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Testing the Effect of Iron Casting Waste on Concrete Compressive Strength

Natsir Abduh [a], Burhanuddin Badrun [a], Andy Rahmadi Herlambang [b]

[a] *Department of Civil Engineering, Faculty of Engineering Universitas Bosowa, Makassar, Indonesia*
[b] *Department of Civil Engineering, Faculty of Engineering Jakarta Global University, Indonesia*
*Corresponding author: *natsir.abduh@universitasbosowa.ac.id*

Abstract—**This study, which tests the compressive strength of concrete incorporating iron casting waste, underscores the potential for waste utilization in concrete technology. By combining iron casting waste into the planned concrete compressive strength, K-250, we have demonstrated the possibility of meeting and exceeding this benchmark. Our quantitative research, utilizing experimental methods, tested the concrete compressive strength and the substitution of iron-casting waste as a fine aggregate. We tested different substitution variations, including 0%, 25%, 50%, 75%, and 100%, using three samples in cylinders measuring 15 cm in diameter and 30 cm high. The research was conducted at the Material and Concrete Laboratory of the Department of Civil Engineering, Universitas Bosowa and Universitas Negeri Makassar. The results of the concrete compressive strength test are promising, with some variations exceeding the planned compressive strength of concrete (K-250). The 25% iron waste variation reached an equivalent of K-400, and the 50% variation reached K-279. The compressive strength of concrete increases with 40% iron waste but begins to decrease at a 50% variation. Different combinations of iron-casting waste and concrete yield different compressive strengths. For instance, a 25% variation produces a compressive strength of 403.597 kg/cm2, a 50% variation produces 279.67 kg/cm2, a 75% variation results in 209.19 kg/cm2, and a 100% variation yields 178.49 kg/cm2. Notably, adding 25% and 50% iron waste resulted in concrete compressive strengths exceeding planned K-250 concrete. Additionally, 40% iron waste increases concrete compressive strength, but it begins to decrease at a 50% variation.**

Keywords—**Concrete compressive strength; iron casting waste; fine aggregate substitution.**

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I. INTRODUCTION

Innovative materials enhance performance, sustainability, and safety, which benefits infrastructure development [1]–[4]. Allusion Panels comprise cladding panels made from stabilized aluminum foam resembling metallic sponges, offering solidity and lightness. Transparent wood has developed transparent wood, allowing natural light while maintaining structural integrity. Hydro ceramics absorb moisture during the day and release it at night, aiding in temperature regulation and reducing energy consumption [5]–[7]. Concrete infused with pigments can improve aesthetics and reduce the urban heat island effect. Bamboo fibers enhance concrete's tensile strength and reduce its environmental impact. Pollution-absorbing bricks contain materials that absorb pollutants from the air, contributing to cleaner urban environments [8]. Microorganisms or capsules within the concrete repair cracks autonomously, extending their lifespan. Concrete is a lightweight material with exceptional strength, useful for bridges and other load-bearing structures. Ongoing research and collaboration drive the adoption of these materials in infrastructure projects.

Self-healing concrete offers several benefits for infrastructure [9]–[14]. Microorganisms or capsules embedded in the concrete can repair small cracks autonomously. This extends the lifespan of structures, reducing maintenance costs and enhancing durability. Self-healing properties minimize the need for frequent inspections and manual repairs. This is especially advantageous for hard-to-reach or large-scale infrastructure. Self-healing concrete reduces repair expenses over the structure's lifetime by preventing crack propagation and subsequent damage [10], [12], [14]. Cracks compromise structural integrity. Self-healing mechanisms maintain the concrete's strength, ensuring safety for occupants and users. Fewer repairs mean less material consumption and waste, contributing to sustainability. Self-healing concrete improves infrastructure resilience, longevity, and overall performance.

Infrastructure development in the use of concrete requires technological support and innovation. Concrete construction is necessary to support infrastructure development and encourage increased consumption of building materials [1], [15], [16]. Concrete exhibits superior mechanical characteristics, such as compressive strength, fracture toughness, and durability, compared to conventional concrete [17]. Evolving concrete technology requires innovative new performance features [18], has the advantage of being very strong and durable [19], contributes to environmental value [20], and can be found in almost every building structure [21].

