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Impact of Incorporating Plastic Fibers, Walnut Shells, and Tire Rubber Fibers on the Mechanical Properties of Concrete

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Abstract

There are serious environmental issues as a result of the increasing amount of waste generated worldwide, especially from industrial and commercial growth. In order to improve the mechanical characteristics of concrete and address waste management, this study explores the possibility of adding three distinct waste materials—plastic fibers, walnut shells, and tire rubber fibers—as additives. In addition to a reference mixture devoid of waste materials, four concrete mixtures were made, each including 1.0% of the cement weight of waste materials. To assess the mechanical properties, such as compressive, splitting tensile, and flexural strengths, extensive testing was carried out on cubic, cylindrical, and prismatic specimens. The findings showed clear differences in performance between the various waste materials. Notably, in comparison with the reference mix, the compressive strength of tire rubber fibers and walnut shells increased by 4.9% and 8.7%, respectively. Likewise, improvements in flexural strength were observed, with tire rubber fibers improving strength by 8.9% and walnut shells by 11.1%. On the other hand, in every evaluated property, plastic fibers continuously showed decreased mechanical performance. Workability studies revealed that all waste-modified mixtures had decreased slump values; nevertheless, because of its porosity and rough surface, the walnut shell mix had the lowest workability. Across waste-modified mixes, splitting tensile strength dropped consistently, with decreases ranging from 11.5% to 12.4%. By showing the potential of waste materials in concrete production, this study sheds light on the mechanical behavior of concrete that incorporates various waste materials, thereby promoting sustainable construction practices.

Keywords

Concrete, Waste materials, Mechanical properties, Sustainability, Recycling

1. Introduction

As a result of the industrial and economic development that the world has witnessed in recent decades, in addition to the exponential population growth, countries across the globe are faced with the continual growth of different kinds of waste accumulation resulting from materials with a lot of use, especially plastics and food waste such as the shells of some foodstuffs, has emerged. Millions of tons of trash are produced globally each year, with a large fraction being non-recyclable. Furthermore, the recycling process consumes energy and adds to pollution. The accumulation of waste in suburban regions and its disposal also present serious environmental risks (Ibrahim Mohammed et al., 2024; Mohammed et al., 2023; Shawais et al., 2024; Tavakoli et al., 2018).

Plastics are a crucial component utilized across various industrial sectors, with packaging being the largest consumer at 36%. Various types of plastic materials offer highly useful and versatile properties. Two key benefits of plastics are their durability and longevity, which enable the production of long-lasting products that require little maintenance, making them very cost-effective over their lifetime. By 2050, an estimated 700 million tons of plastic is anticipated to be produced, with the largest contributors being Asia at 50%, North America at 10%, and Europe at 16% of the total future supply (Ragaert et al., 2017). Approximately 6.5 billion tons of plastic waste are generated globally each year (Jnr et al., 2018).

This plastic waste accumulation is becoming one of the major challenges for our immediate surroundings, most plastics are non-biodegradable and can take more than 400 years to decompose. Plastic waste, therefore, ends up in landfills, which occupy extensive areas and ultimately impact their surrounding environments (da Costa et al., 2016). Due to the adverse effects of plastic waste, researchers have identified recycling as the most sustainable method of managing plastic waste, considering that both landfilling and incineration are limited (Babafemi et al., 2018). All plastics, however, aren't recyclable with existing technologies. Polystyrene, polypropylene and polyvinyl chloride belong to a group of thermoplastics, while epoxy, silicone and polyurethane materials are classified as thermosets, albeit only the latter can be easily recycled (Bajracharya et al., 2017).

Concrete is the most widely used construction material globally, primarily due to its well-recognized advantageous properties (Al-Sulayvani & Al-Talabani, 2015). It consists of a straightforward combination of ingredients, including cement, fine and coarse aggregates, and water, making it more economically viable and durable than other construction materials (Ferriz-Papi & Thomas, 2020). However, concrete has significant drawbacks, including its considerably lower tensile strength, which can lead to failure under tensile stresses. Additionally, there are environmental concerns associated with CO2 emissions and ecosystem destruction from aggregate production (Lehne & Preston, 2018).

