Influence of Steel Chips on the Mechanical and Thermal Properties of Concrete

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Abstract: 1200 million tonnes of steel chips are produced annually by lathes and CNC equipment, and they are challenging to recycle. On the characteristics of concrete, the impact of adding steel chips without first cleaning them (coated with manufacturing lubricants and cooling oils) was examined. In place of fine aggregate, steel waste was included in quantities of 5%, 10%, and 15% of cement weight, corresponding to respective amounts of 1.1%, 2.2%, and 3.3% mass of all materials and 0.33%, 0.66%, and 0.99% volume of concrete mix. A number of factors were examined, including the slump cone, air content, pH value, density, compressive strength, tensile strength, tensile splitting strength, elastic modulus, Poisson's ratio, and thermal parameters. Lathe waste was added, and it was found that while the mechanical characteristics rose, the density fell. Compressive strength rose in comparison to plain concrete by 13.9%, 20.8%, and 36.3%, flexural strength by 7.1%, 12.7%, and 18.2%, and tensile splitting strength by 4.2%, 33.2%, and 38.4% with the addition of 5%, 10%, and 15% metal chips. Additionally, it was found that the inclusion of steel chips decreased thermal diffusivity and improved specific heat capacity. Thermal diffusivity was 25.2% lower than in the reference sample with the addition of 15% metal chips, although specific heat was 23.0% greater. In terms of heat conductivity, no change was seen.

Keywords: recycling; lathe waste; CNC machining; sustainable development; mix modification; workability; mechanical properties; thermal properties.

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1. Introduction

Global steel output is predicted to reach 1869.9 Mt in 2019, up 3.4% from 2018 [1,2]. Steel is in high demand because of the building industry [3,4]. A significant rise in steel output is anticipated due to the expansion of the building sector. Due to the industry's extensive usage of steel products, energy is used [5, CO2 emissions [6,7], and various types and sizes of steel waste are produced [8–11]. Recycled steel scrap is available [12–14]. As a byproduct of creating pieces with precise geometric dimensions and surface finishes, metal chips are produced during the cutting, milling, and turning process [15,16]. About 3–5% of the weight of metal casting is made up of these wastes. Additionally, it has been calculated that industrial lathes create 3–4 kg of chips each working day [17,18] and that the trash produced by lathes and CNC machines might reach 1200 Mt annually [19–21]. Storage of this waste has an adverse effect on the environment and incurs additional expenditures due to chip surface contamination with lubricants or other coolants during the machining process [22]. The recycling of metal chips is challenging as a result, in addition to their elongated spiral structure, tiny size, and surface contaminants [22]. Additionally, when different kinds of materials are treated, the chips that are produced may have distinct characteristics.

Maanvit et al. found 19%, 27%, and 19% respective improvements in compressive strength compared to plain concrete and 50, 100, and 75% respective increases in flexural strength with the inclusion of steel chips at 22%, 33%, and 44% of cement mass as a replacement for fine and coarse aggregate. With the addition of iron filings at 28% and 37% of cement mass as a replacement for fine aggregate, Ismail and Al-Hashmi found gains in compressive strength of 13% and 17% compared to the base sample, a very minor loss (about 2% for a 19% addition). There was a 23%, 24%, and 28% increase in tensile strength, respectively. Compressive strength and flexural strength gains relative to the base sample were determined to be 5%, 8%, and 22%, respectively, with increases in the addition amount to 56%, 75%, and 94% of cement mass. Alwaeli and Nadziakiewicz showed that compressive strength rose by 24%, 30%, 43%, and 50% in comparison to plain concrete with the inclusion of steel scrap at 68%, 136%, 203%, and 271% of cement mass (25, 50, 75, and 100% of fine aggregate). Hemanth Tunga et al. showed an opposite outcome when they included steel waste as a replacement for fine aggregate at amounts of 11%, 17%, and 22% of the cement weight and got reductions in compressive strength.