Concrete structures typically last 50 to 100 years, outperforming many other materials [22]. Their resistance to weathering, erosion, and natural disasters makes them practical for long-term infrastructure. Concrete can be crushed and reused in new projects without losing strength. This reduces the need for new raw materials and minimizes environmental impact. Innovations include using supplementary cementing materials (SCMs) like fly ash and slag to reduce carbon emissions [23]–[28]. “Green” cement produced through carbon capture and storage processes further enhances sustainability. Concrete’s thermal mass helps regulate indoor temperatures, reducing energy consumption and carbon emissions in buildings. In other words, concrete is indispensable for sustainable infrastructure, combining durability, recyclability, and energy-saving properties.

Concrete can crack due to shrinkage, temperature changes, or external loads [29]–[34]. Proper mix design, curing, and reinforcement help mitigate this issue. Steel reinforcement can corrode, weakening the structure. Protective coatings and proper maintenance are essential. Concrete production generates significant carbon dioxide emissions. Innovations like low-carbon cement and recycling can address this challenge. Many existing concrete structures require maintenance, repair, or replacement; balancing costs and safety are crucial [35]. Finding ways to reduce concrete’s environmental footprint while maintaining performance is an ongoing challenge. Addressing these challenges involves collaboration among engineers, researchers, and policymakers.

Therefore, this research developed concrete's compressive strength, which refers to its ability to withstand applied loads without exhibiting cracks or deformations. Concrete tends to decrease in size when subjected to compression, whereas tension forces cause elongation [36]. This property is crucial for ensuring the durability and performance of concrete structures. Compressive strength is the capacity of concrete to handle force (measured in pounds per square inch, or psi) without failing [37], [38]. It indicates how well concrete can bear heavy loads or internal pressures due to factors like freeze-thaw cycles.

To determine compressive strength, cylindrical concrete specimens are tested using a machine that compresses them until they crack or break completely [39]. These tests are typically conducted 28 days after casting, providing a reasonable estimate of the final strength. The quality of raw materials (cement, aggregate) affects strength. A proper water-cement ratio is crucial for achieving the desired strength. Different aggregates impact strength levels. More cement generally leads to higher psi ratings. Local building codes often set minimum psi requirements. For lighter loads (sidewalks, patios), 2500 psi may suffice. Standard residential driveways or garage floors typically require 4000 psi [40]. Understanding the psi ratings helps choose the right concrete mix for a project.

Proper curing is essential for enhancing concrete strength and durability [41]–[43]. Used for flat surfaces (e.g., pavements, driveways). Keep curing water temperature within 20°F of concrete to prevent thermal cracking. Suitable for higher ambient temperatures. It helps prevent the shrinkage of plastic from cracking. Cover the concrete with plastic sheeting or wet curing blankets to maintain moisture. Membrane-curing compounds form a film to reduce evaporation. Accelerates hydration by raising the concrete temperature. It is helpful in achieving early strength gain. Remember, curing time depends on factors like mixture proportions, specified strength, and exposure conditions. For instance, slabs on the ground typically require a minimum of seven days of curing at ambient temperatures above 40°F1

The curing duration significantly affects concrete strength [42], [44]–[46]. During the curing process, hydration continues, allowing cement particles to bond and form a dense matrix. The first few days are crucial. Early curing ensures proper hydration and initial strength development. High Early-Strength Concrete: Some projects require rapid strength gain (e.g., precast elements). Steam or accelerated curing methods achieve this—28-Day Strength: Commonly used benchmark. Concrete continues to gain strength beyond 28 days, but this period provides a reliable estimate [47]. Extended Curing: Prolonged curing (beyond 28 days) enhances long-term durability and resistance to environmental factors. Concrete gains strength as long as it remains moist. Proper curing prevents premature drying and ensures complete hydration. The right balance between early and long-term strength depends on the specific project requirements.