Concrete manufacturers, for instance, use recycled aggregates sourced from demolition debris to reduce quarry depletion, consequently lessening the adverse environmental effects (Al-Luhybi et al., 2022; Awoyera & Adesina, 2020). Nevertheless, these new techniques aimed at improving concrete do not tackle the issue of plastic waste and recycling. Given that concrete lasts longer than plastic, adding plastics to concrete may reduce the amount of unrecycled waste, thus lessening its impact on ecosystems (Santhanam et al., 2020).

Although interest in replacing traditional concrete components with waste materials is increasing, little research has been conducted to determine the optimal types and proportions of waste material that still improves the mechanical properties of concrete, while also maintaining the overall mechanical performance and workability of the concrete product. On the one hand, only a few works tested the mixture of two different waste, like plastic fibers, walnut shells, and tire rubber fibers, to study the reuse of industrial wastes, such as waste foundry sand (WFS) and pumice stone, as effective substitutes for aggregates.

In recent years, attempts have been made to use industrial waste like WFS as substitutes for aggregate in concrete in order to emphasize recycling in place of natural aggregates. Ali et al. (2022) showed that WFS can be effectively used in concrete production as a substitution for fine aggregate in concrete and can enhance fresh and mechanical properties when optimized with response surface methodology (RSM). The fine aggregate was partially replaced with 20% WFS, using Central Composite Design (CCD) methodology, the maximum properties of mechanical performance include the compressive strength of 29.37 MPa, split tensile strength of 3.828 MPa, and flexural strength of 8.0 MPa at 56 days of curing. Beyond this percentage, mechanical properties started to fall due of the high content of fines which affected workability and bonding. Similarly, Ali et al. (2023) utilized pumice stone and fine aggregate in lightweight concrete, similarly showing the capability of RSM as a powerful erecting technique for subsequent optimization to obtain high strength traits of the designs. Among them are Fediuk and Ali (2022), who highlighted the importance of recyclable materials in the green construction industry and stressed the need for incorporating industrial by-products into concrete mixtures to improve sustainability and economic efficiency. Ali and Macioszek (2023) also utilized RSM to examine the influence of using pumice stone as coarse aggregate substitute on lightweight concrete properties. Their experimental results showed that the relative strength characteristics can be reduced with the increase of pumice stone ratio while the curing days remained the same. The substitute ratio was 0% for 50% pumice stone used in lightweight aggregate for all curing day and compiles to the desired limits and expected limits of compressive strength, split tensile strength and flexural strength. Additionally, a 30% replacement with 56 days curing recorded a compressive strength of 20 MPa with a split tensile strength (9.38% of compressive strength) of 1.88 MPa.

The replacement of aggregates in concrete and mortar with walnut shells has emerged as a challenge for environmental reduction and natural resources conservation. The impact of the inclusion of WS in concrete and mortar formulations is an area of active research, with studies and investigations into properties such as compressive strength, density, water uptake, and thermal conductivity. Kamal et al. (2017) examined the feasibility of using walnut shells as a partial replacement for fine aggregate in concrete and reported that up to 30% replacement at a 0.38 water/cement ratio had no negative effect on the compressive strength, at the same time decrease density and water absorption. Similarly, Hilal et al. (2020) studied the addition of walnut shells to self-compacting concrete, reporting that although high levels of WS led to lower performance of concrete in terms of mechanical properties, acceptable-strength lightweight concrete could be produced at up to 35% replacement level. In their work, studying walnut shells in mortar, Abdulwahid and Abdullah (2021) showed that soaking walnut shells in boiling water for 30 minutes was found as an effective treatment that enhanced the mortar properties in terms of a 15% replacement of walnut shells reduced mortar density and thermal conductivity by 15% and 31%, respectively, while ensuring acceptable compressive and flexural strengths.

