, metal waste must be properly managed to prevent pollution and reduce risks to human health (Gea et al., 2024).

Research Methods

This study is a laboratory experiment conducted at Muhammadiyah University of Jember to analyze the performance of unreinforced concrete beams using steel cutting waste as an additive. The waste was used in three different proportions: 0%, 10%, and 15% of the cement weight. The concrete mix design was based on SNI 7656:2012. Furthermore, the consistency of the fresh concrete was determined through a slump test based on SNI 1972:2022, while the compressive strength of the concrete was measured using cylindrical test specimens in accordance with SNI 1974:2011. Flexural strength testing was conducted on beam test specimens using a two-point loading system in accordance with SNI 4431:2011; all test results were reported in MPa. To prevent clumping, the steel turning waste was added gradually (1/3 portion per stage) over 1–2 minutes before the next pour, while the fresh concrete was poured into the formwork in stages to ensure even distribution of the waste. After 24 hours, the concrete was removed from the formwork and cured (by water immersion) for 7 and 28 days. Testing of beam and cylinder samples was

conducted at 7 and 28 days of age. One day before testing, the samples were removed from water immersion for painting and the creation of a 5×5 cm grid on the beams to facilitate fracture pattern analysis.

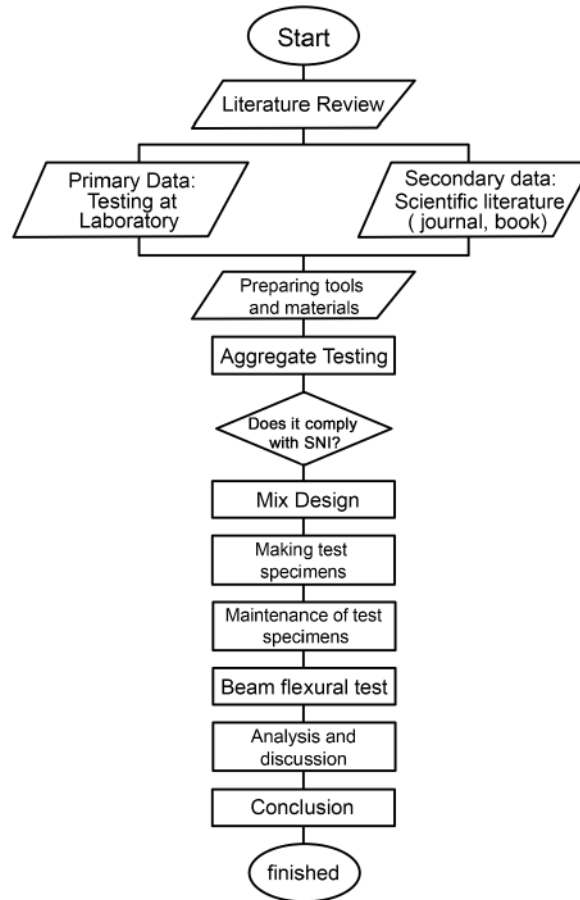


Figure 2. Research flowchart

Test Materials and Objects

This study used Portland Composite Cement (PCC), laboratory-grade water, Lumajang sand as fine aggregate, and crushed stone as coarse aggregate, with the addition of spiral-shaped steel turning waste fibers (± 60 mm). 60 mm in length, selected to avoid mixing difficulties caused by fibers that are too long. The use of steel turning waste percentages of 0%, 10%, and 15% was based on a study by (Iskandar et al., 2022), which found that adding 10% steel turning waste increased the flexural strength of concrete beams by 16.65% compared to normal concrete, with a maximum value of 26.41MPa. Therefore, this study tested a 15% mixture to examine the effect of steel turning waste on flexural strength. Each batch of mix was used to make one cylindrical test specimen and one beam test specimen. The 0% mix consisted of 8.69 kg of cement, 14.75 kg of sand, 24.58 kg of gravel, and 4.00 liters of water. For the 10% and 15% variations, the composition of the base materials remains the same, with the addition of 0.87 kg and 1.30 kg of steel turning waste, respectively. The percentage of steel turning waste is calculated based on the weight of the cement. Specimens for compressive and flexural strength tests were molded into cylinders and beams, respectively, while the slump test was conducted using an Abrams cone. The mix design in accordance with Indonesian National Standards SNI 7656:2012 target compressive 30 Mpa. Compressive strength testing was conducted on cylindrical specimens, while flexural strength testing used beam specimens with a two-point loading method. All specimens were allowed to dry naturally until they reached 28 days of age. Further analysis was conducted by comparing the compressive and flexural strength values between concrete containing lathe waste

fibers and concrete without fiber admixtures.

