Experimental Investigations on Fiber Reinforced Concrete with Lathe Fibers for Sustainable Construction

Dr. S. Thenmozhi[1], Dr.V. Gowri[2], Shilpi Sippi Bhuinyan[3], Saurav Kar[4], Swapnil Balkrishna Gorade[5]

[1]Associate Professor, Department of Civil Engineering, St. Joseph's College of Engineering, OMR, Chennai – 600119, India.
[2]Assistant Professor, Department of Civil Engineering, St. Joseph's College of Engineering, OMR, Chennai – 600119, India.
[3]Assistant Professor, Department of Civil Engineering, All India Shri Shivaji memorial Society's,College of Engineering, Pune – 411001, Maharashtra, India.
[4]Assistant Professor, Department of Civil Engineering, Heritage Institute of Technology, Kolkata-700107, West Bengal, India
[5]Assistant Professor, Department of Civil Engineering, Pimpri Chinchwad College of Engineering, Sector No –26, Nigdi Pradhikaran, Pune – 411044, Maharashtra, India.

Abstract: Because of advancements in steel, more steel waste is being created. industries that produce things. The increase in these wastes has a negative impact on the environment, and it also necessitates a lot of space to store them. rather than discarding Reusing these wastes in many businesses is a significant achievement in terms of lowering environmental pollution and supplying inexpensive goods. This led to the motivation for this study, which looked at the impact of lathe scrap fibers produced by Computer Numerical Control (CNC) lathe machine tools on concrete performance. An experimental investigation was carried out on a few test specimens in order to achieve this goal while taking varying fiber contents into account. We measured the slump and workability of concrete made with various lathe trash fibers. In order to determine the compressive strength and splitting tensile strength of the hardened concrete, 150 mm 150 mm 150 mm cubic specimens and cylindrical specimens with a diameter of 100 mm and a height of 200 mm were examined. Lathe waste scrap was divided into four different volume fractions (0%, 1%, 2%, and 3%). The compressive and splitting tensile strength of fiber-reinforced concrete increases with the addition of lathe scrap, however after a certain value of steel fiber content, there is a loss in workability. Furthermore, microstructural analysis was performed to observe the interaction between lathe scrap fiber and concrete. Good adhesion was observed between the steel fiber and cementitious concrete. According to the results obtained, waste lathe scrap fiber also worked as a good crack arrestor. Lastly, practical empirical equations were developed to calculate the compressive strength and splitting tensile strength of fiber-reinforced concrete produced with waste lathe scrap.
Keywords: Lathe waste; recycling; mechanical properties; concrete; Scanning Electron Microscope.

1.Introduction

Concrete is a common building material used in many structural applications. It is a composite material made of cement, aggregates, water, and various additives. Due to some of the poor characteristics of traditional concrete, such as limited ductility and low tensile strength, it is occasionally reinforced with fibres or polymers in addition to reinforcement bars [1–13]. Although reinforcement bars help the concrete's mechanical characteristics, they might not be enough to prevent cracks from growing too wide.

One of the best methods to limit crack width is to employ fibres in concrete [14]. Fibres are crucial in preventing the concrete drawbacks listed above in addition to crack arrestment [15]. To improve qualities including ductility, crack resistance, tensile and flexural strength, a variety of fibre types can be added to concrete mixtures [16,17]. Widely utilisedfibre types in cement-based materials include steel, glass, polypropylene, polyvinyl alcohol, and carbon [2,18-22]. For instance, although steel fibres are typically used in floor slabs, bridge decks, and impact resistance constructions, glass fibres are typically favoured for the roofs of thin concrete shell structures, precast panels, etc. Additionally, high-performance concrete's toughness and strength are improved at various levels with fibres such steel and polyvinyl alcohol fibre [23]. When compared to conventional steel reinforcement, fibres such waste polypropylene (PP) and metal are more accessible and less expensive [24].

