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Comparison of the Mechanical Behaviour of Concrete Reinforced with Industrial Metal Fibers and Recycled Chips in Acidic Environments

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ABSTRACT

In recent years, most of the laboratory research on the comparison of the mechanical behaviour of reinforced concrete containing industrial metal fibers and recycled chips has been carried out abroad, and it is necessary to carry out special studies on reinforced concrete with domestic materials, so that we can produce a recycled reinforced concrete from metal waste and recycled chips that is resistant to acid attack and can be used in the construction industry. First, we prepare the materials and fibers required for the test, then we design an optimal mixing plan in which industrial metal fibers and recycled chips are used in different percentages. The recycled chips are added to the concrete mix in such a way that the amount of chips we add reduces the amount of fine-grained sand, and the chips replace a small percentage of the sand. Concrete samples are then taken according to the mix design and tested after curing at a specified age. We compare concrete samples containing industrial metal fibers and recycled chips after exposure to an acidic environment with a concrete sample without fibers exposed to an acidic environment to understand how much the presence of fibers and chips in the concrete mix has increased the resistance of the concrete to acid.

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1. Introduction

Concrete is known as one of the most widely used construction materials in construction projects, and due to its widespread use in all construction projects, it requires a lot of mining, which causes serious damage to the environment, and after a while the mines run out, creating a serious problem in the construction industry [1]. To solve this problem, the use of waste construction materials in concrete has become popular in recent decades, replacing some of the main concrete materials to create a concrete that can be used in buildings and construction projects, and this type of concrete is called recycled concrete [2,3].

Concrete has many weaknesses and is damaged in adverse weather conditions, acidic environments, etc., which is a problem in construction projects [4]. For this reason, in recent years, fibers have been used in concrete, which is called fiber concrete. The use of fiber concrete has received attention in recent years [5-7]. Ordinary concrete has a small amount of porosity, which causes the

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penetration of destructive factors into the concrete. The presence of fibers in concrete not only increases its resistance but also improves its performance against destructive factors. Because it reduces the porosity of the concrete and prevents the penetration of destructive factors into the concrete. Yossari et al. [8] showed that fiber-reinforced concrete (such as steel, polypropylene, and glass fibers) performs better than conventional concrete against acid attacks and leaching processes. This study indicates that adding fibers to concrete can increase the service life of concrete structures in highly corrosive and acidic environments. They also found that the type and quantity of fibers directly affect the concrete's resistance to these conditions.

Wang et al. [9] demonstrated that basalt fiber reinforced concrete exhibits high corrosion resistance in acidic environments. This type of concrete shows particularly high resistance to acids such as sulphuric acid, suffering less structural strength loss. The results of this study suggest that using basalt fibers as reinforcement can be an effective option for producing concrete used in acidic environments, such as refineries or chemical plants. Tigerjan et al. [10] showed that the mechanical behaviour of fabric-reinforced concrete differs significantly between acidic and alkaline environments. In acidic environments, this type of concrete can exhibit good resistance, but its mechanical properties deteriorate in alkaline environments. This research highlights that fabric-reinforced concrete can be an effective solution for applications requiring resistance to corrosive environments. Moreover, specific environmental conditions can influence the performance of this type of concrete, necessitating more careful design for each specific application. Kim et al. [11] found that the type of fiber used has a significant impact on the durability properties of concrete. In particular, fibers like glass and steel improve the concrete’s resistance to environmental stresses, abrasion, and corrosion. This research emphasizes that choosing the right fiber type for each project can enhance the concrete’s performance against specific environmental challenges, including acid attacks, temperature fluctuations, and humidity. Additionally, the study showed that the use of fibers in concrete can extend the lifespan of structures and reduce maintenance needs. Achudhan et al. [4] demonstrated that the use of FRP (fiber-reinforced polymer) can effectively enhance the mechanical properties of concrete beams, particularly in harsh and damaging environmental conditions, such as acidic environments. The inclusion of FRP in reinforced concrete increases its flexural and tensile strength, as well as its resistance to corrosion from various environmental factors. This research could be valuable for investigating the behaviour of different reinforcements under harsh environmental conditions, including acidic ones.