Test Specimen

Cylinder

Test specimens for the compressive strength of cylindrical specimen with a diameter of 15 cm and a height of 30 cm are shown in Table 1 below.

Table 1. Test Cylinder

Testing	Sample Code	Age (days)	Fiber Percentage (%)	Cement (kg)	Steel fiber (kg)	Number of Samples
Compressive Strength	BN 0% 7D	7	0	8.69	0	2
	BN 0% 28D	28	0	8.69	0	2
	BLB 10% 7D	7	10	8.69	0.87	2
	BLB 10% 28D	28	10	8.69	0.87	2
	BLB 15% 7D	7	15	8.69	1.30	2
	BLB 15% 28D	28	15	8.69	1.30	2
Total Samples						12

Beam Specimen

The concrete beam used as a flexural test specimen measuring 15 cm wide, 15 cm high, and 60 cm long is shown in table 2 below.

Table 2. Test Block

Testing	Sample Code		Fiber percentage (%)	Cement (kg)	Steel fiber (kg)	Number of Samples
Flexural Strength	BN 0% 7D	7	0	8.69	0	2
	BN 0% 28D	28	0	8.69	0	2
	BLB 10% 7D	7	10	8.69	0.87	2
	BLB 10% 28D	28	10	8.69	0.87	2
	BLB 15% 7D	7	15	8.69	1.30	2
	BLB 15% 28D	28	15	8.69	1.30	2
Total Samples						12

Description:

BN : Normal Concrete

BLB : Concrete with Steel Turning Waste

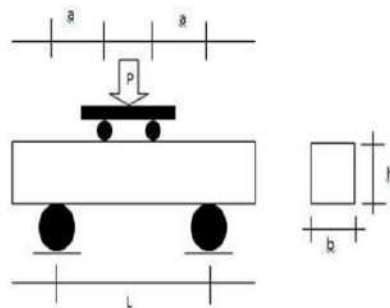


Figure 3. Illustration of Flexural Strength Testing

Source: Setiawan et al (2025)

Figure 3 above shows a two-point flexural test on a simple beam. The initial crack forms at

midspan due to the maximum tensile stress, and the peak load determines the flexural strength, which is a concrete performance parameter (Setiawan et al., 2025). The total length of the concrete beam specimen is 600 mm, with a clear span of 450 mm, measured from the inner edge of one support to the inner edge of the other.

Research Results and Discussion

Slump Value

The slump test was conducted using Abrams cones of standard dimensions—10 cm, 20 cm, and 30 cm—to evaluate the workability of the concrete mix. The results showed that the addition of steel waste fibers had a significant effect on the consistency and flow characteristics of fresh concrete. In general, as the percentage of steel fibers varied, slight changes in slump values were observed, reflecting differences in the mixture's ability to deform under its own weight. This behavior indicates that the presence of steel waste fibers plays a role in modifying the internal cohesion of the concrete mixture. The slump test results reported by Erlina et al. (2022) showed a slump of 13 cm for the 0% mixture, while mixtures containing 5% and 10% substitutions yielded a slump of 12 cm. By comparison, this study recorded slump values of 6 cm, 5 cm, and 5.5 cm for the 0%, 10%, and 15% mixtures, respectively. The relatively lower slump values observed in this study can be attributed to the specific application of concrete as rigid pavement, which generally requires a lower workability level. Nevertheless, all mix variations produced slump values within the specified range of 5–7 cm, indicating that the concrete remains suitable for rigid pavement applications according to SNI 1972:2022. The complete results of these tests are summarized and presented in Table 3 for further analysis.