Experimental investigations conducted on rubberized concrete indicate that the inclusion of tire rubber fibers as a substitute (partial/full) for natural aggregates greatly influence the mechanical characteristics of rubberized concrete. Khaloo et al. (2008) examined the effect on concrete strength at different levels of rubber content, finding a decrease in compressive strength and modulus of elasticity but an improvement in toughness and impact resistance. From Aslani (2016)'s extensive experimental program to evaluate compressive, tensile, and flexural strengths of rubberized concrete stated, with the increase of rubber content the strength will be decreased but ductility enhanced. Rubberized concrete showed better energy absorption and robustness under dynamic loading, although workability and density declined, according to Sgobba et al. (2010), who investigated the ideal mix proportions of rubber aggregates.

The answer to many environmental problems of the world is waste use which is the fundamental measure that can be taken to dispose of waste which increases amount of landfilling because of waste as well as can minimize the component of construction industry and the component of aggregates. Two main methods are mentioned in the following sections, which could be as (1) utilization of recycled waste as concrete reinforcement fibers, that is, to have strength, and (2) utilization of recycled waste as concrete substitutes. Plastic fibers providing reinforcement in concrete can be beneficial in terms of sustainability, structural design and durability. From this aspect, optimization of concrete mix and distributed rebar quantity highly contributes to structure efficiency and economical construction (Snell et al., 2017). Synthetic materials can be added to the concrete to enhance its ductility knowing that polymers will not oxidize as steel bars.

In many cases, plastics are also used as coarse or fine aggregates, which is very beneficial from an environmental point of view. Pacheco-Torgal (2019) examined the impact of polyethylene terephthalate (PET) from plastic bottles in partially replacing sand in concrete (up to 50%). Overall, it is concluded that recycled PET can be used in green concrete casting with a defined replacement percentage. Due to the characteristics of this plastic, which mainly differ from those of other aggregates, this method reduces the concrete's dead load in the structure and can even be applied to non-structural parts where high compressive strength is not-required (Omary et al., 2016). Thus, the utilization of such plastic waste with concrete will provide an excellent opportunity for enhancing the sustainability of the concrete industry and fulfilling the sustainable construction by enhancing thermal performance, reducing the consumption of natural resources and waste intake, eliminating the pollution and saving energy (Ferriz-Papi & Thomas, 2020). Mixing process with polymer as an aggregate is the easiest approach to use plastics in the concrete mixture. This straightforward technique enables factories to create batches capable of serving various functions. The other technique is to heat up the plastics and mix it with the gravel (coarse aggregate) and allow it to cool. Around a few hours later, the plastic bonds tightly with the aggregate (Zhang & Poon, 2018). Moreover, Al-Luhybi and Qader (2021) investigated through an experimental test for the mechanical performance of hardened concrete with waste PET plastic. To test the impact of the material, they incorporated fibers in three different lengths — 22 mm, 45 mm, and a mixture of them — in concrete mixtures. The mixes underwent various tests, including compressive strength, splitting tensile strength, flexural strength, slump, and ultrasonic pulse velocity measurements. Their results showed that concrete with PET waste as fibers could maintain acceptable compressive strength; thus, it could be used for more endogenous applications with lower structural strength requirements.

The purpose of this study is to see how the addition of various waste materials (plastic fibers, walnut shells, and tire rubber fibers) influences the mechanical behavior of concrete. It also investigates the most effective waste material for an improvement of the compressive, flexural and tensile strength and whether the waste material can be used to achieve sustainable concrete.

An experimental approach was used to answer these questions. To this end, four distinct mixtures were formulated: a control containing no waste and three other mixes modified with 1.0% (to cement mass) plastic fibers, walnut shells, and rubber tires). The compressive, splitting tensile, and flexural strengths of cubic, cylindrical, and prismatic specimens were examined through standardized tests. The workability of fresh concrete was evaluated through slump tests. These experiments not only demonstrate the ability to use waste materials in concrete but also explore their structural development for potential opportunities in sustainable construction.

Research significance

The main objective of this study is to conduct an experimental investigation to study the effect of specific types of waste (Plastic fibers, walnut shells, and tire rubber fibers) on the behavior of concrete and the effects resulting from adding these wastes to the mechanical properties of concrete to obtain a complete understanding of the behavior of such types of concrete and thus obtain a method for disposing of wastes in an environmentally friendly and pollution-free. Thus, this research can contribute to solving the problem of waste disposal safely and cheaply, as well as improving some properties of concrete.