Additionally, it might be more cost-effective to use waste polypropylene and steel scrap from nearby lathes and workshops directly as fibres rather than recycling them. The cost of waste lathe scraps gathered from workshops and other steel businesses is quite low, according to El-Sayed [25], Sezhiyan and Rajkumar [26], and Vijayaku-mar et al. [27]. Industrial steel fibres or waste fibres produced by diverse businesses are two options for the regularly utilised steel fibres. Concrete benefits from industrial steel fibres by having stronger mechanical qualities. Industrial steel fibres are pricey, too, and their use raises the cost of fiber-reinforced concrete [27]. Because of this, using reused or recycled waste fibres in concrete is becoming more popular [28]. In addition to being environmentally beneficial, waste fibres function nearly as well as conventional industrial fibres [29]. Hybrid fibres, which combine waste and industrial fibres, are utilised in some areas to outperform plain concrete in terms of performance. Recently, the amount of waste products produced by lathe and Computer Numerical Control (CNC) equipment has increased, including used tyres and steel swarf. These waste products can be used in the concrete mix as fibre or to replace the natural aggregate.

Utilising recycled materials can help create ecologically friendly concrete as well as reduce land contamination [30]. The impact of steel waste produced by lathes and CNC machines on the characteristics of concrete has been investigated in this study. Solid trash known as steel swarf is typically produced during the cutting, milling, and turning processes in the steel manufacturing sectors. Given how challenging it is to recycle steel swarf, its considerable production is a significant problem [31]. It was favoured, nonetheless, as an alternative to aggregates in concrete [28,32-34]. Additionally, steel swarf, which has qualities similar to those of steel fibre, can be used as an alternate reinforcement in concrete. Waste from steel lathes has been found to significantly slow the spread of cracks. The impact of various quantities of steel lathe waste on the performance of concrete was examined by Mansi et al. [37]. Their findings [37] showed that the use of steel lathe waste enhanced the mechanical qualities of concrete, such as compression strength. However, when the amount of lathe steel waste increased, the concrete's workability decreased. An experimental investigation was undertaken by Bhavana and Rangarao [38] to look at how different steel scrap amounts affected self-compacting and conventional concrete. Eight beam specimens were taken into consideration for comparing the deformational behaviour of these various concrete kinds.

The flexural behaviour of concrete made by waste lathe fibre was investigated by Akshaya et al. [39]. Lathe fibre inclusion has been demonstrated to boost concrete's flexural strength and reduce fracture breadth. An experimental investigation was conducted by Vasudev and Vishnuram [40] to determine whether turn steel scraps may be used as a fibre in concrete of the M40 and M60 grades. The ultimate load capacities of the M40 grade concrete and the M60 concrete both increased by 22% and 17%, respectively, with the addition of lathe fibre. Lathe scrap's impact on the workability and compressive strength of M30 grade concrete was researched by Gawatre et al. [41]. Lathe scrap fibres have been found

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to increase compressive strength by up to 11%. With the addition of more fibre, the workability of the concrete decreased. Similar to this, Nazir et al. [42] looked at how straight lathe steel fibre affected the workability and mechanical characteristics of M20 concrete. Use of lathe steel fibre results in 15% improvements in compression strength, 30% increases in split tensile strength, and 42% increases in bending strength. According to Joy and Rajeev [43], M25 grade concrete's flexural strength was not significantly affected by the low quantity of steel scrap fibre, but it did perform well in compressive strength and splitting tensile strength.