Table 3. Slump Value Test Results

Description	Sample Code	Cement water ratio	slump value
No turning waste	BN	0.46	60 mm
10% steel turning waste	BLB 10%	0.46	50 mm
15% steel turning waste	BLB 15%	0.46	55 mm

For rigid pavement design, the required slump value ranges between 5-7 cm in accordance with the (SNI 1972:2022) specification. This range is considered adequate to ensure proper workability while maintaining the strength and durability needed for pavement performance. Based on the slump values obtained in the present study, all concrete samples fall within this specified range. Therefore, it can be concluded that each mixture satisfies the workability requirements for rigid pavement design and is suitable for practical application in the field. The slump value was obtained from the average of the test samples

Compressive Strength

Compression tests were conducted on the 7th and 28th days using a compression testing machine to determine the maximum load (P_{max}). The compressive strength was determined based on the results of the cylindrical specimen tests.

Table 4. Compressive Strength Tes

Sample Code	Sample Height	Diameter (mm)	Cross-sectional Area, A (mm ²)	Crush Pressure (kN)	Average Crush Pressure (kN)	Compressive Strength (σ), (MPa)	Average Strength (σ), (MPa)
BN 0% 7D	300	150	17662.5	210	226.50	11.89	12.82

BN 0% 7D	300	150	17662.5	243		13.76	
BLB 10% 7D	300	150	17662.5	280	361.00	15.85	20.44
BLB 10% 7D	300	150	17662.5	442		25.02	
BLB 15% 7D	300	150	17662.5	354	344.00	20.04	19.48
BLB 15% 7D	300	150	17662.5	334		18.91	
BN 0% 28D	300	150	17662.5	345	397.50	19.53	22.51
BN 0% 28D	300	150	17662.5	450		25.48	
BLB 10% 28D	300	150	17662.5	493	513.50	27.91	29.07
BLB 10% 28D	300	150	17662.5	534		30.23	
BLB 15% 28D	300	150	17662.5	552	557.50	31.25	31.56
BLB 15% 28D	300	150	17662.5	563		31.88	

Based on the data in the table, the compressive strength tests showed a significant increase in concrete reinforced with steel turning waste fibers, both at 7 days and 28 days. At 7 days, concrete without fiber reinforcement recorded an average compressive strength of 12.82 MPa, while concrete with 10% fiber reached 20.44 MPa—a 37.27% increase—and concrete with 15% fiber reached 19.48 MPa, with a standard deviation of 4.15. In the 28-day test, ordinary concrete had a compressive strength of 22.51 MPa, whereas concrete with 10% fiber reached 29.07 MPa and concrete with 15% fiber recorded the highest value of 31.56 MPa—a 28.67% increase compared to ordinary concrete—with a standard deviation of 4.68, as shown in Figure 3. From these results, it can be concluded that the 10% fiber mixture provided maximum compressive strength at 7 days, while the 15% mixture provided the highest compressive strength at 28 days. For normal concrete at 28 days of age, the compressive strength did not reach the target specified in the mix design because the pouring process was not fully controlled; as a result, the density of the cast cylinders was not optimal, preventing the concrete from achieving the target compressive strength of 30 MPa.