2. Experimental work

To implement the experimental program of the present study, four mixtures were adopted, three of which contained different waste materials with the same amount (1.0%) of cement weight. The reference mixture did not contain waste materials and was designed to achieve a target compressive strength of 30 MPa at 28 days, which is typical for structural concrete applications. The control mixture was prepared using the following proportions, the other three mixtures contained fibers extracted from plastic bottles, walnut shells, and rubber threads from tires. Tests were conducted on cubic, cylindrical, and prismatic specimens to evaluate compressive strength, tensile strength, and flexural strength, respectively. Fig. 1 shows the methodology flowchart of this experimental study.

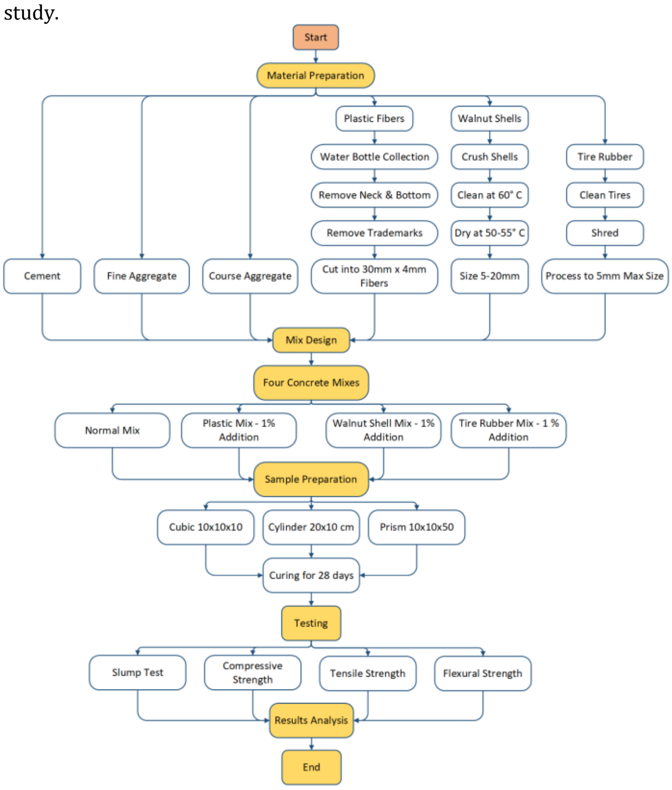

Fig. 1 Research methodology of the current study

2.1 Materials description

The following materials were utilized in this experimental investigation:

Cement

In this study, locally available Ordinary Portland Cement (OPC) was employed. The fineness of cement = 295 m2/kg, specific gravity = 3.15. The chemical compositions of OPC were shown in Table 1. The physical properties of the cement utilized are given in Table 2. It is satisfied to the Iraqi Standard Specifications (IQS(No.5), 2009).

Table 1. Composition of chemicals of the utilized cement

Property	Composition content (%)	IQS Standard, No. 5 (IQS(No.5), 2009)
Oxide composition		
Alumina, Al_2O_3	5.03	
Silica, SiO_2	20.77	
Ferric Oxide, Fe_2O_3	3.1	
Lime, CaO	62.6	
Sulphatic Anhydride, SO_3	2.16	Max. 2.5
Magnesia, MgO	2.3	Max. 5
Compound composition		
C_3A	8.28	
C_2S	26.45	
C_3S	44.52	
C_4AF	9.15	
Free Lime	1.41	
Loss on ignition	1.15	Max. 4
Solid solution	15.71	
Insoluble Residue	0.23	

Table 2. Physical characteristics of the employed cement

Property	Test result	IQS Standard, No. 5 (IQS(No.5), 2009)
Initial setting time (min)	120	≥45
Final setting time (min)	255	≤600
Compressive strength (MPa)		
at 2 days	17.3	≥10.0
at 28 days	52.9	≥32.5

Fine and coarse aggregates

The aggregates used in the present study were locally available round river aggregates, which were used in all mixtures. The natural coarse aggregate demonstrated a specific gravity of 2.66 and a water absorption rate of 0.71%, while the fine aggregate showed a specific gravity of 2.61 and a higher water absorption rate of 1.9%. The maximum size of the coarse aggregate was 19 mm. Fig. 2 depicts the sieve analysis results of the used sand.