Sawdust left over from lathes is a highly valuable recycling resource that may be used in a variety of industrial processes. The economic added value of concrete manufacturing is increased by adding waste turning sawdust directly to the concrete without putting it through a second industrial operation. Only the separation and sizing of additives in concrete may require further processing. Thus, since the addition of lathe sawdust to concrete will enhance the concrete's mechanical performance, it will have benefits such allowing for the use of less steel in steel-reinforced concrete. Previous studies have demonstrated the usefulness of lathe scrap fibres produced by lathe and CNC machines in civil engineering applications. For a variety of applications, recycled steel fiber-reinforced concrete still needs to perform structurally better [44–47]. This inspiration led to the performance of an experimental research to establish the ideal quantity of lathe scrap fibres for the concrete mixture. First, varied amounts of fibres were taken into consideration while examining the impact of lathe waste on slump value and workability on freshly-poured concrete. The mechanical characteristics of fiber-reinforced concrete made with various lathe scrap fibre contents were then examined in the concrete's cured stage. Compressive strength tests on cubic and cylinder samples were carried out for this reason. In order to determine the splitting tensile strength, cylindrical samples were used. Additionally, beam samples with diameters of 100 100 400 mm and a span length of 300 mm underwent experimental tests. For the bending behaviour, test specimen load-displacement curves were developed. The most optimal fibre dosage for fiber-reinforced concrete was then optimised using lathe scrap steel fibre. To study how lathe scrap fibre and concrete interact, microstructural investigation was also carried out. Additionally, useful empirical formulae for the compression strength and splitting tensile strength of fiber-reinforced concrete were derived.

2. Experimental Work

CEM I 32.5 Portland Cement was chosen as the cement in this study. Table 1 lists this cement's chemical characteristics. For fine and coarse aggregates, maximum aggregate sizes of 4 mm and 12 mm were used. The ratio of aggregate to cement was chosen to be 0.22, and the ratio of water to cement was chosen to be 0.60. The ratio of coarse aggregate (4–12 mm) to fine aggregate (0–4 mm) was almost 52% to 48%, respectively. The use of lathe waste sawdust allowed researchers to examine how the fibre ratio affects concrete's compressive strength, split tensile strength, and bending performance. Figure 1a depicts the steel wires that were used.The recycled steel wires that were produced by the lathe machine had a helical shape. Before use, the recycled steel wires were cut into smaller pieces. In order to conduct a fair comparison, efforts were made to achieve the same length and proportion. The percentage of the lengths used for the lathe waste sawdust is shown in Figure 1b. Lathe waste typically measured between 30 and 50 mm.

Figure1. Recycledsteelwires

MixProcedure,WorkabilityandSlumpTest

All aggregates, cement, and water were first combined in the mixer for the mixing process. To guarantee a uniform distribution of the turning sawdust in the concrete mixture and to avoid agglomeration, the sawdust was then progressively strewn into the concrete. Aggregation was seen in the mixture containing 3% lathe waste, despite the steel wires being added to the mixture gradually. After a 2% fibre content ratio, workability significantly decreased. Working with the combination that contained 3% lathe (CNC) waste was exceedingly challenging. Testing for slumps was also done. Figure 2 shows the results of the slump tests.As can be observed, the slump values obtained using steel lathe waste chips are consistently lower than those obtained using the reference specimen. Additionally, as the fibre ratio rises, the slump value falls. The slump value of the reference sample was 19 cm, but as the fibre content increased, it reduced to 17, 10, and 5 cm.

TestProcedure

To ascertain the mechanical characteristics of the concrete produced by the inclusion of machine tool wastes, four different types of experiments were performed. These tests are the splitting tensile, bending, cubic compressive strength, and cylindrical compressive strength, respectively. Here are a few pictures of the examined samples: Figure 3a depicts the compressive strength in cubic units, Figure 3b in cylindrical units, Figure 3c in split tensile, and Figure 3d in flexural tests. The results were averaged across three samples from each experimental group. Both cube specimens measuring 150 x 150 x 150 mm and cylindrical specimens measuring 100 mm in diameter and 200 mm in height were used to assess the compressive strength capabilities.Compressive strength and stress curves were produced with the cylindrical sample testing, however only compressive strength data were acquired with the cubic sample tests. Cylindrical samples were fractured at a loading rate of 5 kN/s, while cubic samples were shattered at an average loading speed of 6 kN/s. Splitting tensile tests also made use of cylindrical test specimens. Prisms measuring 100 100 400 mm in size, with an opening of 300 mm and a loading speed of 0.5 mm/sn, were used for the bending tests. The test produced curves that demonstrated the bending behaviour.