Other studies have examined the use of steel waste as fibres. For concrete with fibre addition at 7%, 10%, and 13% of cement mass compared to plain concrete, Kumaran et al. showed improvements in compressive strength of 5%, 11%, and 9% and increases in flexural strength of 9%, 19%, and 10%. With the inclusion of fibre up to 25% of cement mass, Gawatre et al. found an increase in compressive strength (11%) and afterwards a drop. Dharmaraj exhibited similar outcomes. Compressive strength grew up to 10% with the addition of shreds of scrap iron, then it started to decline. They utilised fly ash despite the fact that the maximum compressive strength was 53%. According to Seetharam et al. [19], concrete with fibre additions of 10, 20, and 30% of cement weight had similarly large improvements in compressive strength (40%, 51%, and 62%). Mohammed et al.'s results for comparable fibre contents (31%, 48%, and 65% of cement mass) were only 7%, 12%, and 15% stronger than the reference sample in terms of compressive strength.

On the basis of the aforementioned, it can be inferred that the outcomes for concretes including metal chips are considerably diverse, necessitating more research before they can be widely applied. Steel chips are also categorised differently by various scientists (some call them aggregate, others scattered fibres). Therefore, the purpose of this study was to evaluate how the mechanical and thermal characteristics of concrete would change if fine aggregate were replaced with steel chips. The use of lathe chips without pre-cleaning (coated with production lubricants and cooling oils), which is novel and intends to enhance the use of production-process waste materials in building, differs from earlier studies. Compressive, flexural, and split tensile strength, elastic modulus, Poisson's coefficient, thermal conductivity, diffusivity, and specific conductivity tests of mixed and cured concrete containing 5, 10, and 15 wt.% of steel chips were performed. The amount of steel chips utilised was 5, 10, and 15% by weight of cement, which is equivalent to 1.1%, 2.2%, and 3.3% by mass of all materials and 0.33%, 0.66%, and 0.99% by volume of concrete mix, respectively. The findings demonstrate that concrete may be managed effectively and sustainably while enhancing its mechanical properties.

2. Materials

2.1. Specimen Preparation

Portland cement, aggregate, tap water, an additive, and steel scrap were used to create the combination.

2.1.1. Cement

According to the EN 197:1:2011 specification, CEM I 42.5R Portland cement was used (Górazd ze Cement Works, Opole, Poland).

2.1.2. Aggregate

The mixture's aggregate was crushed basalt sand with fractions ranging from 0 to 4 millimetres.

2.1.3. Admixture

Utilising superplasticizer (Atlas Duruflow PE-531, Bydgoszcz, Poland), less water was used to liquefy the mixture. The item satisfies EN 934-2:2009+A1:2012 requirements.

2.1.4. Addition of Steel Waste

The steel chips utilised were curved and somewhat twisted post-production steel chips produced by CNC machine tools (without huge, stringy drill chips). Steel grade 18CrNiMo7-6 that complied with EN ISO 683-3:2019 was used to make the chips. Gears, shafts, and toothed wheels are all made of this steel. In terms of substance, shape, size, and level of contamination, the trash is diverse. XRF spectrometry was used to establish its chemical makeup. In this investigation, manufacturing lubricants and cooling oils were employed to cover unclean steel chips. Testing for the presence of organic compounds on the chip surface at 450 °C revealed the presence of roughly 6% of organic chemicals with a post-production origin. The proportion of organic compounds rose to roughly 10% after the material was heated to 900 C. The weakening of the chips and the evaporation of their components were likely the causes of the increased loss on ignition (LOI).

2.2. Mixture Composition

A reference combination (without the addition of steel waste) and three mixes with various quantities of steel waste were examined. The composition of the mixture. According to a technique for creating concrete recipes with enhanced sand points, or sand concrete with a sand point value exceeding 90%, the composition of the reference mixture (M0) was established. The absence of coarse material larger than 4.0 mm is the key concept underlying the creation of this kind of concrete. Due to the large percentage of fine-grained aggregate in the pile, it is required to utilise additional cement in order to slurry the fine fractions' grains. Additionally, the proportion of coarse-grained aggregate in the mixture composition has a major role in determining the strength of the concrete. By including a lot of cement, the specified (high) strength for concrete without coarse aggregate was attained.

The inclusion of steel waste was utilised as a substitute for fine aggregate in the other mixes (M1-M3). For each combination, the water to cement ratio was 0.49.