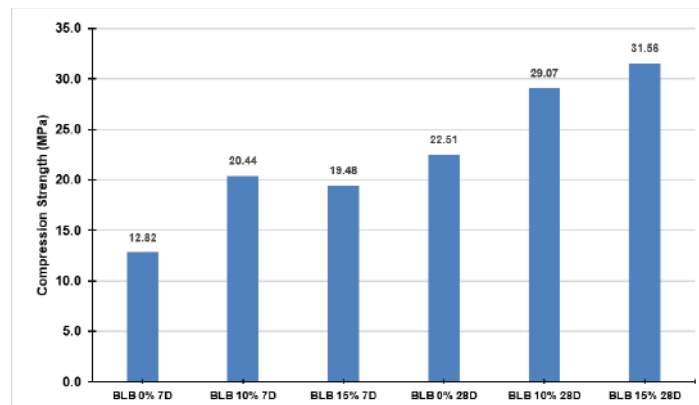


Figure 4. Combination of 7-day and 28-day Compressive Strength Test Graphs

The graph in Figure 4 above shows that the addition of steel fibers (BLB) increases compressive strength of concrete at 7 and 28 days. At 7 days, concrete compressive strength without fibers was 12.82 MPa, increasing to 20.44 MPa with a 10% addition, then decreasing slightly to 19.48 MPa with a 15% addition. At 28 days, all variations showed an increase, namely 22.51 MPa (0%), 29.07 MPa (10%), and the highest value of 31.56 MPa at 15%. Overall, the use of steel fibers has a positive effect on the concrete compressive strength, and best results obtained at a 15% content on the 28th day. The highest compressive strength at 7 days was obtained for the 10% substitution level, at 20.44 MPa. This indicates that this proportion achieves an optimal balance between the availability of cement for the initial hydration process and the filler effect of the substitute material, resulting in a denser cement paste structure. However, at 28 days, the 15% substitution variation yielded the highest compressive strength of 31.56 MPa because the pozzolanic reaction proceeded further, forming additional binding compounds that filled the capillary pores and improved the density and microstructural bonding of the concrete. Thus, a 10% substitution is more effective in increasing compressive strength at early ages, while a 15% substitution contributes more significantly to the development of compressive strength at later ages due to the pozzolanic reaction, which requires a longer duration.

Flexural Strength

In this study, flexural strength testing was conducted on beams aged 7 and 28 days with dimensions of 60 cm × 15 cm × 15 cm using standard flexural testing frames. Flexural strength testing of the beams was conducted by applying two concentrated loads at a distance of 1/3 of the span. The highest flexural strength of concrete beams at 7 days of age was 3.00 MPa for the 10% lathe waste variation. Meanwhile, at 28 days, the highest flexural strength was observed in the sample with 15% metal shavings, at 4.03 MPa, as reported in the study (Sukmawati et al., 2021). on the effect of adding steel turning waste to the flexural strength of concrete beams. In that study, the highest flexural strength values were observed in the 0% metal shavings variation at 1.050 MPa, the 10% variation at 1.200 MPa, and the 12% variation at 1.556 MPa; the results indicated that a higher percentage of steel turning waste resulted in higher flexural strength values.

Table 5. Flexural Strength Tet

Sample Code	Ltotal (mm)	Maximum Load, P (kN)	Average P (kN)	Flexural Strength PL/bh ² (σ), (MPa)	Average Strength (σ), (MPa)
BN 0% 7D	600	23	23.5	3.07	3.13
BN 0% 7D	600	24		3.20	
BLB 10% 7D	600	25.5	22.5	3.40	3.00
BLB 10% 7D	600	19.5		2.60	
BLB 15% 7D	600	21	20.75	2.80	2.77
BLB 15% 7D	600	20.5		2.73	
BN 0% 28D	600	22.5	23.75	3.00	3.17
BN 0% 28D	600	25		3.33	
BLB 10% 28D	600	23.5	25.25	3.13	3.37
BLB 10% 28D	600	27		3.60	
BLB 15% 28D	600	33.5	30.25	4.47	4.03
BLB 15% 28D	600	27		3.60	

Based on the data for the two ages of the specimens in the table above, the flexural strength tests revealed different patterns between the 7-day-old and 28-day-old concrete samples due to the addition of steel powder. At 7 days, the unmodified concrete recorded an average flexural strength of 3.13 MPa, while the concrete with 10% steel powder reached 3.00 MPa and the concrete with 15% steel powder only 2.77 MPa, indicating an 11.50% decrease in the 15% variant compared to

the unmodified concrete. Conversely, at 28 days, the standard concrete had a flexural strength of 3.17 MPa, while the concrete with 10% steel powder reached 3.37 MPa and the concrete with 15% steel powder recorded the highest value of 4.03 MPa—a 27.1% increase compared to standard concrete. From these results, it can be concluded that although the addition of 15% steel turning waste caused a decrease in flexural strength at 7 days, this mixture actually provided maximum flexural strength at 28 days, a value that meets the minimum flexural strength standard for rigid pavement according to the 2024 Road Pavement Design Manual (MDPJ) regarding rigid pavement for roads with low traffic loads. The minimum flexural strength values for local roads are 3.5 MPa and 3.8 MPa for collector roads.

Crack Patterns and Failure in Beam Samples

This study discusses the crack patterns of concrete samples during flexural testing. Below are the crack patterns that occurred during concrete beam testing for variations of 0%, 10%, and 15% milling waste at 28 days of age.