In the construction process, it is always important to recognize the compressive strength of concrete [48], usually characterized based on tests carried out on concrete cylinders or cubes under relatively fast loading conditions [49]. Compressive strength is an essential aspect in the design of concrete structures [50] and is a crucial parameter for designing and evaluating concrete structures [51]. Concrete's main components are materials that can have environmental consequences, emphasizing the importance of adopting environmentally friendly practices to reduce environmental impact [16].

As the use of raw materials for concrete buildings increases, it reduces natural resources and increases CO_2 emissions [52]. These impacts occur during material exploration, such as sand and gravel, which poses sustainability concerns [53] or during construction. Still, many possibilities exist to reduce the environmental impact of concrete structures [54]. The cement industry is very energy intensive and produces a lot of dust, odors, noise, and emissions from cement plants, causing carbon dioxide (CO_2), nitrogen oxides (NO_x), and sulfur dioxide (SO_2) [55]. This condition requires our attention to increase innovation further.

Many studies have been conducted to harness the potential of local raw materials, production waste, or recycled materials.

Iron casting waste can be used as a substitute for fine aggregate (sand) to make concrete. According to various research papers, waste iron provides maximum strength compared to other wastes [56]. The mixture with iron slag instead of 20% coarse aggregate gave the best results in compressive strength, tensile strength, and flexural strength, increasing by 51.75%, 52.9%, and 36%, respectively [57]. The growth of the construction industry encourages the steel industry to expand [58], [59]. Steel processing through the casting process produces iron-casting residues in the form of waste. Waste is disposed of because it is considered worthless, has no economic value, and requires unique management because of its nature, concentration, and volume [60]. Uncontrolled waste disposal can result in heavy, severe metal pollution in water, soil, and plants [61]. Global issues show how different sources of pollution affect the environment, population health, and sustainable development [62].

One of the steel industry's producers of iron slag is Barawaja Co. Ltd. in Makassar City, South Sulawesi, which has a production capacity of 15,000 tons/year. Several types of waste are produced monthly, including 14 tons of iron slag, 14 tons of ladle/dross slag, 400 kg billet/scale skin, and 200 kg fine slag. Reusing solid waste materials offers an approach to solving pollution problems arising from waste at production sites [63].

Concrete is the material most often used in construction, both in building and road infrastructure [64]. According to SK-SNI 03-2847-2000, concrete is a mixture of Portland cement/other hydraulic cement, rough aggregate (split), fine aggregate, and water with or without additives that form a solid mass [65], [66]. Cement is a binding material that regulates and hardens itself to bind to other materials [67]. Cement hardening gives strength and durability to concrete [68]. Concrete can be durable, inexpensive, easy to print, and has good compressive strength and rigidity [56].

The diversity of particles used in the manufacture of concrete contributes to the strength of concrete, which can vary significantly [69]. Aggregate usually occupies about 70% to 80% of the total concrete mass, and coarse aggregate takes the central part [1], [15]. The selection and proportions should be carefully considered to control the quality of the concrete structure. Aggregate assessment is expressed as a percentage of weight through a standard filter measuring 1.5 inches and 0.75 inches. Sieves 0.375 inches, 0.187 inches, and 0.0937 inches are used for rough aggregate assessment, and 0.375 inches, 0.187 inches, 0.0937, 0.0469 inches, 0.0232 inches, 0.0117 inches, and 0.0059 inches are used for aggregate smooth [67]. Fine aggregates can be rock ash, natural sand, processed sand, or both [70]–[73]. Using other materials as alternative substitutions or as substitutes for fine aggregates from different sources can be effective, economical, and sustainable [74]. Iron casting waste from the iron industry can be used as a substitute for fine aggregate or sand [56].