Al-Ajarma et al. [12] examined hollow concrete columns, which are commonly used in tall and heavy structures due to their reduced weight and concrete consumption. Their research showed that using GFRP (glass fiber reinforced polymer) as reinforcement can increase the strength and resistance of these columns to flexural and tensile loads, particularly in acidic environments, which often cause corrosion and shorten the lifespan of structures. These results can assist in comparing different reinforcement options and selecting the best solution for acidic environments.

In recent decades, the use of fiber concrete in construction has become popular and various fibers are used in concrete. One of the fibers used in concrete is metal fiber. Metal fibers are used in concrete in different types and materials and increase the strength of concrete. One of the metal fibers used in concrete is industrial metal fiber, which, in addition to increasing the strength of concrete, also helps the environment because the problem of disposing of these industrial metal fibers is very damaging to the environment. The use of these fibers in concrete increases the resistance of concrete to acidic destructive factors, provided that the fibers are added to the concrete in appropriate percentages, because the presence of excessive metal fibers in concrete causes metal fibers exposed to an acidic environment to corrode over time, and acidic and chemical agents to penetrate the concrete, and over time the concrete loses its effectiveness. Recycled sawdust has been used as a partial replacement for sand in concrete, which in addition to improving the strength of the concrete, reduces the problem of industrial waste disposal and causes less damage to the environment [8].

Table 1
Specifications of cement used

Description	Result
Initial Setting Time	185 minutes
Final Setting Time	230 minutes
Specific Gravity of Cement	3.15 g/cm³
Normal Consistency of Cement	26%

2. Research Methodology

2.1. Materials used

2.1.1. Cement

Portland cement type 2 from Bojnourd Cement Company was used in this study. This cement has a medium resistance to sulphate attack due to the amount of aluminate phase. On the other hand, it can be used in almost bulky concrete due to its medium heat of hydration. This cement has a minimum compressive strength of 440 kg/cm^2 at 28 days. This cement is also known as modified cement by the buyers. This cement has the ability to resist heat and salt, which makes the reinforcement resistant to rust. The Table 1 shows the specifications of the cement used.

2.1.2. Coarse sand

The sand used in this thesis is factory-made broken sand that is crushed by a crusher and graded by successive sieves. 60 to 70 percent of the total aggregate grains in concrete are sand and play the role of the concrete skeleton. The use of broken grains is very suitable due to the presence of sharp corners and increases the strength of concrete. The specifications of the sand used are given in the Table 2.

Table 2
Coarse sand specifications

Category Name Sand	Seed diameter size (mm)
Coarse	25 to 60
Almond	12 to 25
Peanut	5 to 12

Figure 1: Coarse sand

2.1.3. Fine grained sand

The sand used in this paper is of the mineral type, which is crushed by a machine in the factory and sedimented several times to remove the silt and clay it contains and to make the resulting sand free of impurities so that it can be used in the production of high-strength concrete. Sand makes up 30 to 40 percent of concrete aggregates.

2.1.4. Water in concrete

Drinking water has been used in this study. Water and cement are chemically combined, and as a result of this combination, cement paste is obtained, in which neutral particles and grains of sand and gravel remain suspended until the cement paste sets. Water also acts as a lubricant between the fine particles and grains of sand and gravel, giving the concrete its workability and application properties and making it easy to pour.

The use of inappropriate water in concrete construction leads to the following issues and problems:

- The setting time of the cement is delayed, the concrete becomes slow.
- It causes a reduction in the final strength of the concrete. (Sometimes the strength is reduced by up to 30 per cent).
- Causes corrosion and gradual deterioration of reinforcing steel.
- Causes stains on the surface of the final dried concrete, which is particularly problematic in concrete used on facades.