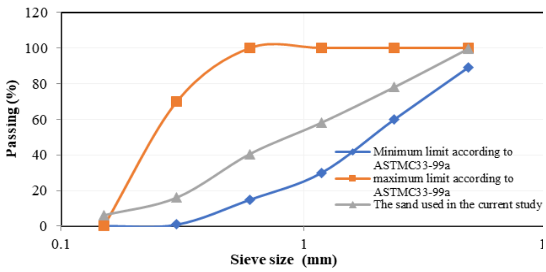

Fig. 2 Sieve analysis result of the employed sand

Plastic fibers (PET)

There are different types, shapes, and sizes of plastic waste, so in this study, waste plastic water bottles were used to produce plastic fibers from these bottles after removing the bottle neck and bottom and removing the trademarks applied to them to obtain homogeneous fibers. The remaining plastic was then cut into fibers measuring 30 mm in length and 4 mm in width, as illustrated in Fig. 3.

Fig. 3 Process of making plastic PET fibers

Walnut shells

Walnut shells were subjected to mechanical processing to achieve a particle size of 5 to 20 mm. Walnut shells were collected from walnut trees and cleaned by washing them with water at 60 °C to remove organic materials. Then, the shells were dried in an oven at 50-55 °C. 70% of these shells were 5 to 10 mm long. The process of making and preparing the walnut shells is illustrated in Fig. 4.

Fig. 4 Methods of preparing walnut shells in the laboratory

Tire rubber fibers

Used car tires can be utilized to produce tire fibers to be added to the concrete mixture for the present study. The tire is cleaned and ground to convert the used tire rubber into rubber fibers for use in the concrete mixture. The tire is cut in a special cutting machine to become smaller fiber pieces with a maximum size of 5 mm as shown in Fig. 5.

Fig. 5 Methods of preparing tire rubber fibers (M. Mhaya et al., 2021)

2.2 Process of mixing, preparing, and casting

According to the quantities of materials for each concrete mix shown in Table 3, the amounts of materials required for one mix are calculated. It should also be noted that three samples of each concrete mix were tested, and their average value was calculated. The water-cement (W/C) ratio of 0.45 was used as a moderate value to ensure appropriate workability and strength. It is known that decreasing W/C ratios improves strength and durability, however lowering it will reduce workability, in contrast a high W/C ratio will increase workability but will reduce the mechanical properties. Furthermore, since the modified concrete must still be sufficiently workable to allow proper mixing and placement, a ratio of 0.45 was chosen that is high enough to allow this proper placement but prevent the material from becoming too weak. According to (ASTM-C192/C192M-15, 2015), coarse aggregate and fine aggregate will be placed in the mixer and to achieve a saturated surface dry (SSD) condition, additional water is added to them and stirred for 2 minutes. After that, cement is added with the mixing water and the materials are mixed for 3 minutes to reach a homogeneous condition. After the mixing process is completed, the slump test of the mixtures is carried out to determine the workability. Then, the test specimens are poured immediately, using a vibrator. After 24 hours, the specimens are de-molded from the molds and then treated in curing water for another 28 days before being tested.

Table 3. Mix design and proportions of the present study

Mix ID	Waste %	Cement Kg/m³	Sand Kg/m³	Gravel Kg/m³	W/C ratio	Mix proportion
Normal mix	0	300	450	900	0.45	1:1.5:3
Plastic mix	1	300	450	900	0.45	
Walnut shell mix	1	300	450	900	0.45	
Tire mix	1	300	450	900	0.45	

2.3 Testing procedure

Compressive strength testing

The mechanical test was carried out after 28 days using a universal compression machine with a capacity of 2000 kN to measure the compressive strength. The strength of each concrete mix was determined by testing cubic samples with dimensions of (100×100×100 mm). The test load was applied at a loading rate of 0.3 MPa/s according to (BS(EN-12390-3), 2019). The dependent average strength was calculated using three measurements.