Water quality in the concrete mix can affect the workmanship, hardening, and strength of the concrete. Drinkable water produces good strength properties in concrete and a 33.34% increase in compressive strength compared to wastewater [68]. The cement-water ratio (W/C) has an essential impact on concrete [48]. The higher the value of the slump test, the easier it is to work with concrete, but the amount of water given in the slump test must be considered to determine the quality of the concrete. Concrete mixtures are designed to provide high quality and durability and meet concrete structure requirements. Concrete properties are better if the compressive strength is high because the quality is based on compressive strength [64]. Many parameters affect the properties of concrete, such as the type and size of aggregate and the type and content of cement. Testing the essential parameters: density, elastic modulus, compressive strength, surface hardness, and absorption [75]. The research objective was to determine the compressive strength of concrete produced by adding iron casting waste to the planned compressive strength of concrete, namely K-250.

II. Materials and Method

This type of quantitative research uses an experimental method to compare the compressive strength of concrete-to-concrete plants, namely K-250, by substituting iron casting waste. The study was conducted at the Material and Concrete Laboratory of the Department of Civil Engineering, Universitas Bosowa and Universitas Negeri Makassar. Substitution of iron casting waste against fine aggregate (sand) through variations of 0%, 25%, 50%, 75% and 100%.

A. Materials

The sample or test object is a cylinder measuring 15 cm in diameter and 30 cm high, tested at 28 days of concrete. The procedure to ensure the strength of concrete is to do a cylinder test [48], [76]. The research samples used in this study were 15 pieces, shown in Table 1.

TABLE I
PERCENTAGE OF IRON CASTING WASTE (ICW) AGAINST FIND AGGREGATE (SAND)

0% ICW (the sample)	**25% ICW (the sample)**	**50% ICW (the sample)**	**75% ICW (the sample)**	**100% ICW (the sample)**
K1.1	K2. 1	K3.1	K4.1	K5.1
K1.2	K2.2	K3.2	K4.2	K5.2
K1.3	K2.3	K3.3	K4.3	K5.3
Total Research Sample: 15				

Furthermore, the following figure shows the materials used in making cylindrical concrete samples: cement, crude aggregate, and fine aggregate (sand and iron casting waste).


Cement


Coarse aggregate


Sand


Iron casting waste

Fig. 1 Materials for making cylindrical concrete

1) Mix Design: In planning a mixture of fresh concrete, the proportion is determined based on the results of previous testing of the aggregate characteristics and adjusted for the planned compressive strength of the concrete. Concrete mixture design is a process carried out using recommendations and experience so that if an experimental error occurs in the design, the test results fail [48]. The concrete mixture's design is shown in Tables 2 and 3.

TABLE II
CONCRETE MIX DESIGN

Description	Amount/Score	Unit
Cement water factor	0,3	-
Cement water factor max.	0,6	-
Slum test value	60 – 80	mm
Max. size of coarse aggregate	20	mm
Cement	410	kg/m3
Coarse aggregate	68	%
Fine aggregate	32	%
Weight of coarse aggregate	1,108.4	kg/m3
Weight of fine aggregate	524.6	kg/m3
Total of weight aggregate	1,633	kg/m3

The cement water factor is the mix's water ratio to cement. In your case, it's 0.3, which means 0.3 parts water for every part of cement. The maximum allowable value is 0.6, ensuring that the mix stays cool. The slump test measures the consistency or workability of fresh concrete. A value of 60–80 mm indicates moderate workability. If the slump is too high (above 80 mm), the concrete may be too fluid; if too low (below 60 mm), it might be too stiff. The maximum size of coarse aggregate (20 mm in your case) affects the strength and workability of the concrete. Larger aggregates provide better strength but may reduce workability. Table 2 above specifies the weights of cement, coarse aggregate, and fine aggregate per cubic meter (kg/m³). The percentages indicate the proportion of coarse and fine aggregates in the mix. The sum of coarse and fine aggregates' weights gives the total aggregate weight (1,633 kg/m³). Concrete mix design is crucial for achieving the desired properties, such as strength, durability, and workability. Adjustments can be made based on project requirements and local conditions.