Figure 2: Consumable sand

Table 3
Stone material specifications

Sieve size (mm) and (micrometer)	Residual weight on each sieve (g)	Percentage of residual fraction per sieve (%)	Percentage of residual fraction per sieve (%)
5/9	0	0	100
75/4	20	2	98
36/2	45	5/4	5/95
18/1	85	5/8	5/91
600	120	12	88
300	185	5/18	5/81
150	230	23	77
pan	315	5/31	5/68
Total	1000	-	-

2.2. Superplasticiser

This chemical has many uses and its standard use in concrete also brings many benefits. Superplasticisers have many uses and can be used to produce higher quality concrete. Due to its properties, concrete shrinks in cold weather and loses the required fluidity, so by adding superplasticiser to the concrete, it is made fluid to the required extent. Another use of these materials is in prefabricated concrete moulds. In addition to the mould, superplasticisers are also used in the concrete material to produce concrete with high strength and durability.

2.2.1. Use of concrete superplasticisers

Superplasticisers were used for making hard and strong concrete, production of micro-silica concrete, increasing concrete efficiency, reducing the water-cement ratio, increase concrete flow and increase production speed.

2.2.2. Main constituents of concrete superplasticisers

Concrete superplasticisers consist of lignosulphonates, melamine formaldehyde sulphonate, naphthalene formaldehyde sulphonate, synthetic polymers and water-soluble copolymers.

2.2.3. MTOCRETEN-480 Concrete Superplasticiser

MTOCRETEN-480 is a chloride-free concrete superplasticizer based on melamine formaldehyde and is used to produce strong concrete. This product is available in two forms: solution and powder, the powder to be dissolved in water before use. Strong concrete is completely fluid, but the adhesion of its elements is maintained even at a slump of 200 mm, and this type of concrete is self-dense and at the same time free from segregation. This superplasticiser was used in this experiment because, in addition to reducing the water/cement ratio and increasing resistance to chemical agents, it also increases the strength of the concrete to a certain extent.

Table 4
Lubricant properties and specifications

Description	Specifications
Superplasticizer paint	Clear to slightly cloudy liquid
Specific gravity	1.1 g/cm^3
Input air	Airless

2.3. Recycled shavings

Iron shavings were used in this research. The shavings are obtained from the machining of industrial parts and some shavings are used to replace aggregate in concrete to increase the strength of the concrete. The shavings are in the form of fine grains and are combined in a sand and gravel mixture and then added to the cement paste.

Figure 3: Consumable chips

2.3.1. Steel Fibers in Concrete

The use of various types of steel fibers in concrete is used as concrete or mortar reinforcement to increase concrete strength, reduce shrinkage, control cracking, increase durability and improve mechanical properties of concrete, and as alternative reinforcing fibers for thermal bars in concrete structures. In this study, steel fibers were used at different percentages as woven fibers in concrete.

2.3.2. Effect of steel fibers in concrete

Stee fibers increase the tensile, flexural and shear strength of concrete, increase in impact resistance and energy absorption, reduced installation costs due to the price of concrete steel fibers, decrease in manpower and project implementation time.

Table 5
Steel fiber specifications

Fiber Type	Density (Kg/m^3)	Maximum Strain at rupture	Tensile Strength (Mpa)	Diameter	Length (mm)
Ind. Steel	7850	8/0	1050	<4	50
Ind. Steel	7850	8/0	1050	<4	25

2.3.3. Acid Destructive of Concrete

In this study, battery water was used as a substance that endangers concrete, which acts like carbonic acid and causes concrete to lose its strength over time. The attack of carbonic acid is mild and gradually destroys concrete.

2.4. Laboratory program

In this research we first studied the materials used, then we mixed these materials at different percentages and took concrete samples and tested them. The tests include testing the compressive and tensile strength of the concrete.

The concrete is tested after being immersed in acid and its resistance is determined.

2.4.1. Mixing ratios used

In this study, 5 series of concrete specimens are tested, 4 of which are concrete specimens containing metal fibers and recycled chips at certain percentages, and 1 series of ordinary concrete specimens without fibers. The test results of the fiber concrete samples made of steel fibers and recycled chips are compared with ordinary concrete without fibers after exposure to acid to find out what is the optimum mixing plan for making acid-resistant concrete containing steel fibers and recycled chips.

In this mix design, (10, 15, 20, 25) kilograms of steel fibers per cubic metre are used, a superplasticiser is also used to increase the fluidity of the concrete and its resistance to acid, and recycled chips are also added to the concrete mix in fine form as a partial replacement for fine-grained sand.