Tensile strength testing

The tensile strength was measured by conducting a tensile test. Cylindrical specimens (100×200 mm) of each concrete mixture were tested for tensile strength. The average strength results are obtained over three samples. The tensile load was applied at a loading rate of (1.5) kN/s, according to (ASTM-C469, 2010)

Flexural strength testing

Also known as modulus of rupture or flexural strength, it is a material property. The transverse bending test was performed using a prism of dimensions (100×100×500 mm) to fracture using the three-point bending test technique. The flexural strength represents the maximum stress to which the material is subjected at the moment of yielding. It is denoted by the symbol (σ): $\sigma = F/bd$.

3. Results and discussion

3.1 Workability results

One of the most crucial parameters of concrete is workability. As shown in Table 4 and Figure 6, respectively, the inclusion of waste materials had a substantial impact on the workability of concrete as determined by slump tests. In comparison to the reference mix, which attained a 60 mm slump within (ASTM-C143/C143M-12, 2012) requirements, all modified mixes displayed lower slump values. Because of its smooth surface properties, the tire rubber mix showed somewhat greater workability than other waste mixtures. The workability of the plastic fiber and walnut shell mixes was extremely low, with the walnut shell mix performing the worst because of its porosity and rough surface texture.

Table 4. Slump values for all mixtures employed in this investigation

Mix type	Slump value (mm)	Workability assessment
Normal mix (Reference)	60	Within ASTM C143 (ASTM-C143/C143M-12, 2012) specification limits
Plastic fiber mix	< 60	Very low workability due to high surface area
Walnut shell mix	< 60	Lowest workability due to rough surface and porosity
Tire rubber mix	< 60 but > other mixes	Better than other waste mixes due to smooth surface

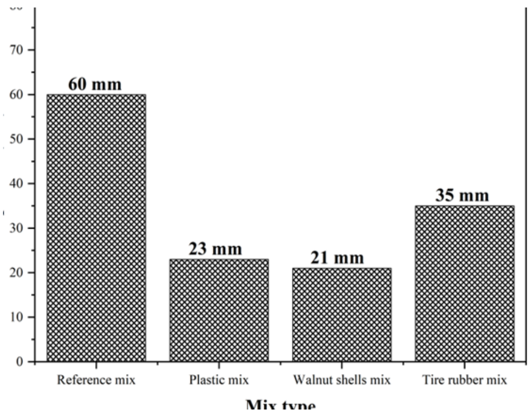

Fig. 6. Effects of adding different waste materials on the slump of fresh concrete

3.2 Compressive strength results

Compressive strength is one of the significant mechanical properties of concrete that determines its structural performance. After 28 days of curing, the tire rubber fibers and walnut shells both shown increases in compressive strength over the reference mix (31.68 MPa), as indicated in Table 5 and Figure 7, respectively. With a strength of 34.43 MPa (+8.7%), the walnut shells mix was the strongest, followed by the tire rubber fibers mix at 33.23 MPa (+4.9%). The plastic fiber mix's compressive strength, however, dropped to just 27.85 MPa (-12.1%). Each mix type exhibits unique fracture characteristics in the failure patterns seen in Fig. 8–10, with the waste materials having an impact on the crack propagation patterns.

Table 5. The compressive strength results for all mixture types employed in this investigation after 28 days of curing period

Mix type	Test results (MPa)	Performance vs Reference
Reference	31.68	Baseline
Plastic fiber mix	27.85	-12.1%
Walnut shell mix	34.43	+8.7%
Tire rubber mix	33.23	+4.9%

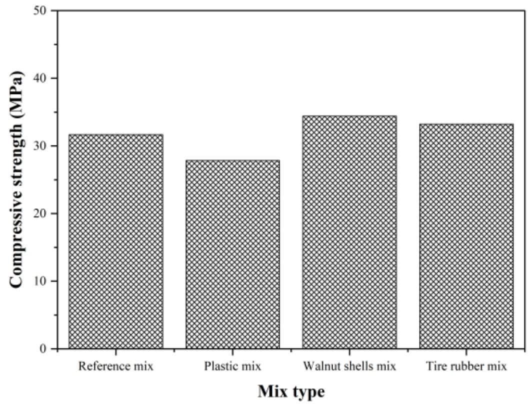

Fig. 7. Effects of adding different waste materials on the compressive strength of hardened concrete