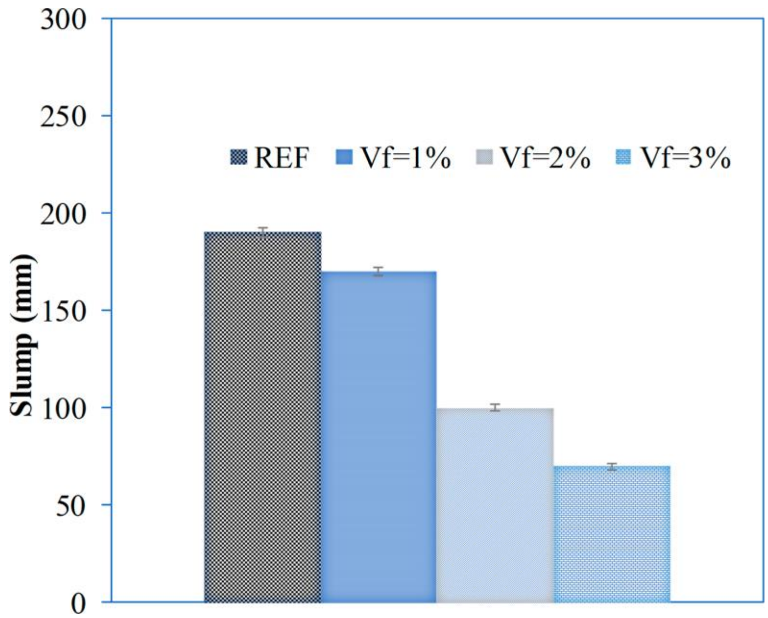

Figure2. Slump test.

The mixes were combined, then put into moulds and vibrated for 30 seconds. After casting, the samples were left at ambient temperature for 24 hours. The samples were then examined after 28 days of curing.

Figure3. Mechanical test setups

Experimental Results and Discussions

Compressive Strength

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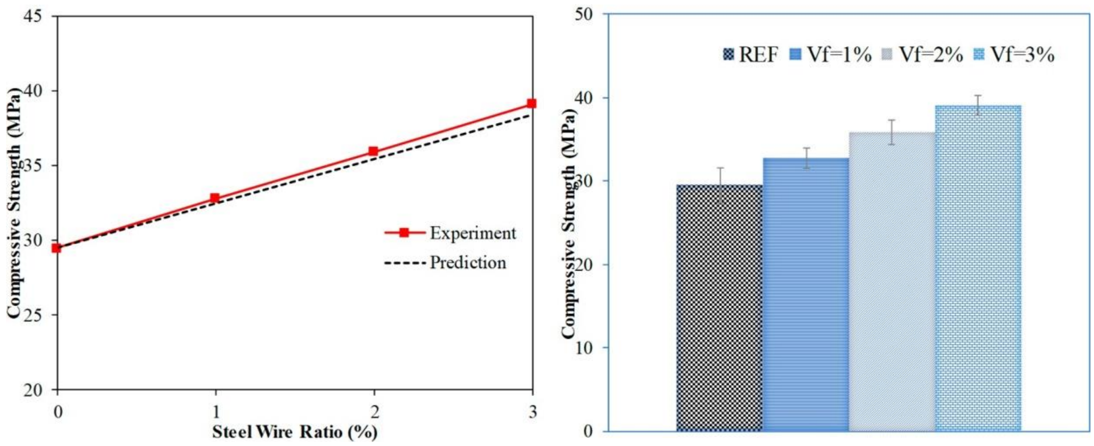
The test results for the compressive strength of cubic specimens measuring 150 mm, 150 mm, and 150 mm are shown in Figure 4. The graph in Figure 4b displays the compressive strength values for the reference samples and the concrete produced by adding lathe steel waste, going from left to right. The samples that contained waste material outperformed the reference samples in compressive strength, which is a good sign. The graph in Figure 4b demonstrates the relationship between the ratio of turning waste in concrete and the increase in compressive strength.



(a) (b)

Figure4. Results of compressive strength.