TABLE III
REQUIREMENTS FOR CONCRETE MIX MATERIAL PER-M3

Description	Normal Concrete		Mixed Variations 25% x 75%		Mixed Variations 50% x 50%		Mixed Variations 75% x 25%		Mixed Variations 100% x 0%	
	Vol. (L)	Weight (kg)	Vol. (L)	Weight (kg)	Vol. (L)	Weight (kg)	Vol. (L)	Weight (kg)	Vol. (L)	Weight (kg)
Weight	1,000	2,245	1,000	2319.76	1,000	234.53	1,000	2469.29	1,000	2554.05
Cement	135.22	410	135.22	410	135.22	410	135.22	410	135.22	410
Rough aggregate	427.95	1108.40	427. 95	1108.40	427. 95	1108.40	427. 95	1108.40	427.95	1108.40
Iron Casting Waste	0	0	57.96	205.16	115. 91	410.33	173.87	615.49	231.82	821.65
Sand	231.82	521.60	173. 96	391.20	115. 91	260.80	57. 96	130.40	0	0
Water	205	205	205	205	205	205	205	205	205	205

2) Concrete Compressive Strength: Tests are carried out to determine the compressive strength of concrete produced on the test specimens by giving a load until the cylinder concrete is destroyed. Concrete compressive strength can be calculated by the formula:

$$f'c = \frac{P}{A}\ (Mpa) \quad (1)$$

where f'c is concrete compressive strength (kg/cm2), P is maximum of load compressive (kg/cm2), A is cylinder cross-section area (cm2, mm2), and D is the diameter of the concrete cylinder (cm, mm). The following equipment is used to make cylindrical concrete samples, as shown in the figure below.

Filter analysis tool | Concrete Mixer | Concrete Cylinder | Conc.Compr.Strength. Test Tool

Fig. 2 Equipment for making cylindrical concrete samples

III. Results and Discussion

A. Test the Characteristics of the Aggregate

1) Coarse Aggregate: Table 4 below shows the characteristics of coarse aggregates.

TABLE IV
CHARACTERISTICS OF COARSE AGGREGATE

No	Characteristics	The Interval	Specification ASTM	Result	Information
1	Specific gravity	1.6 - 3.2 %	C128	2.59 %	fulfill
2	Water content	3.0 - 5.0 %	C128	1.22 %	fulfill

Table 4 above shows the characteristics of the coarse aggregate. The specific gravity of coarse aggregate measures its density relative to water. It's expressed as a dimensionless ratio. The specified interval is 1.6% to 3.2%. The result of 2.59% falls within this range, indicating that the aggregate fulfills the requirement. ASTM standard C128 provides guidelines for determining specific gravity. Meanwhile, water content affects the workability and strength of concrete. It is expressed as a percentage. The specified interval is 3.0% to 5.0%. The result of 1.22% also fulfills this requirement. ASTM standard C128 provides guidelines for measuring water content. Meeting these specifications ensures the quality and performance of concrete.

2) Fine aggregate (Sand): Table 5 below shows the characteristics of fine aggregates.

TABLE V
CHARACTERISTICS OF FINE AGGREGATE

No	Characteristics	The Interval	Specification ASTM	Result	Information
1	Specific gravity	1.6–3.2 %	C128	2.25 %	fulfill
2	Water content	0.5 - 2.0 %	C128	3.08 %	fulfill

Table 5 shows the characteristics of the fine aggregate. Specific gravity measures the density of the fine aggregate relative to water. It's expressed as a dimensionless ratio. The specified interval is 1.6% to 3.2%. The result of 2.25% falls within this range, indicating that the fine aggregate fulfills the requirement. ASTM standard C128 provides guidelines for determining specific gravity. Meanwhile, water content affects the workability and strength of concrete. It is expressed as a percentage. The specified interval is 0.5% to 2.0%. The result of 3.08% exceeds this range. Ensuring that the fine aggregate meets the specified water content for optimal concrete performance is essential.

3) Fine aggregate (Iron Casting Waste): Table 6 below shows the characteristics of iron casting waste.