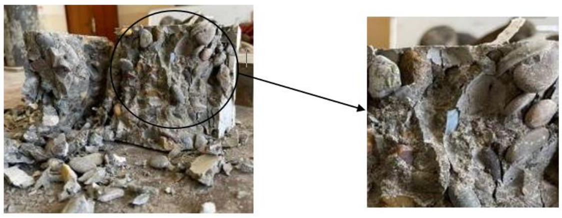

Fig. 8: Failure of cubic sample containing plastic fibers after the compressive strength test

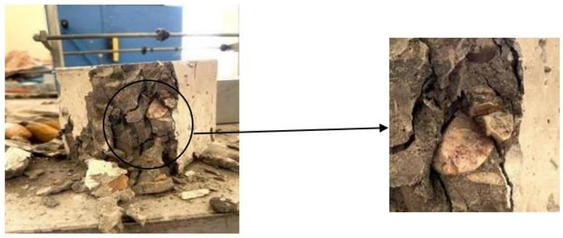

Fig. 9: Failure of cubic sample containing walnut shells after the compressive strength test

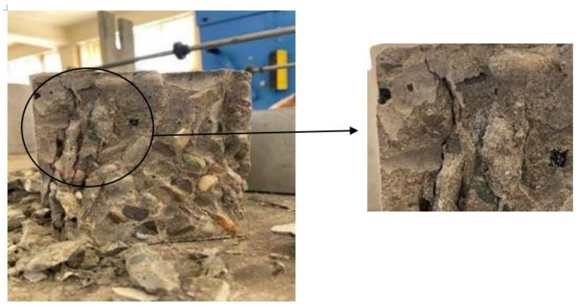

Fig. 10: Failure of cubic sample containing tire rubber fibers after the compressive strength test

3.3 Splitting tensile strength results

Tensile strength is essential for assessing a concrete structure's resistance to crack and failure when subjected to tensile forces. A different pattern emerged from the splitting tensile strength testing. As indicated in Table 6 and Figure 11, respectively, all waste-modified mixes performed worse than the reference mix (4.60 MPa). While the plastic fiber mix performed somewhat better with an 11.5% reduction (4.07 MPa), the tire rubber fiber and walnut shell mixes both displayed reductions of 12.4% (4.03 MPa). The usual patterns of splitting failure in cylindrical specimens for various waste materials are shown on Fig. 12.

Table 6. The splitting tensile strength values for all mixture types employed in this investigation after 28 days of curing period

Mix type	Test results (MPa)	Performance vs Reference
Reference	4.60	Baseline
Plastic Fiber Mix	4.07	-11.5%
Walnut Shell Mix	4.03	-12.4%
Tire Rubber Mix	4.03	-12.4%

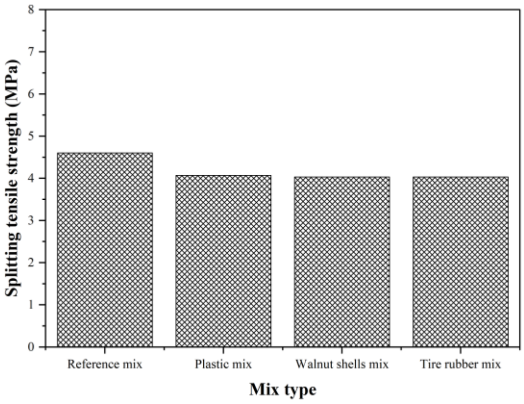

Fig. 11. Effects of adding different waste materials on the splitting tensile strength of hardened concrete

Fig. 12 Failure of cylindrical samples containing different waste materials after the splitting tensile strength test

3.4 Flexural strength results

Flexural strength or modulus of rupture is an engineering acceptance test to measure a material's ability to resist deformation under load. Tests of flexural strength yielded interesting results that somewhat paralleled the patterns of compressive strength. With 5.0 MPa (+11.1% over reference), the walnut shells mix performed the best, closely followed by the tire rubber mix at 4.9 MPa (+8.9%). As indicated in Table 7 and Fig. 13, the plastic fiber mix again performed the worst, at 3.6 MPa (-20.0% lower than the reference value of 4.5 MPa). The failure patterns in flexural testing are depicted in Fig. 14–16, which also indicate the effects of various waste materials on the formation of cracks and the ultimate failure modes.