The aggregate and steel chips were combined for 3 minutes with the dry components first. Then 1% of the cement's weight worth of water blended with a superplasticizer was added. After 6 minutes of thorough mixing, the liquid was put into the moulds. Moulds in the forms of 150 mm by 150 mm by 150 mm cubes, 150 mm by 300 mm cylinders, and 100 mm by 100 mm by 500 mm and 40 mm by 40 mm by 160 mm beams were employed. A vibrating table was used to condense the mixture within the mould. After sample preparation, water was kept from evaporating from the mold's top for 24 hours. All samples were created in a lab setting (21°C, 50% humidity). After 36 hours, samples were taken from the moulds. Until testing on day 28, the samples were kept in water in line with EN 12390-2:2019.

3. Research Methodology

3.1. Testing the Concrete Mixtures

The consistency, air content and pH value of each concrete mixture were tested.

3.1.1. Slump Test

According to EN 12350-2:2019, the Abrams cone (Merazet, Poznan, Poland) was used to measure the consistency of the concrete mix. For each combination, the slump cone test (SC) was run on five samples.

3.1.2. Air Content

The EN 12350-7:2019 pressure technique was used to test the air content. The sample was put into an 8-liter porosimeter (Merazet, Poznan, Poland), and water was pumped into the container while it was under pressure. After equalising the pressure, the measurement was recorded. For each combo, five samples underwent the test.

3.1.3. PH Value

According to PN-EN 1015-3:2001+A2:2007, the liquid phase extracted from fresh mixes had its acidity and alkalinity (pH) values measured. A Testo 206 ph2 device (Testo, Pruszków, Poland) was used for the test. After 180 seconds, the observed pH value was recorded. For each combo, five samples underwent the test.

3.2. Test of Hardened Samples

After the concrete had hardened for 28 days, the tests were conducted. Samples prepared from the analysed mixes (M0, M1, M2 and M3) were evaluated for density as well as mechanical and thermal characteristics.

3.2.1. Density

According to EN 12390-7:2019, the density of hardened samples for 150 mm 150 mm 150 mm cubes was measured. For each combo, five samples underwent the test.

3.2.2. Mechanical Properties

A Zwick machine with a force range of 0-5000 kN was used for the tests. According to EN 12390-3:2019, samples (cubes) measuring 150 mm 150 mm 150 mm underwent compression testing. According to EN 12390-5:2019, flexural strength was evaluated on 100 mm 100 mm 500 mm beams using a three-point bending method with support spacing of 300 mm [46]. According to EN 12390-6:2010, cylindrical samples measuring 150 mm by 300 mm had their splitting tensile strength tested. According to EN 12390-13:2014, cylindrical samples measuring 150 mm by 300 mm were tested for elastic modulus and Poisson's ratio using 100 mm long strain gauges placed on the specimens' opposing sides at half their height.

3.2.3. Thermal Properties

Using the ISOMET 2114 analyzer, measurements for thermal conductivity, thermal diffusivity, and specific heat were conducted. The purpose of the test was to measure how much the tested material's temperature changed in response to heat flow impulses. The 60 mm diameter probe that was in direct contact with the concrete sample that had a minimum thickness of 25 mm was heated by electric resistor heaters. It was presumptively believed that a body with no restrictions is where heat propagates. A time-dependent record of the temperature was made. For each sample, five measurements were made in five separate places. The final result was determined by averaging the measurements that were obtained. For each combo, ten samples were used in the test.

4. Results

4.1. Concrete Mixture

The test results for the concrete mixture that were achieved. For each combination, the values shown are the averages of five samples. No evidence of particle agglomeration during mixing or pouring was found for any of the mixtures.

When compared to the reference mixture, the workability of the mixes M1 and M2 improved. This could be because a superplasticizer was used in this work, since slump can be enhanced without affecting the water-to-cement ratio by adding chemical admixtures (such a superplasticizer).

S1 class (M0 and M3) and S2 class (M1 and M2) mixes were evaluated. The same class of workability was attained by Shewalul for 42.5. similar to the quantity of steel trash in this study, concrete class with the addition of steel scraps in the amount of 15% of cement content (0.5% vol. of concrete). In contrast to ordinary concrete (2.3% 0.1%), the air content of the tested combinations with steel chips rose (from 2.8% 0.1% to 3.2% 0.1%). This is most likely a result of the chips' erratic forms. Additionally, a little impact of the steel chips was seen on the mixture's pH level. This leads to the conclusion that chip corrosion and possible concrete reinforcing are unaffected by the addition of chips using steel bars.