According to the findings of the cubic samples' compressive strength tests, the reference sample's compressive strength was 29.5 MPa, but after adding 1%, 2%, or 3% of lathe waste chips, it was closer to 32.8 MPa, 35.9 MPa, or 39.1 MPa (Figure 4a). Using an analytical solution, the results of the compressive strength experimental strength test are also estimated. The results show that there is a about 1% variation between the experimental results and the estimated results. This demonstrates that by using the analytical approach instead of experimenting, future studies will be able to forecast outcomes. In their investigation, Yazc et al. [48] discovered that by adding three different fibre quantities of carbon, the strength of concrete rose by 4% to 19% 0.5, 1, and 1.5 percent, depending on the volume of concrete. According to this study, adding lathe waste chips to concrete boosts its compressive strength by 9% to 32%. As a result, waste turning sawdust offers superior compressive strength, as demonstrated by the research done by Yazc et al. [48]. Table 2 displays the experimental and analytically projected compressive strength values.

Table1. Experimental and predicted compressive strength.

V_f	**LatheWasteChips**	
%	**Experiment**	**Prediction**
0	29.5	29.5
1	32.8	32.5

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2	35.9	35.4
3	39.1	38.4

Compressivestrengthwithrecycledsteelwirescanbecomputedutilizedthefollowingproposedequations:
$f_{LATHE,c}=f_c{}'1+0.10V_f$(1)
where fLATHE,c is the compressive strength of concrete with lathe waste chips and fc′ is the compressive strength of plain concrete.

The results of the cylindrical samples' compressive strength are shown in Figure 5. The specimens' ability for elastic behaviour and maximum strength have increased, according to the data. Strength and ductility increased proportionally to the waste volume ratio. According to Neves and Almeida's [49] research, fibre additions can boost concrete's compressive strength by up to 1.5% while slightly lowering its Young's modulus. However, it is clear from the graph that the addition of lathe waste chips results in a very significant rise in Young's modulus.

The findings of Shah and Rangan's investigation showed that lathe waste greatly raised final pressure while also improving the hardness and ductility of concrete [50]. To corroborate this, Tscheg et al.'s study [51] found that, in comparison to synthetic macrofiber-reinforced concrete samples, steel fiber-reinforced concrete samples generally showed a substantially larger rise in load-displacement curves. In his research with fibre volume ratios of 0.25%, 0.375%, and 0.50%, Lee [52] concluded that as the fibre volume ratio in concrete rises, so does the capacity to absorb energy. The graphs in Figure 5 also show that as the fibre volume ratio rises, the energy absorption capacity increases at a faster pace.

SplittingTensileStrength

The split tensile strength test is used to determine the tensile strength of concrete. Figure 6 displays the concrete's splitting tensile strength results after the addition of lathe waste chips. An analytical solution verified the results that were obtained. The experimental method findings and analytical solution estimations are compared in Figure 6a. The graph lines' overlap is evidence of the accuracy of the experimental work. Figure 6b demonstrates that the split tensile strength test is improved by the use of lathe waste.

The actual and anticipated split tensile strength values are presented in Table 3. The analytical solution result was 2.82 MPa, while the experimental result for the reference sample was 2.83 MPa. The experimental result was 3.08 MPa with 1% addition of lathe waste chips, whereas the analytical solution was 3.04 MPa. The experimental result was 3.29 MPa with a 2% contribution, while the analytical solution result was 3.26 MPa. The findings were 3.53 MPa and 3.48 MPa in the analytical solution with a 3% contribution. As the additive ratio of the lathe material increases, the results in the table demonstrate a proportional increase in strength of 1.09%.

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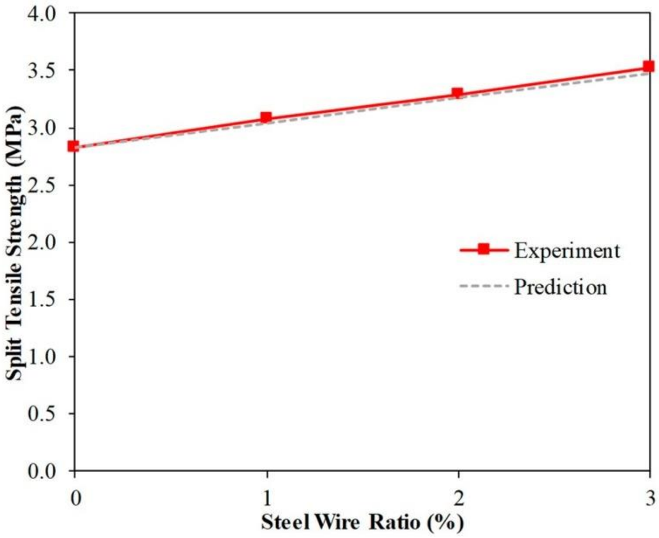
(a) **(b)**