TABLE VI
CHARACTERISTICS OF IRON CASTING WASTE

No	Characteristics	The Interval	Specification ASTM	Result	Information
1	Specific gravity	1.6–3.2 %	C128	3.54 %	fulfill
2	Fineness	3.0–5.0	C128	1.29	fulfill

Table 5 indicates that specific gravity measures the density of the material relative to water. It is expressed as a dimensionless ratio. The specified interval is 1.6% to 3.2%. The result of 3.54% exceeds this range. It is essential to assess whether this deviation impacts the waste's suitability for its intended purpose. Meanwhile, fineness refers to the particle size distribution of the waste material. The specified interval is 3.0% to 5.0%. The result of 1.29% falls below this range. Consider how this fineness affects the waste's behavior in concrete or other applications. Understanding these characteristics helps determine the waste material's usability and potential applications.

4) Characteristics and Analysis Result of Course and Fine Aggregate Sieve. Table 7 presents the analysis results of course and fine aggregate sieves.

TABLE VII
ANALYSIS RESULT OF COARSE AND FINE AGGREGATE SIEVE

Number	**Cumulative pass filter (%)**				**Aggregate type**		**Max aggrg.**	**Combined/**
Filter	**ICW (%)**	**Sand (%)**	**Fine Aggr.**	**Coarse Aggr.**	**Sand 32%**	**B.Stone 68%**	**size 20 mm**	**average**
1"	100.00	0.00	100.00	100.00	32.00	68.00	100 - 100	100.00
3/4"	100.00	0.00	100.00	100.00	32.00	68.00	100 - 100	100.00
3/8"	100.00	0.00	100.00	39.26	32.00	26.70	45 - 75	58.70
4	93.68	0.00	93.68	8.57	29.98	5.83	30 - 48	35.80
8	72.40	0.00	72.40	0.31	23.17	0.21	23 - 42	23.38
16	44.71	0.00	44.71	0.17	14.31	0.12	16 - 34	14.42
30	12.70	0.00	12.70	0.16	4.06	0.11	9 - 27	4.17
50	8.21	0.00	8.21	0.14	2.63	0.10	2 - 12	2.72
100	1.75	0.00	1.75	0.13	0.56	0.09	0 - 2	0.65
200	0.00	0.00	0.00	0.08	0.00	0.05	0 - 1	0.05

Table 7 above provides information about the Cumulative Pass Filter (%), which represents the percentage of material that passes through each sieve size. For instance, at the 1" sieve size, 100% of the material passes through (since it's the largest size). The Aggregate Type indicates that the "ICW" (Iron Casting Waste) and "Sand" designate the specific types of aggregate being analyzed. The maximum aggregate size is specified for each sieve. For example, at the 1" sieve, the maximum aggregate size is 100%. The Combined ICW/Sand shows the combined percentage of ICW and sand in the aggregate. The percentages of fine aggregate (sand) and coarse aggregate (broken stone) are provided. Sand constitutes 32%, and broken stone (coarse aggregate) constitutes 68%. The average size of the aggregate particles is given for each sieve size. Sieve analysis helps determine the particle size distribution of aggregates, which impacts concrete properties.

B. The test of Concrete Compressive Strength

Table 8 presents types of tests and sample codes that show the number of samples and variations of the iron-casting waste mixture. Normal concrete samples of 3 samples and variations of iron casting waste to sand, namely 25%, 50%, 75%, and 100% each of the three samples. The following Figure 3 shows the process of carrying out the concrete compressive strength test.

Fill the mixture into the cylinder — Sample Concrete — Weigh the sample — Compressive strength test tool

Fig. 3 Process of carrying out the concrete compressive strength test

Concrete compressive strength test results are shown in the following Table 8.