4.2. Hardened Concrete

These numbers represent the averages of 10 samples for the other attributes and five samples for density for each blend. The connections between the mechanical/thermal characteristics and the amount of the employed addition of lathe steel chips were created based on the data obtained.

5. Discussion

5.1. Slump Cone

The workability of the mixture reduced as steel chips were added to the cement mass in amounts ranging from 5% to 15%. Whether used as scattered fibres [17,19,21] or as an aggregate replacement, this tendency is in line with the observations of other scientists. Steel waste up to 2.75 mm thick and 4.75 mm in length caused slump cones to fall by 21%, 37%, and 58%, respectively, when it made up 22%, 33%, and 44% of the cement mass. Maanvit et al. also found the same outcomes for steel waste with lengths of 10–20 mm, thicknesses of 0.25 mm, and the same quantity. Ismail and Al-Hashmi also noted a 23% reduction in the slump cone for concrete when steel chips were employed in place of fine aggregate at a ratio of 56% cement weight to 53% chips with a size range of 0.6-1.18 mm. Even though the same researchers saw an 8% drop when chips were introduced at 38% of the cement mass, 92% of the chips used in that experiment were 1.18–2.36 mm long. Gewatre et al. utilised steel chips as fibre in the range of 8-42% of cement weight and found that the slump cone decreased similarly with increasing fibre concentration compared to plain concrete. More slump cone reductions were recorded by Seetharam et al. [19] for a concrete mixture that included the inclusion of lathe chips at 10%, 20%, and 30% of the cement weight. The slump cone shrank by 12% in comparison to the reference mix at 10% addition. Due to inadequate lathe chip anchoring, Abbas [17] calculated a 25% drop for steel fibre addition at 15.3% of cement weight and a 50% decrease for addition at 31.2% of cement weight. For spiral steel chips 25–40 mm long and 0.3-0.75 mm thick at 3%, 6%, 9%, and 12% of cement weight, Purohit et al. [21] found that the slump cone decreased by 6%, 12%, 18%, and 18%, respectively. The mixture's composition is to blame for the study's less liquid fluidity. Furthermore, comparable reductions in slump cone for the same steel chips content were found for longer chips described in this work and in [21] (the slopes of the curves are identical.

5.2. Density

Concrete density declined by 2.9%, 7.0%, and 8.6%, respectively, in comparison to the reference sample when more steel waste was added (5%, 10%, and 15% of cement mass), and this association is linear. Given that granite aggregate weighs more than steel scrap, this was unexpected. Photographs of the microstructure of the concrete samples with various amounts of steel fragments were obtained to explain this phenomena. There are no air pockets or collections of steel chips, as can be seen. The sample is not segregated and the chips are dispersed consistently, which suggests that the test samples were created properly. This anomaly is presumably caused by the aggregate's bulk density and the fact that it did not fit where the wrapped lathe chips were. Further study will be conducted on this.

Similar findings were also made by Mohammed et al., who found that adding steel chips as fibres in the proportion of 65% of the cement weight decreased the density of the sample by 2.7% when compared to plain concrete. Other study discovered an inverse correlation, although the difference was negligible (usually less than 5% as compared to plain concrete). Steel chips, the majority of which (92%) were between 1.18 and 2.36 mm in size, were used by Ismail and Al-Hashmi as a replacement for fine aggregate, and they saw a 3.2% increase in density. Ismail and Al-Hashmi observed an 8% increase in density for concrete with an addition of steel scrap at 94% of cement weight compared to a reference sample using chips, the bulk of which (53%) were between 0.6 and 1.18 mm in length. Abbas [17] and Qureshi and Ahmed measured slight increases in density using steel chip fibres. Abbas [17] found a 2% increase in density for concrete with an addition of chips at 15% of cement weight and a 3.6% increase for concrete with an addition at 31% of cement weight utilising steel chips (both straight and spiral, 50 mm in length, 1 mm in thick, and 2 mm broad).