2.4.2. Sample making method

To make the samples in this study, we first prepared 15 cm moulds and then greased them with oil to prevent the

Table 6
Optimal mixing plan Kg/m^3

Sample Name	Cement	Sand	Gravel	Water	Recycled Chips	Plasticizer	Steel Fibers
Plain Concrete	450	1000	710	260	0	0	0
Concrete (M1)	450	993	710	260	7	4.5	10
Concrete (M2)	450	988.5	710	260	11.5	5.85	15
Concrete (M3)	450	983.5	710	260	16.5	6.75	20
Concrete (M4)	450	980	710	260	20	9	25

concrete from sticking to them. After preparing the moulds, we mix the concrete according to the desired mixing schedule. The concrete mixing process takes between 3 and 5 minutes to mix the desired fibers well into the concrete paste and distribute them throughout the concrete. After mixing the steel fibers, recycled chips and lubricant, we pour the concrete into the cube moulds in 3 stages, hitting them 25 times at each stage to remove the air in the concrete, then smoothing it out and leaving it in place for 24 hours without moving it. Then we remove the samples from the mould and cure the concrete.

Figure 4: Cubic mold

2.4.3. Curing

Concrete curing is a process that prevents the loss of moisture in the concrete and maintains its temperature as much as possible. This is done at the start of sampling at an early age to maintain the moisture content of the concrete and ensure that the final hardened concrete is of the highest quality and strength.

2.5. Concrete testing

2.5.1. Slump test

Concrete slump, or inverted slump cone, is determined by a relatively simple test using a very simple instrument. This instrument consists of a hollow incomplete cone with a handle, a steel rod for compaction, a steel base plate and a tape measure for measurement. Concrete slump testing is one of the methods used to determine the workability and flowability of fresh concrete. This test is usually carried out in a concrete laboratory under specific environmental conditions or on site using a slump testing machine.

The conventional slump test is one of the easiest tests to perform on concrete. It is very inexpensive and the results are immediate. For this reason, the slump test has been the most widely used and common test for determining the workability and flowability of concrete since 1922.

2.5.2. Concrete Compressive Strength Test

The purpose of a compressive strength test is to determine the compressive strength of a cylindrical or cubic concrete specimen. The compressive strength of any material is its resistance to failure under compressive loading. For concrete in particular, compressive strength is an important parameter in determining the performance of the concrete throughout the life of the structure.

The compressive strength of concrete is determined in the batching plant laboratory for each batch in order to maintain the desired quality of concrete during the curing period.

The strength of concrete members is required. Concrete specimens are prepared and tested under compressive load to determine their compressive strength. In very simple terms, compressive strength is calculated by dividing the failure load by the area of application of the load, usually after 28 days of concrete storage and curing.

To determine the compressive strength of concrete, a minimum of two samples are selected for each test and are soaked in water for 24 hours prior to testing. The samples are then tested in a testing machine and the compressive strength of the sample is calculated by dividing the maximum load applied by its cross-sectional area.

The lower the water/cement ratio, the higher the compressive strength. The strength of concrete is expressed in the United States in psi per square inch and in the SI unit in megapascals. For typical applications, the compressive strength of concrete is between 0.1 and 61 MPa.

Figure 5: Jack for compressive strength testing

Table 7
Compressive strength test results in MPa

Sample name	Compressive strength of the sample 7 days	Compressive strength of the sample 28 days	Compressive strength of concrete exposed to acid
Fiberless concrete	46/25	73/34	71/30
Concrete 10 m1	87/25	71/36	69/32
Concrete 15 m2	49/28	84/39	68/38
Concrete 20 m3	76/21	47/33	46/28
Concrete 25 m4	83/19	34/22	78/21