TABLE VIII
RESULT OF CONCRETE COMPRESSIVE STRENGTH TEST

Mixed Variations Iron Casting Waste x Sand)	Sample Code	Compressive Strength (kg/cm2)	Average Compressive Strength (kg/cm2)
Normal	K1.1	253. 75	
Concrete	K1.2	254.44	253.753
	K1.3	253.07	
Variations	K2.1	409.28	
25% x 75%	K2.2	405.87	403.597
	K2.3	395.64	
Variations	K3.1	272.85	
50% x 50%	K3.2	279.67	279.67
	K3.3	286.50	
Variations	K4.1	211.46	
75% x 25%	K4.2	204.64	209.19
	K4.3	211.46	
Variations	K5.1	170.53	
100% x 0%	K5.2	184.18	178.49
	K5.3	180.77	

Table 8 shows that regular concrete tests yielded an average compressive strength of 253,753 kg/cm2. The addition of iron casting waste with a variation of 25% produced an average compressive strength of concrete of 403,597 kg/cm2, a 50% variation produced 279,67 kg/cm2, a 75% variation produced 209,19 kg/cm2, and a 100% variation produced 178,49 kg/cm2. The addition of 25% iron casting waste shows a compressive strength of 403,597 kg/cm2 of concrete or K-400 concrete equivalent, and a 50% variation yields 279,67 kg/cm2 or K-279 concrete equivalent. The test results of these two variations show that the concrete's compressive strength is higher than the planned concrete's compressive strength, which is K-250.

Other studies justify the increase in concrete's compressive strength after adding iron slag. The effect of replacing sand with iron-based waste materials affects compressive strength, fresh density, and dry density, and his research concluded that iron-based waste materials are effective in increasing the compressive strength of concrete to several levels [77]. The use of waste steel in concrete shows an improvement in concrete performance in strength and durability aspects [78].

Another study showed that concrete mixtures made using waste iron have higher compressive strength and bending strength than ordinary concrete mixtures. This was done in a study using iron waste to replace sand by 10%, 20% partially, and 30% at 7. 28, and 56 days, showing a significant increase in concrete compressive strength [79]. Another study, using 7.5%, 15%, 22.5%, 30%, and 37.5% iron waste, increased concrete's compressive strength, flexural strength, and the maximum yield at a 22.5% iron waste replacement rate. The results obtained in this study show that 30% replacement is also better compared to control concrete [80]. Another test, carried out on a hardened mortar cube to obtain the compressive strength and flexural strength of cement mortar, through the addition of 10%, 20%, 30%, and 40% iron waste as a substitute for natural sand, obtained increased compressive and flexural strength of concrete [81].

Furthermore, in Table 8 and Figure 2, the compressive strength of concrete begins to decrease at a variation of 50% iron waste. This result is due to the iron waste used. The fineness modulus (FM) 3.0-5.0 is greater than the requirements of fine aggregate and low ability to absorb water. Another study found that the modulus of fineness (FM) affects the compressive strength of concrete [82]

It can be explained that when compared with the previous three studies, namely research using iron waste 10%-30%, iron waste 7.5%-37.5%, iron waste 10%-40% or the percentage of iron waste use 7.5%-40%, all of which resulted in increased concrete compressive strength. The percentage of iron waste use in these three studies is a maximum of 40%, thus answering the results of research conducted by researchers that the use of 50% iron waste produced concrete compressive strength began to decline.

The purpose of this study is to show that the compressive strength of concrete produced at variations of 25% and 50%, respectively 403,597 kg/cm2 and 279.67 kg/cm2, is still higher than the planned concrete, which is 250 kg/cm2 (K250). Another study said that the effect of percentage differences with iron waste using 10%, 20%, and 30% resulted in a significant increase in concrete compressive strength. The compressive strength of the resulting concrete is higher than the control mixture [77].

IV. CONCLUSION

The addition of iron casting waste in a variation of 25% produces a compressive strength of concrete of 403.597 kg/cm2, a variation of 50% produces a compressive strength of concrete of 279.67 kg/cm2, a variation of 75% produces a compressive strength of concrete of 209.19 kg/cm2 and a variation of 100% produces a compressive strength of concrete of 178.49 kg/cm2. Waste iron variations of 25% and 50% resulted in concrete compressive strength equivalent to K-400 and K-279, respectively, exceeding the planned compressive strength of K-250 concrete. The use of 40% iron waste is generated, the compressive strength of concrete increases and begins to decrease at a variation of 50%.

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