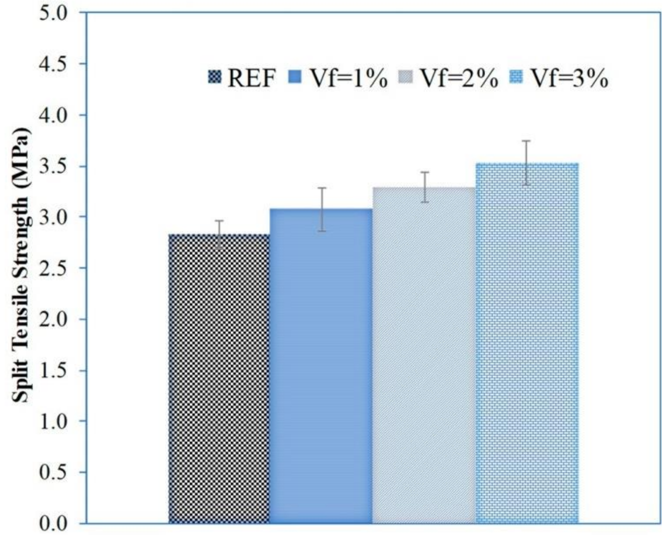


Figure5. Results of splitting tensile strength.

Flexural Performance

Figure 6 depicts the effects of adding lathe waste chips on the flexural strength of concrete. The findings demonstrate that the addition of high lathe waste chips causes the flexural strength to rise proportionately. When lathe waste chips are added, it can be seen that the flexural strength improves when compared to the reference sample; a 1% addition results in a flexural strength of 3.8 kN. The value for a 2% increment was 4.5 kN. At a 3% increase, it offered a 5 kN bending strength. While the displacement of the reference sample was roughly 2 mm, the addition of lathe waste chip caused an impressive increase in the fibre ratio.Zhenng and Feldmen [53] studied synthetic fiber-reinforced concrete and found that it had higher post-crack energy absorption capacity and ductility, as well as significantly higher flexural fatigue strength and toughness limit than plain concrete. Fiber-reinforced concretes may, however, also suffer from drawbacks such clumping. With the lathe waste chips addition, no such issue was experienced. According to Xu et al. [54], the best hook-end fibre increased the ultimate flexural strength of concrete produced by adding straight, corrugated, and hook-end steel fibres by a maximum of 165.07%. Furthermore, it is encouraging that this outcome was achieved using a lathe waste chips additive, which is not an industrial good and does not.