5.3. Compressive Strength

The results of the samples' compressive strength testing after 28 days of hardening are shown in Table 8. Comparing the compressive strength of M1 to the reference sample (50.4 0.3 MPa), M1's compressive strength rose by 13.9%, M2's by 20.8%, and M3's by 36.3%. Shewalul, Arunakanthi and Ch. Kumar, and these researchers all came to the same conclusions. By adding chips at 6%, 12%, and 19% of the cement mass, Arunakanthi and Ch. Kumar were able to raise the compressive strength of concrete by 15%, 22%, and 25%. For 5% and 10% of cement mass utilised as a substitute for fine aggregate, Prabu et al. showed roughly a 20% improvement. Shewalul reached findings comparable to those found in by achieving a 26.8% increase for steel chips addition at 13% of cement mass. Other researchers have also shown gains in compressive strength for concrete that uses steel chips in place of fine aggregate. In comparison to this work, Shukla [20] found lesser gains in compressive strength (5 and 14% for the addition of chips in the quantity at 6% and 12% of cement mass). Ismail and Al-Hashmi showed the similar result, whereas Hemanth Tunga et al. showed a larger compressive strength increase (23%) for adding at 6% of cement mass. Sheikh and Reza replaced the coarse aggregate with lathe waste and still saw a 35.9% improvement. greater gains in compressive strength (24%, 30%, 43%, and 50%), although for a significantly greater proportion of steel chips (68%, according to Alwaeli and Nadziakiewicz, were determined.

Lathe chips used as steel fibres showed the same pattern. According to Kumaran et al., concrete with fibre addition in percentages similar to those in this investigation (7%, 10%, and 13% of cement mass) increased in compressive strength by 5%, 11%, and 9% when compared to plain concrete. For addition at 4%, 6%, and 8% of cement mass with a w/c ratio of 0.4, Ghumare found 16.0%, 19.5%, and 21.3% improvement (the increase computed for 5% of cement mass was equivalent to 17.7%). For the same cement class as in this work, Althoey and Hosen found 5% and 13% increases with metal chips injected at 10.8% and 21.6% of cement mass, respectively. Seetharam et al. [19] reported a larger gain in compressive strength (40%) for addition at 10% of cement mass, whereas Purohit et al. [21] showed increases of 3%, 4%, 20%, and 8% for addition at 3%, 6%, 9%, and 12% of cement weight, respectively. Mansi et al. [18] found that steel fibre insertion at 1% and 2% of the sample weight resulted in a comparable improvement in compressive strength compared to the reference sample (15% and 13%) as in our investigation. Other researchers also noted increases of 11–13%. For concrete with a lesser addition of steel chips (at 0.5-2% of cement weight), Ashok et al. and Shrivastavaa and Joshib found a maximum strength improvement of around 3%. The reference sample was destroyed in the same manner as the samples that had metal lathe waste added. Compressive strength and chip addition are linearly correlated. The findings are consistent with other scientists' observations (Figure 10). Kumaran et al. calculated 5%, 11%, and 9% improvements in compressive strength relative to the reference sample for adding lathe chips as fibres at 7%, 10%, and 13% of cement weight, however those values are less than half of those found in our investigation. In comparison to the reference sample, Abbas [17] found that adding lathe chips at 15%, 23%, and 31% of cement weight resulted in a modest 2% improvement in strength. Mohammed et al. achieved compressive strength improvements of 7%, 12%, and 15%, respectively, in comparison to the reference sample for additions of 31%, 48%, and 65% by weight of cement. It is clear that the association between compressive strength and lathe waste content that was found is consistent with findings made by previous researchers [17]. In this instance, the curve's approximate slope.

Hemanth Tunga et al. investigated concrete with additive contents similar to those in this study (6%, 11%, 17%, and 22% of cement weight), and they found that a 6% addition of chips increased compressive strength by 23% before decreasing. The largest increase in compressive strength (11%) was attained with an addition of 25% of cement weight, however Gawatre et al. found the same association for concrete with lathe chips added at 8–42% of cement weight. Both Maanvit et al. and Prasad et al. noted the rise in compressive strength followed by a subsequent reduction. For 10% of shredder-added scrap iron, Dharmaraj likewise saw an increase in compressive strength of up to 53%, followed by a decline. Here, with the addition of more steel scrap, a nearly unbelievable rise in compressive strength can be shown, although the experimental investigations of other scientists show a very modest or even zero increase. It's possible that this is connected to the chosen mixture composition.