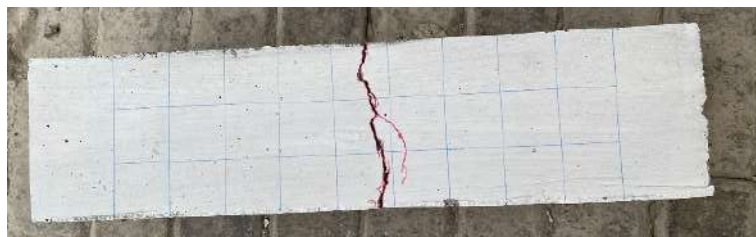


Figure 5. Crack and fracture patterns Sample 0% lathe fiber variation



Figure 6. Crack and fracture patterns Sample 10% turnout variation



Figure 7. Crack and fracture patterns Sample 15% turnout variation

Figures 5 through 7 show the condition of the concrete beam samples after the flexural test. The flexural strength of the 0% concrete sample was 3.17 MPa, that of the 10% sample was 3.37 MPa, and that of the concrete sample with 15% waste added was 4.03 MPa. The sample containing 15% steel turning waste had the highest flexural strength of 4.03 MPa. The observation of initial cracking cannot be conducted separately from collapse cracking because the initial cracks identified during testing occur simultaneously with the progression of cracking until the point of collapse. Therefore, the evaluation of crack resistance was conducted by comparing the initial cracking load between concrete without steel fibers (0%) and concrete with steel fibers (15%). The test results

showed that the initial cracking load increased from 3.13 MPa in the 0% variation to 4.03 MPa in the 15% variation, representing an increase of 28.72%.

Conclusion

The experimental results show that the use of steel cutting waste affects the mechanical properties of concrete, particularly compressive strength and flexural strength. At 7 days of age, concrete with 10% steel cutting waste exhibited the highest compressive strength, at 20.44 MPa, while the 15% mixture yielded 19.48 MPa. After reaching 28 days, the compressive strength increased to 29.07 MPa in the 10% mixture and 31.56 MPa in the 15% mixture, while normal concrete reached only 22.51 MPa. In contrast to compressive strength, flexural strength at 7 days of age decreased, from 3.13 MPa in normal concrete to 3.00 MPa for the 10% mixture and 2.77 MPa for the 15% mixture. However, at 28 days, these values increased to 3.37 MPa for the 10% mixture and 4.03 MPa for the 15% mixture, while normal concrete reached 3.17 MPa. Based on all the variations analyzed, the mixture containing 15% steel cutting waste exhibited the best performance at 28 days, both in terms of compressive strength and flexural strength. These results illustrate the mechanical behavior of concrete containing steel cutting waste based on the laboratory conditions and testing period used. To gain a more comprehensive understanding, further research is needed to examine the long-term performance of the concrete, including its resistance to sulfate and chloride exposure, carbonation, wet-dry cycles, shrinkage, abrasion, and flexural fatigue due to repeated loading. In addition, a quantitative evaluation is required. In addition, field trials should be conducted to evaluate mixing consistency, workability, quality control, and the practical performance of rigid pavement concrete containing steel turning waste.

As a suggestion for further research, it is recommended to examine durability aspects through tests for resistance to sulfates, chlorides, carbonation, wet-dry cycles, shrinkage, and abrasion or freeze-thaw (if relevant) to assess matrix degradation and the risk of fiber corrosion. Regarding fatigue, flexural fatigue testing (S–N curve) should be conducted on beams or mini pavement segments with variations in stress, frequency, and amplitude to determine the relationship between the number of cycles and residual strength as well as stiffness degradation. For crack behavior, it is recommended to quantify crack initiation and propagation using CMOD, crack width, post-crack toughness, and residual strength (e.g., in accordance with ASTM C1609), as well as to analyze crack patterns in relation to fiber dosage and morphology. Finally, regarding field applications, it is necessary to conduct field trials on small-scale rigid pavement segments, evaluate workability and mixing consistency in the field, develop quality control protocols in accordance with ASTM C1399/C1609 and ACI 544, and perform cost-benefit analyses and life-cycle assessments (LCA) to evaluate economic and environmental feasibility.

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