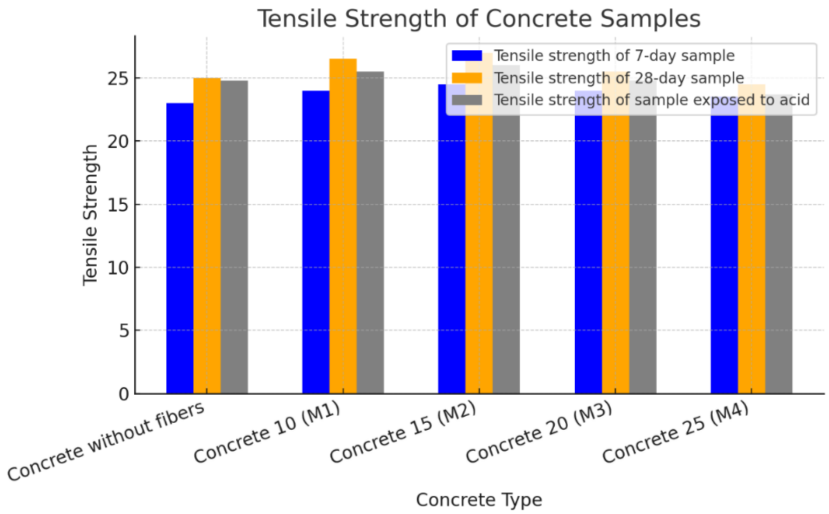

Figure 11: Tensile strength test results

2.5.3. Testing Concrete Tensile Strength

Concrete tensile strength is one of the most fundamental and important properties that significantly affects the cracking rate of structures. In addition, concrete is very weak in tension due to its brittle nature, so it is not expected to withstand direct tension, so if the tensile strength of the concrete is exceeded, cracks will form in the concrete. To determine the amount of force that is likely to cause cracking in a concrete member, it is necessary to determine the tensile strength of the concrete. Tensile testing of concrete by dividing or halving a cylindrical specimen is one method of determining the tensile strength of concrete.

3. Results

3.1. Compressive strength

In this research, after sampling and curing the samples, which were placed in water for 28 days to reach their final strength, the samples were tested using a concrete compressive strength testing machine. From each concrete sample, a 7-day sample and a 28-day sample were tested and also a sample after curing was placed in acid and tested again to record the final strength. The results are shown in the Table 7.

3.1.1. Slump test

In general, the addition of industrial metal fibers and recycled chips to the concrete mix will reduce the slump of the concrete. The high percentage and large surface area of the fibers can collect more cement paste around them, increasing the viscosity of the concrete mix and reducing slump.

Because recycled chips have a fine cross section, they absorb more water and increase the water-to-cement ratio. To reduce the water-to-cement ratio, we used a superplasticiser in the concrete mix. In this study it was observed that adding more fibers and recycled chips reduced the slump of the concrete, with the control sample having the highest slump and the sample containing 25 kg of industrial metal fibers having the lowest slump.

4. Results discussions

From tests carried out on reinforced concrete containing industrial metal fibers and acid-resistant recycled chips, it was found that concrete with suitable fibers up to a certain percentage had good resistance to acids, but as more fibers were added to the concrete, the resistance decreased somewhat. Acids increase the porosity of concrete due to the corrosion of metal materials in the samples, which is the main factor in reducing the strength of concrete. Also, in concrete structures, if the porosity increases, destructive factors will penetrate into the concrete, and if rebar is used in it, it will also cause corrosion of the rebar, which will cause the concrete structure to fail.

In this test, by adding the right amount of fibers, we were able to create a strong recycled concrete that does not harm the environment and uses a lower percentage of aggregate than normal concrete.

5. Conclusion

The following results were obtained from the conducted study:

- The use of metal fibers and recycled chips in concrete resulted in the creation of a recycled fiber concrete, which uses industrial waste to create a quality product in the construction industry.
- Industrial fibers and recycled chips are abundant in Iran, so it does not require much money to prepare them, which increases their use in concrete.
- The use of metal fibers and recycled chips in concrete increased the resistance of concrete to mechanical behaviour and improved the properties of ordinary concrete.
- The use of metal fibers in concrete together with recycled chips in certain percentages turned ordinary concrete into a reinforced concrete that is resistant to acid attacks and can withstand chemical attacks that are a destructive factor for concrete.
- Optimal use of recycled chips in concrete can result in less use of fine-grained materials in concrete and less damage to sand and gravel resources.
- The use of industrial waste reduces the problems associated with the disposal of these materials and can be used directly.

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