5.4. Flexural Strength

Table 8 displays the findings about the samples' flexural strength. Flexural strength was found to improve by 7.1%, 12.7%, and 18.2%, respectively, when steel lathe waste was added to cement at concentrations of 5%, 10%, and 15%, compared to the reference sample (10.8 0.1 MPa). According to Figure 11, there is a linear correlation between the sample's tensile flexural strength and the amount of steel chips added. Arunakanthi and Ch. Kumar came to the same conclusion. For the same amounts of steel chip addition (3%, 6%, 9%, and 12%), they saw greater gains in flexural strength (18%, 27%, and 38%) compared to the base sample. However, in this instance, steel chips were utilised as fibre. The association between flexural strength and lathe waste content is identical, though, if the quantity of lathe chips is compared to the cement content (the slope of the curves is approximative; see). Kumaran et al., who reported 9%, 19%, and 10% improvements in flexural strength for concrete with fibre inclusion at 7%, 10%, and 13% of cement mass compared to plain concrete, found the same association. Similar to the use of conventional fibres or recycled fibres, this has to do with fracture prevention and crack bridging. By Shrivastava and Joshi, same phenomena for concrete containing lathe chips as fibre was described.

According to other scientists' studies, the flexural strength increases as steel chip content increases. Similar improvement (13.15%) was noted by Ghumare for concrete with lathe chip content at 8% of cement mass and a w/c ratio of 0.45, although the amount was less than the outcomes of our investigation. Similar flexural strength values for M30 concrete with 5% and 10% addition of steel chips and w/c = 0.4 were reported by Prabu et al., although the increase was significantly more than in our investigation. Ismail and Al-Hashmi found that steel chips applied as a fine aggregate substitute at 19% of cement weight resulted in a similar improvement in flexural strength (22%) compared to the base sample. Ismail and Al-Hashmi achieved a slightly smaller gain in tensile strength (9%) for the same quantity of chips in a different test, although this was likely because they used a combination of metal and plastic chips in that instance. Maanwit et al. investigated additions at 22%, 33%, and 44% of cement weight and found 50%, 100%, and 75% improvements in flexural strength in comparison to the reference sample. Prasad et al. achieved comparable gains (50%, 94%, and 69%) with the same addition quantities of larger-sized lathe chips (as a replacement for fine and coarse aggregate). In his research, Dharmaraj found that adding fly ash and steel fiber—shredded scrap iron—to concrete at a ratio of 10 to 25 percent of cement weight resulted in a 3% improvement in compressive strength for 15% scrap iron. When Ashok et al. added steel chips in the range of 0.5 to 2% of cement weight, they were able to achieve a maximum improvement in strength of 42% over the reference sample. Seetharam et al. [19] demonstrated a reduction in strength with the inclusion of steel chips as fibre at 10%, 20%, and 30% of cement weight.

5.5. Splitting Tensile Strength

The results of splitting tensile strength tests performed on materials containing various amounts of steel chips. In comparison to the reference sample (2.89 0.03 MPa), it was found that adding steel lathe waste at 5%, 10%, and 15% of cement weight increased splitting tensile strength by 4.2%, 33.2%, and 38.4%, respectively. With additions of 5% and 10% of steel chips and w/c = 0.4, Prabu et al.'s research on M30 concrete produced the same flexural strength values and increases. Similar results (4.37 MPa) were obtained by Shewalul for M25 concrete using steel chips as a substitute for fine aggregate at 13% of cement mass, although the increase was somewhat less (11.2%). Strengthening of the breaking tensile bond relative to the base samples for the same addition as in this investigation (7%, 10%, and 13% of cement weight), Kumaran et al. showed lesser improvements in splitting tensile strength (11%, 15%, and 13%) compared to the reference sample. For a sample with 6% additional cement mass added as steel chips, Hemanth Tunga et al. found the biggest gain in splitting tensile strength (14%) before finding a drop. For samples that had steel chips added at 22%, 33%, and 44% of the cement weight, respectively, Maanvit et al. found improvements in strength of 38%, 79%, and 51% in comparison to the reference sample. Additionally, Prasad et al. reported substantially lower improvements in tensile strength for the same levels of addition but for a mixture of steel and plastic chips. Both Mohammed et al. and Kumaran et al. noted the similar association. Mohammed et al.'s results for concrete with additions of 31%, 48%, and 65% by weight of cement, respectively, resulted in improvements in splitting tensile strength of 42%, 11%, and 20%. When Ashok et al. tested an addition at a lower concentration between 0.5% and 2.0% of cement weight, they found that a 20% increase in splitting tensile strength was the highest improvement.