The findings indicate that although some waste materials, including tire rubber fibers and walnut shells, can improve mechanical properties like flexural and compressive strength, they typically decrease workability and splitting tensile strength. Although the amount of the reduction varied based on the particular quality being examined, the waste plastic fiber consistently showed decreased performance across all mechanical parameters.

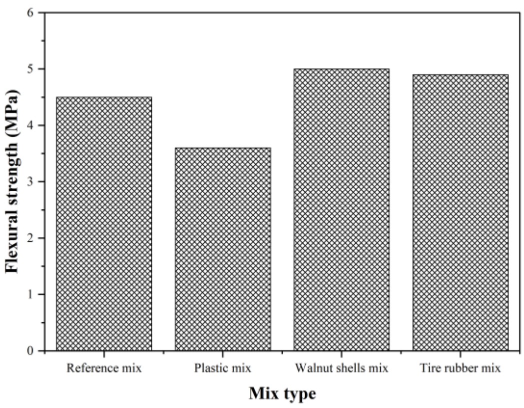

Fig. 13 Effects of adding different waste materials on the flexural strength of hardened concrete.

Table 7. The flexural strength values for all mixture types employed in this investigation after 28 days of curing period

Mix type	Flexural strength (MPa)	Performance vs Reference
Reference	4.5	Baseline
Plastic fiber mix	3.6	-20.0%
Walnut shell mix	5.0	+11.1%
Tire rubber mix	4.9	+8.9%

Fig. 14 Failure of a prism sample containing PET plastic fibers after the flexural strength test

Fig. 15 Failure of a prism sample containing walnut shells after the flexural strength test

Fig. 16 Failure of a prism sample containing tire rubber after the flexural strength test

4. Conclusions

Researchers are looking at innovative methods to recycle waste materials in the building sector as a result of the growing worldwide difficulties of waste management and sustainable construction. The effects of adding three distinct waste materials—plastic fibers, walnut shells, and tire rubber fibers—on the mechanical properties of concrete were thoroughly investigated experimentally in this study. The study sought to further the development of building materials and environmental sustainability by methodically evaluating the performance of these waste-modified concrete mixtures. The following are the study's main findings:

1. The workability of waste-modified concrete was lower than that of the reference mix. The smooth surface of tire rubber made workability a little better, while the rough texture and porosity of walnut shells resulted in the biggest decrease. On the contrary, plastic fibers, which are smooth and not water infused, reduce the

slump values very much. The decreasing resolvability therefore is presumably not only related to higher texture or porosity, but it also happens, at least indirectly, as an effect of increasing the surface area of additive, which is able to soak up water, therefore, and of a real damage of the concrete matrix due to the presence of them.

2. The tire rubber mix increased by 4.9%, but the walnut shell mix surpassed additional modifications, improving strength by 8.7%. Plastic fibers, on the other hand, decreased strength by 12.1%.
3. Splitting tensile strength was decreased by all waste materials, with plastic fibers doing slightly better with an 11.5% loss and tire rubber mixtures and walnut shell exhibiting a 12.4% decrease.
4. Additionally, tire rubber produced an 8.9% gain in flexural strength, while walnut shells led with an 11.1% rise. With a 20% decrease, plastic fibers had the worst impact.

This study illustrates the potential use of waste materials in concrete; however, further studies should be conducted to improve mechanical performance through optimized mix proportions. Further studies can be carried out to use varying percentages of waste material, alternative treatment methods to increase bond strength and long-term durability studies in different environmental conditions. Moreover, the thermophysical and acoustic behavior of this kind of concrete requires scope for future investigations to embed in a wider context of sustainable construction applications.

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