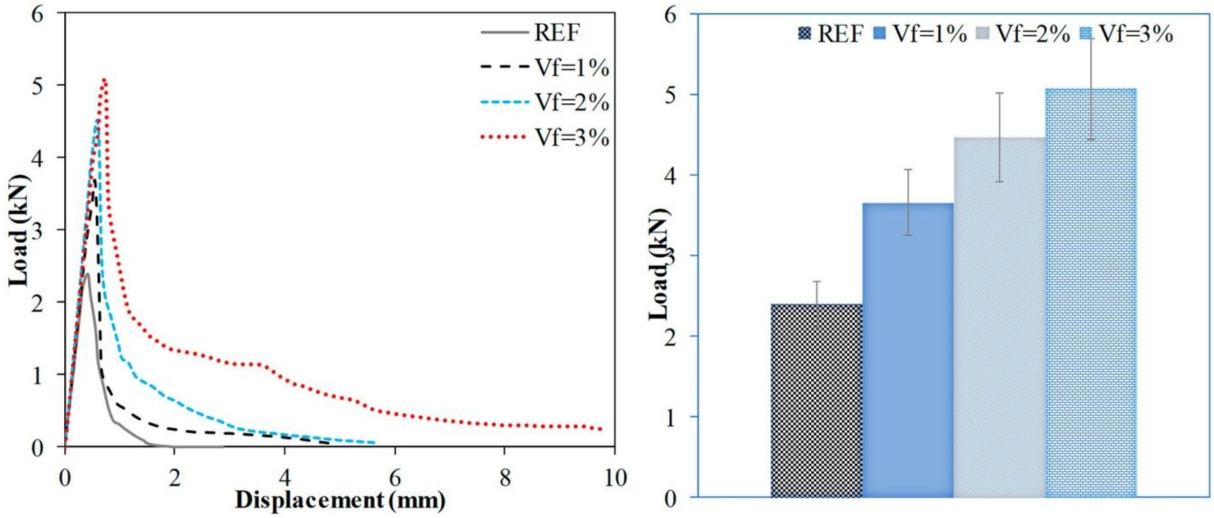
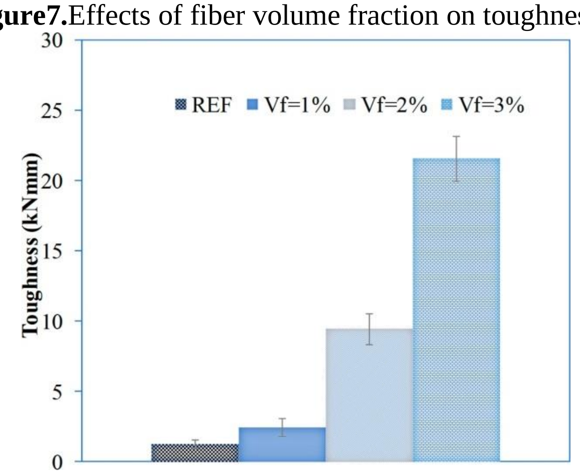


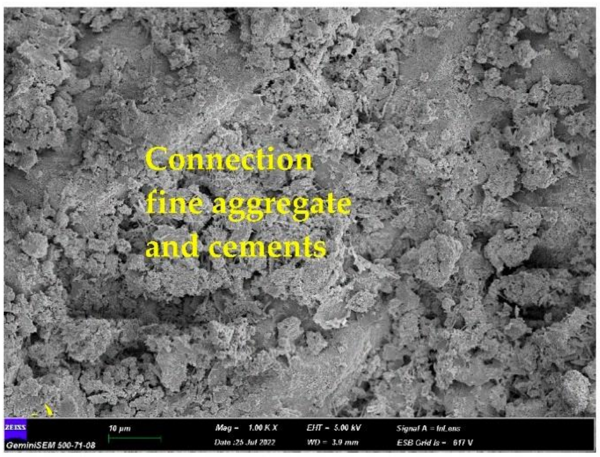
Figure6. Results offlexural strength.

The toughness of concrete is one of the most significant findings from this investigation. The toughness values are shown in Figure 8. Generally speaking, brittle materials are less tough than ductile materials. According to the data, it can be seen that adding sawdust to lathe waste chips increases their toughness significantly. While the toughness of the reference sample is almost zero, it can be seen that adding 1.2 kN, 2% 10 kN, and 3% lathe waste chips increases the toughness to about 22 kN. In their experimental work using steel fibres with various geometries, Soluioti et al. [55] found that hook-end fibres offer more resilience in concrete than fibres with wavy geometry.Although the geometry of lathe waste chips was wavy and irregular, it still provided high toughness. According to Yoo et al. [56], spun fibres have the maximum flexural strength, but at a Vf of at least 1.5%, they are comparable to straight fibres in terms of strength and toughness. They reported that poorer flexural strength and toughness were seen in hook fibre samples compared to straight ones at a Vf greater than or equal to 1.0%. As a result, waste lathe chips are longer, and their high addition to concrete greatly increases both strength and hardness, as shown by the graph in Figure 7.