Similar to other mechanical properties, it can be seen that the obtained curve for the correlation between splitting tensile strength and lathe waste content has a slope that is very similar to relationships established by other researchers [21], particularly to the outcomes obtained by Purohit et al. [21].

5.6. Elastic Modulus and Poisson's Ratio

In comparison to plain concrete (32.0 0.4 GPa), the elasticity modulus rose from 0.6% to 6.2% with the inclusion of steel scrap. This phenomena is similar with Shewalul's findings, however the study's results showed larger levels. The reference sample's Poisson's ratio was 0.120 0.03. The results for samples M1–M3 can be seen to be within the measurement error limit.

5.7. Thermal Properties

The thermal characteristics for concrete sample samples. Thermal conductivity was unaffected by the inclusion of lathe waste, which made up between 5% and 15% of the cement mass.

In comparison to the reference sample, a 3.7%, 17.5%, and 25.2% reduction in thermal diffusivity was found for lathe waste additions of 5%, 10%, and 15%. Thermal diffusivity and steel chip concentration were shown to be correlated linearly (Figure 13). Additionally, Figure 13 displays the precise heat measurements for concrete with various quantities of steel chips. In comparison to the original sample, specific heat increased by 10.4%, 14.8%, and 23.0% with the addition of 5%, 10%, and 15% of lathe waste, respectively. The found correlation is comparable to steel-fibered concrete [14].

6. Conclusions

The study's objective was to determine if it would be feasible to use lathe chips, which were coated in cooling fluids and manufacturing lubricants, as post-production waste materials in concrete without first cleaning them. Three different addition contents (5%, 10%, and 15% of the cement weight) were employed in this study to replace fine aggregate. The findings of this experimental investigation allow for the following inferences:

1. For waste additions of 5% and 10% by weight of cement, the concrete mix became more workable and qualified for the S2 class. The S1 class included the reference samples and samples that had 15% waste lathe added.

2. In contrast to ordinary concrete (2.3% 0.1%), the air content of the tested combinations with steel chips (Table 7) rose (from 2.8% 0.1% to 3.2% 0.1%). The uneven form of the chips is possibly to blame for this.

3. Compared to the reference sample, the compressive strength of concrete after 28 days rose linearly from 50.4 MPa to 68.7 MPa. Steel chips used at 15% of cement weight resulted in a 36.3% improvement in compressive strength.

From 10.83 MPa, which served as the reference value, through 12.8 MPa, the flexural strength rose linearly. This translates as a 15.0% increase in flexural strength due to the steel chip addition.

5. When compared to the reference sample, the 15 weight percent additive's splitting tensile strength rose by 38.4%.

6. For additions of metal lathe waste ranging from 5% to 15% of cement weight, a modest rise in elastic modulus was seen, increasing from roughly 1% to 6%.

7. It was shown that the thermal conductivity of concrete is unaffected by the use of steel chips in place of fine aggregate.

8. When steel chips were added at 5%, 10%, and 15%, thermal diffusivity decreased by 3.7%, 17.5%, and 25.2%.

In comparison to the reference sample, the specific heat of concrete containing 15% steel chips as a substitute for fine aggregate increased by 23.0%.

Additionally, it was shown in this study that correlations between characteristics and lathe chip content for various concrete mixes are comparable because of the adoption of lathe chip content in relation to cement content. The curves' slopes are approximations.

Due to the use of various cement classes, aggregate types and fractions, types of plasticizers, and types, qualities, and levels of contamination of the added steel chips, differences between these results and results obtained by other scientists can be seen based on the obtained results and correlations between properties and lathe chip content.

Furthermore, it was shown that substituting lathe chips for fine aggregate in the range of 5% to 15% can enhance the mechanical characteristics of concrete without the need for pre-cleaning (provided they are covered with production lubricants and cooling oils). It was especially striking that the results were better than those of chips prepared using the traditional approach, which involved melting the chips.

This article is a component of a larger research effort that aims to create ecologically friendly concrete in accordance with the concepts of sustainable development and closed-loop economy. Further testing of this material, particularly fatigue testing, will be planned in light of the improvements in the mechanical characteristics of concrete brought about by the inclusion of chips.

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