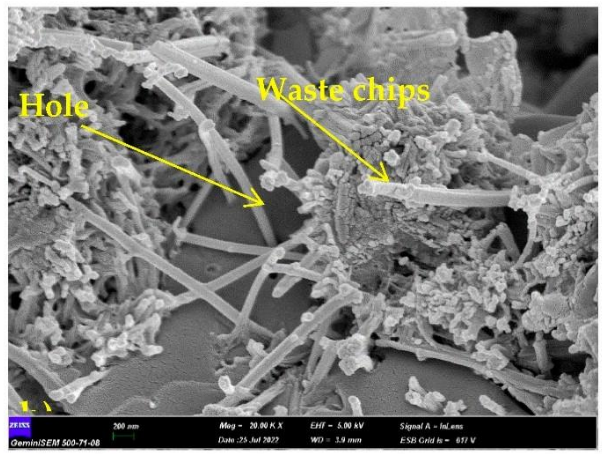
Figure7. Effects of fiber volume fraction on toughness.



On sample pieces collected from concrete samples made from lathe waste chips, scanning electron microscope (SEM) analysis was done. Figure 10 displays the primary observed findings of the SEM investigation. Note that the concrete samples created using lathe waste chips are magnified 500 times in the SEM examination photos. Figure 10a,b illustrates how adding lathe waste chips to the concrete's microscopic porosity structure results in a strong connection. Additionally, the connection between the fibres and the concrete results in an improvement in the ductility, toughness, and elastic resistance capacity of the concrete. The lathe waste chips' waved texture is another crucial characteristic that contributes to effective adherence.Lathe chips bond well with cement and aggregate, as seen in Figures 10c, d. The interface and gap states of the lathe waste chips are depicted in Figure 10e,f.



(a)



(b)

6.Conclusions and Summary

From an economic and environmental standpoint, waste materials are a major concern. The importance of finding long-lasting answers to these issues is growing daily. One of the most prevalent waste types—waste chips produced by lathe and CNC machines—was considered in this study, and its impact on the performance of concrete was examined. In order to achieve this goal, the performance of waste chip-produced concrete was evaluated in both the fresh and hardened phases. The workability and slump characteristics of concrete made with various amounts of lathe scrap fibre were identified for fresh concrete.Mechanical characteristics such as compressive strength, splitting tensile strength, and bending strength were examined in the case of hardened concrete. Then, these characteristics were contrasted with those of regular concrete. Additionally, microstructural study was done to see how lathe scrap fibre and concrete interacted. The following are the main conclusions reached by this study:

In the slump test, it was shown that the slump and workability reduced as the amount of waste chips rose. The slump value reduced by 11% with the addition of 1% waste chip, 47% with the addition of 2% waste chip, and 74% with the addition of 3% waste chip. The results of the compressive tests revealed that ordinary concrete had a compression strength of 29.5 MPa. The compression strength was improved by 11%, 22%, and 33%, respectively, by the addition of 1%, 2%, and 3% lathe waste chips. Additionally, it was discovered that the compressive strength increases proportionally as the quantity of lathe waste chips increases.The splitting tensile strength of plain concrete was calculated to be 2.83

MPa based on the findings of the split tensile strength test. With an increase in chip content, concrete's split tensile strength rose. In comparison to plain concrete, the splitting tensile strength of the concrete created with additives of 1%, 2%, and 3% chips rose by 9%, 16%, and 25%, respectively.
Analytical equations for the compressive strength and split tensile strength were derived by using curve fitting to the data collected from the test results. About 1% separate experimental values from estimated values.Generalised strength equations were created by taking into account these proposed expressions and earlier studies carried out by other academics. These suggested equations can be used to determine the compressive strength and splitting tensile strength of fiber-reinforced concrete made from leftover lathe scrap.

Given the increased workability and capacity, it is advised to use 2% lathe waste. Workability issues can arise when more than 2% of the steel from the lathe is used. According to the findings of the microstructural investigation, the waste steel lathe and cement-based concrete exhibit strong adhesion, and the waste lathe scrap fibre is crucial in reducing the crack width.

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